ECOLOGICAL AND COMPARATIVE PERFORMANCE STUDIES ON HIGH-RATE SEWAGE FILTER MEDIA

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SUMMARY

Used waters containing high concentrations of organic materials have proved difficult to treat to suitable standards for discharge to inland waters ,using conventional biological filtration.

The use of two stage filtration has been shown to produce effluents of a higher standard than single stage filtration. This investigation was undertaken to determine the optimum conditions for two stage filtration where the primary stage employed various types of biological media designed to accept high organic loadings.

Pilot and laboratory scale filters were designed and constructed to investigate the mechanisms of two stage filtration. The quality of effluents obtained from the pilot scale high-rate filters was examined and their effects on nitrification in laboratory scale secondary filters employing low organic loadings observed. The ecological maturation of the high-rate primary filters was monitored.

The study indicated that under the loading conditions considered, the high-rate filter media developed biological films which could support carbonaceous oxidation in proportion to the media specific surface areas. Random packed media developed weights of biological film in proportion to their specific surface areas. Modular media supported significantly less film per unit of specific surface area.

The dominant flora and fauna of high-rate filter films were identified. After two years of operation, the filters had not fully matured.

Suitable primary high-rate filter effluents could be obtained to permit full nitrification in laboratory scale nitrifying filters. Further studies are required to optimise the use of high-rate filtration.

KEY WORDS

High-rate filtration, nitrifying filters.

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1. THE EARLY STAGES IN THE DEVELOPMENT OF SEWAGE TREATMENT IN BRITAIN.

The development of sewerage and sewage systems stems from the waste disposal problems created by localised concentrations of people and effluents of industrial production. The history of sewage disposal and treatment has been well chronicled by the Institute of Water Pollution Control publications of Stanbridge (1976) and a synopsis written by Sidwick and Murray (1976).

The Royal Commission appointed in 1832 to study the Poor Law may be considered as a landmark in public health reform. One of the Assistant Commissioners, Edwin Chadwick, appointed to carry out field studies, reported in 1842 on the need to create unified drainage systems using carefully designed sewers to improve public hygiene. Until 1815, it had been illegal to admit foul waters to surface drainage. In poor overcrowded urban communities, privies and cesspools were frequently not provided, the inhabitants using the open streets for disposal of all wastes. If communal "middens" or "ashpits" had been dug, adjacent water supply springs or wells were often severely contaminated. In 1847, it became compulsory to drain houses into sewers. The development of the water carriage system had a marked benefit on the health of the community. However, as a result of these developments, the condition of receiving water courses deteriorated.

Due to these problems, the Public Health Act of 1876 prohibited the entry of untreated sewage into streams and it became illegal to continue such discharges. However, because of the lack of knowledge of sewage treatment, the Act was difficult to enforce. Subsequently, a Sewage Commission was established in 1882, which reported in 1884. It advocated the chemical precipitation of organic matter and land

treatment of the effluent prior to disposal to a water course. This led to the development of sedimentation tanks for removal of the solid matter. Due to the large areas of land required for treatment of the effluent, methods were developed for the "artificial treatment" of sewage. One of the early workers in this field was Dibdin who considered the purificatory action of tanks containing porous media such as coke breeze or porous clay, used in a fill and drain manner, to be due partly to physical and partly biological processes; the waste matter which adhered to the media surfaces when the tank was filled with sewage was subsequently biologically degraded when the tank was drained.

At this stage, it was not fully realised that organic matter utilization by microbial organisms was the dominant activity within the filter. Yet the introduction of these and similar processes led to improved conditions in receiving water courses.

As a result of the development of improved methods of sewage treatment, a Royal Commission on Sewage Disposal was appointed in 1898 to determine what sewage treatment and disposal methods could be adopted; the findings were to have significant effects upon the direction of sewage treatment developments until the present day. The outcome of the various reports of the Royal Commission established sewage treatment on a scientific footing and set standards which should be attained for effluents discharged to water courses. The Fifth Report established a suspended solids standard for sewage works effluents of three parts per hundred thousand, whilst the Eighth Report set a dissolved oxygen absorption over five days at 65°F of two parts per hundred thousand. These values have become to be known to-day as the 'Royal Commission' 20:30 standard, that is,

the effluent from a sewage works should not have a Biochemical Oxygen Demand (BOD) of greater than 20 mg /l, or a suspended solids value of greater than 30 mg / l, The Eighth Report also assumed that a dilution factor of at least eight times would be available in the receiving water.

At the turn of the century and prior to World War 1, designers and operators of sewage disposal works became increasingly aware of the important role of bacteria; indeed the Second Report of the Royal Commission of 1902 was involved almost wholly with the bacterial problems associated with sewage disposal. Haigh Johnson (1914) gives a comprehensive account of the flora and fauna observed in percolating filters although the role of each organism is not clearly defined.

At this time in America, experiments were being carried out into the oxidation of sewage by the activated sludge process. Later experiments by Ardern & Lockett at Manchester in G.B., showed that it was possible to obtain a fully nitrified effluent from an activated sludge process treating raw sewage. These experiments formed the basis of the activated sludge treatment plants at Daveyhulme and Withington. During the 1920's and 1930's the activated sludge process gained acceptance and became more widely employed, although the percolating filter remained the dominant system. During the 1920's biofiltration became popular in the U.S.A. Biofiltration involves reapplication of filter effluent to the surface of the filter. The purpose of the system was to prevent the occurrence of ponding. The increased flow rates were thought to be responsible for flushing excess film out of the filter, and prevent the filter from becoming anaerobic by maintaining a dissolved oxygen reserve

in the applied liquor. Jenks (1937) gives a descriptive account of the development of percolating filters in the U.S.A. During the 1930's, further legislation in G.B. enforced local authorities to accept trade effluents discharged into public sewers. These Acts had the effect of increasing the organic strength and volumetric loading to many sewage works; additionally, these trade effluents often were more difficult to oxidise than domestic sewage. In combination with developments in sewage treatment in the U.S.A., this appears to have stimulated further research into various forms of biological filtration. The use of recirculation, double filtration and alternating double filtration have all been examined. The use of high rate filtration employed as the primary stage of double or multistage system of filtration is discussed in the following chapter.

2. A REVIEW OF LITERATURE ON HIGH RATE FILTRATION.

It is perhaps appropriate to first attempt to define high rate filtration of used waters. Bruce and Merkens (1970) have defined high rate filtration to be where the hydraulic load applied to the filter media is in excess of $3m^3/m^3/d$ or where the organic load is in excess of 0.6 kg. BOD/m^3/d. Such a definition is purely arbitrary; a hydraulic load of 2.8 $m^3/m^3/d$ could just as well be considered high rate as an intermediate rate. In order to draw more meaningful comparisons between the relative efficiencies of filters, the load may be better expressed in terms of weight of BOD applied per unit area of the media specific surface.

Although high-rate biological filters have not commonly been used for the purification of municipal wastes in G.B., they have been employed as "roughing" filters for strong industrial effluents (Askew 1969) and as a temporary measure to reduce the load on overload sewage works (McDonald 1971, Anon. 1973 a and b).

In the U.S.A., filters have been loaded with domestic sewage and industrial wastes at high hydraulic rates for the last 30 years, (Stanbridge 1954), with few problems of operation. One of the main reasons why high rate filtration has been more successful in America than in G.B., is probably the much weaker sewage to be treated; hence film accumulation in winter, leading to "ponding" and a frequently associated drop in efficiency of BOD removal, has not been a common problem. Also, high recirculation rates were frequently employed.

Only three sewage treatment works in G.B., employing high rate filtration have been reported in the literature; these being at

Northampton (Andrews 1964; Eden et al. 1966) and Dunstable (Anon. 1963); in both of these cases the high-rate filters act as primary filters effecting partial treatment of the sewage. In the third case, Kingston and Seymour (Hemming 1973) man-made media is employed for treatment of macerated sewage prior to estuarine disposal.

A review of the literature reveals that current studies of high-rate filters stems from works in the 1930s in the U.S.A. (Levine et al. (1936), Levine (1940), Halvorson et al. (1936), Mohlmann (1936) and Jenks (1937)). These publications appear to have stimulated research in G.B., notably the studies of Goldthorpe (1938), Goldthorpe and Nixon (1942), Thompson (1942), Beedham (1947), and Oldroyd (1952) in the West Riding of Yorkshire and studies elsewhere of Tomlinson and Hall (1950), Barraclough (1954) and Peach (1957). Studies have also been carried out in South Africa by Dekema and Krige (1949).

Interest in high rate filtration was renewed in the early 1960s by the introduction of man-made media which were designed to obviate certain problems associated with the use of mineral media, which will be considered later.

High-rate filters have several potential uses in preference to alternative methods of used-water treatment. They can be employed to partially remove carbonaceous matter and other oxygen demanding materials from strong sewages and wastes in order to ensure efficient working of standard low-rate filters or activated sludge plants. If they are used with the above intention in mind, then the consequences of their use can be the prevention of film accumulation on a secondary filter; and also they may effect such

carbonaceous reduction that the effluent from the secondary filter is well nitrified.

They can be used as "roughing" filters for industries to reduce the load discharged to the sewers and therby reduce the trade effluent charges, and/or relieve treatment problems at a recipient sewage treatment works. High-rate filters using man-made media are being increasingly employed in this context. One such medium, 'Flocor' has been used for the treatment of whisky distillation effluents (Hemming 1970), brewery effluents (Askew 1967),winery effluents (Jolly 1972), dairy effluents (Hemmings 1971a), poultry processing effluents (Summers 1972), fruit and vegetable wastes (Askew 1969) and textile wastes (Hemming 1971b). Where strong wastes are to be dealt with, two or three high-rate filters with interstage settlement may be employed.

High-rate filters may also be employed with sedimentation as the sole method of sewage treatment in a situation where the quality of the final effluent does not have to attain very stringent standards; for example, coastal towns where dilution of the effluent is great (that is, in comparison to that of the dilution of an effluent from an inland town entering a river).

In order that high-rate filtration can be employed in the appropriate situations, laboratory and pilot scale studies may need to be carried out to asses :- the efficiency of BOD removal at various organic and hydraulic loadings; the effect of specific surface area; uniformity of packing and void capacity of the various media; depth of media; retention times and their significance; necessary settlement of the influent and the effluent; effects of ventilation and temperature; nitrification in the secondary treatment plant;

the biological nature and quantity of film accumulated.

A. Nature of Media.

In order to compare various removal efficiencies of biological filters, it is necessary to define parameters for the media employed. One such parameter is the specific surface area. This term can be defined as the total surface area of unit volume of media.

The grade of any one type of mineral media chosen is often a necessary compromise between the specific surface area and the pore size. The greatest surface area per unit volume is obtained with the smallest grade of media, but as the size of the media decreases there is a concomitant decline in the mean pore size which may lead to problems of "ponding", a clogging of the filter bed interstices. The significance of the particle size on the specific surface area and void capacity has been described by Schroepfer (1951), Wukash and Bloodgood (1966), and by Bruce (1968).

Schroepfer and Bruce also consider the importance of particle shape; both workers found that within one size grading of particles an increase in irregularity of the media caused a significant increase in the void capacity, which may help prevent ponding of the media as a result of film accumulation. The particle shape and size affect the pore size distribution as pointed out by Bruce (1968). Media of a configuration that provides large void capacities of very small pores are of limited suitability for biological filters, since such pores may be quickly blocked.

It was appreciated in the 1930s and 1940s that the size of media had a significant effect upon the treatment of used waters. Jenks (1937) using a standard volume stated that "it appears that increased

size of rock does not condition the degree of purification so much as the time required to attain it", meaning that greater recirculation/feed ratios were necessary, to increase the retention time, with increasing size of media. This is due to the decreasing surface area of microbial film available to effect purification. Goldthorpe and Nixon (1942), attempting to treat sewage by two stage filtration, of which the primary stage was a high-rate filter, appreciated the significance of surface area upon filter performance. Unfortunately the value of their studies was reduced by the manner in which the filters were packed and also the outbreak of World War 11, which resulted in a marked change in the nature of the sewage.

Levine et al. (1936) succeeded in increasing the rate of filtration of sewage by the use of ceramic media. The media used were various sizes of Raschig rings - hollow cylinders of diameter equal to their length. The ceramic media showed a greater BOD removal in terms of quantity and efficiency over conventional media. The filters could be satisfactorily loaded at high rates because of the high void capacities and comparatively high specific surface area.

Comparative studies on the efficiency of BOD removal by various grades of natural media carried out by Thompson (1942), Hawkes (1952), Hawkes and Jenkins (1955), Truesdale et al. (1961) and work on ceramic media by Levine et al. (1936) have all indicated that the greatest efficiency and total BOD removal occurs in filters with the greatest specific surface area. However, as noted by Thompson (1942), Hawkes and Jenkins (1955), and Truesdale and Eden (1963), the smallest grade of media are most likely to pond with a consequent fall in efficiency. This result suggests that the optimum grade of media in a given situation is the smallest in which an accumulation of solids does not block the voids.

Since the advent of plastics, it has been possible to design packings which have far greater specific surface areas than the stone media commonly used, whilst maintaining a much higher void capacity (usually greater than 90%). Such media may have regular pore sizes (that is, of uniform distribution), which are of much greater dimension than that of the mineral media and hence bridging by the film accumulation and subsequent blockages are reduced. Many of the advantages and disadvantages of plastic media in comparison to natural media have been listed by Chipperfield (1966) and Landine (1972); a summary of which is given below.

Advantages.

1. Plastic media can be designed with high void capacity of large regular pore size whilst maintaining a large surface area greatly limiting the likelihood of ponding.

2. Much higher specific surface areas are feasible than for mineral media, therefore high hydraulic loadings may be applied and consequently the size and volume of filters may be much less.

3. Plastic media is much less dense than mineral media, even when covered with a thick bios, hence filter structural costs can be markedly reduced.

4. Because of the light weight of plastic media, filters may be quickly installed in situations where an immediate temporary solution to a waste problem is needed.

Disadvantages.

1. Plastic media tends to be more fragile than mineral media and could be subject to greater damage; particularly to the

surface of filters during maintenance operations.

2. Plastic media is more expensive than mineral media per volume.

3. Plastic media such as Cloisonyle and Flocor need uniform distribution of the waste over the surface of the filter since little lateral spread is possible within the filter.

Table 2.1 gives an indication of the ranges of specific surface areas and void capacities of various media. Comparative studies of loadings and removal efficiencies of plastic media have been carried out during the last decade in G.B. From results of experimental filters at Derby and Cheltenham, Joslin et al. (1971) found that the BOD removal per unit surface area would appear to be similar for both mineral and synthetic media, although the relationship between BOD removal and specific surface area is not linear.

Work reported by Bruce and Merkens (1970) suggests that the physical configuration of the media may have a significant effect upon the performance. The particular media (Cloisonyle) referred to presents only vertical surfaces and allows no lateral spread of the sewage; consequently, good distribution of the feed over the filter is vital.

Plastic media of the varieties listed in Table 2.1 have enabled hydraulic loadings of up to $24 m^3/m^3/d$ to be applied to the primary filters but studies at the Water Pollution Research Laboratory (Bruce and Merkens 1970) have shown that increasing hydraulic loading, in excess of that required to completely wet the surface area of the film, results in a decline in the percentage BOD removal, although

Table 2.1 Specific surface areas and percentage void capacity of various media.

MEDIA		CHARACTERISTICS	SPECIFIC SURFACE AREA m^2/m^3	PERCENTAGE VOID CAPACITY
Rounded gravel	(a)	25 mm (1 inch)	145	42.8
Rounded gravel	(a)	63.5 ($2\frac{1}{2}$ ins)	65	46.2
Rock	(a)	25 mm (1 inch)	140	51.3
Rock	(a)	63.5 ($2\frac{1}{2}$ ins)	90	52.7
Clinker	(a)	25 mm (1 inch)	200	53.8
Clinker	(a)	63.5 mm ($2\frac{1}{2}$ ins)	120	57.0
Slag	(a)	25 mm (1 inch)	195	38.9
Slag	(a)	63.5 ($2\frac{1}{2}$ ins)	105	42.0
Slag	(c)	100 mm (4 ins)	49	-
Slag	(c)	125 mm (5 ins)	10	-
Granite	(c)	100 mm (4 ins)	49	-
Crushed basalt	(c)	63.5 - 125 mm	45	-
(1) Flocor E	(b)	PVC modular	85	98.0
(1) Flocor M	(b)	Packings	135	98.0
(1) Flocor RS		PVC Random	240	94.0
(1) Flocor R2S		Packings	140	94.0
(2) Biopac 90		PVC Random	85	91.0
(2) Biopac 50	(d)	Packings	124	91.0
(3) Filterpac YTH 1130	(d)	PVC Random Packings	167	93.0
(4) Cloisonyle	(b)	Separate vertical PVC tubes	220	94.0
(2) Surfpac standard	(b)	Modular PVC sheets	82	94.0
(2) Surfpac crinkleclose	(b)	Modular PVC sheets	187	94.0

(a) Data after Truesdale and Eden (1963)

(b) Data after Bruce (1970)

(c) Data after Bruce et al. (1974)

(d) Data after Banks et al. (1974)

Manufacturers: (1) ICI Ltd., (2) Hydronyl Ltd., (3) Mass Transfer, (4) Cegadur & Co. Ltd.

the absolute weight of BOD removed may increase. Therefore such high hydraulic loadings, though not creating any maintenance problems, are not necessarily suited to two stage filtration most commonly being considered. Recent studies have indicated hydraulic loadings of plastic media in the range 6 - 12 $m^3/m^3/d$ of average strength sewage produced settled effluents of suitable BOD strengths for secondary treatment, where the intention is to achieve a nitrified effluent of R.C. standards (Joslin et al. 1971).

B. Retention Times.

In many studies, the retention time of liquids within filters has been shown to be a factor regulating the degree of biological purification occurring (Bruce 1970, Bruce and Merkens 1970, Schulze 1960, Eckenfelder 1961). In what manner the retention time affects BOD removal and other purification processes has not been satisfactorily explained as yet. However, it is thought that increasing the retention time up to a certain value does result in an improved effluent from the filter.

The retention time of any filter is governed by the media characteristics, hydraulic loading, the frequency of dosing, and the degree of film accumulation.

In many of the theories presented to explain the effect of retention times, the degree of biological film activity has not been regarded as a separate significant factor, which according to results shown by Craft and Ingols (1973) clearly has some importance. Germain (1966) stated "Waste residence time within the filter is an indirect parameter; it does not affect the rate of reaction, but merely defines how close to completion the reaction can proceed

within the waste residence time provided".

The media characteristics clearly affect the retention time of a filter. The distribution of the surface area (i.e. the proportions of vertical, inclined and horizontal surfaces) may have an effect (as suggested by Bruce and Merkens 1970). The pore size distribution also has a very significant effect upon retention time curves. The more uniform the pore sizes within a filter the less the spread of the tracer concentration versus time curve, which means that any fraction of the applied liquid has a more equal opportunity to receive biological purification.

The pore size itself can have an important effect upon the retention time of a liquid; film accumulation in smaller pores having a greater effect in retaining the liquid than in larger pores.

The greater the specific surface area of any media, the longer the retention time is likely to be; assuming similar surface tension forces, the larger the surface area available, the greater the volume of liquid that may be retained. This trend is shown by studies at the Water Pollution Research Laboratory reported by Bruce and Merkens (1970).

Another feature of filter media, particularly synthetic, is the degree of surface wetting. Modular media such as Flocor and Surfpac, and also tubular media such as Cloisonyle, must have a uniform distribution of liquid to the upper surface, since the degree of lateral spread within the filter is severely restricted. The minimum irrigation rate to obtain complete surface wetting of Flocor E is said to be 1.47 $m^3/m^3/$ hour (Askew 1969).

The hydraulic loading applied to a filter also affects the

retention time. In effect, increasing the hydraulic loading is comparable to reducing the available surface area of the media. That is, increasing the hydraulic load tends to reduce the period of retention and may also reduce the overall length of time over which all the liquid is retained, as shown by Meltzer (1962). According to Howland et al. (1963), the theoretical contact time varies with the third or two thirds inverse power of the hydraulic load depending on whether the flow is turbulent or laminar. In practice, the value has been found by Burgess et al. (1961) to be 0.408, 0.760 by Meltzer (1962), 0.575 by Bryan and Moeller (1963), 0.480 by Germain (1966) and 0.930 by Rincke and Walters (1970). However this theoretical 'n' factor does not take into account the nature of the film attached to the media surface. The presence of a film may reduce the available surface area for flow and may also cause part of the flow to percolate the film, hence it is conceivable that in practice, 'n' may exceed two thirds.

The degree of film accumulation has a very significant impact upon the retention characteristics of a filter. On low-rate filters, Solbe et al. (1974) have shown how film accumulation can increase the retention time two or three fold. Excessive uneven accumulation of film may result in short circuiting (Truesdale et al. 1961), that is, channelling of the liquid within the filter resulting in reduced retention times. The precise manner in which film accumulation affects the hold up of liquid has been the subject of controversy, (Meltzer 1962). The water within a filter may usefully be considered to be in three discrete but interchangeable phases. Water is retained within the film by integration into the biological material and absorption. This water may be in a state of dynamic equilibrium

with adsorbed water on the film. This latter water is considered to be retained by surface tension effects and other similar surface phenomena. A third form of water within the filter is that which is in motion through the filter at any given time. This water is easily displaced by the next dose to be applied and corresponds to the peaks shown in tracer concentration versus time curves. However the retention time of a liquid within a filter, as previously mentioned, is an indirect factor on purification. It may only give a guide to the period over which organic matter is retained within the filter. This organic matter may be in solid, colloidal or dissolved form. The organic matter within each phase may have its own retention characteristic which may differ from that of the liquid.

In summary, high-rate filters have similar retention characteristics to low-rate filters; the most significant difference is the very short retention period, commonly of only a few minutes duration, whereas low-rate filters may have retention times measured in terms of hours.

C. BOD Removal and Hydraulic Loadings.

The use of large gradings of natural media and synthetic media of high void capacity allows treatment of wastes at high BOD and hydraulic loadings, without severe problems of film accumulation. Hydraulic loadings up to 24 $m^3/m^3/d$ have been reported (Bruce and Merkens 1970). However, it has been shown that as the hydraulic load, at a constant BOD strength, to a filter is increased there is a decline in the BOD removal efficiency, although the absolute quantity of BOD removed increases to a maximum. This phenomena is shown in figures 2.1 and 2.2. As a consequence, increasing the hydraulic

Figure 2.1 Relation between % BOD Removal and Hydraulic Loading.

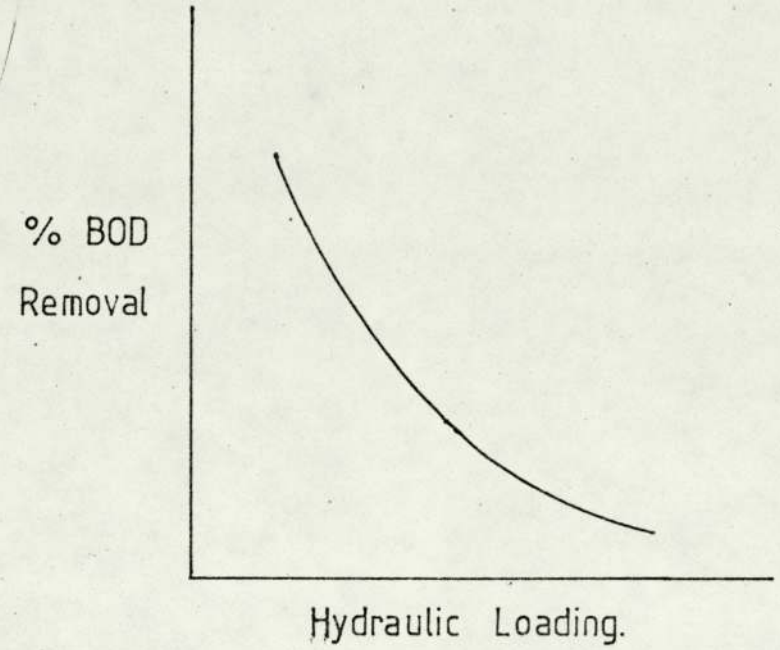
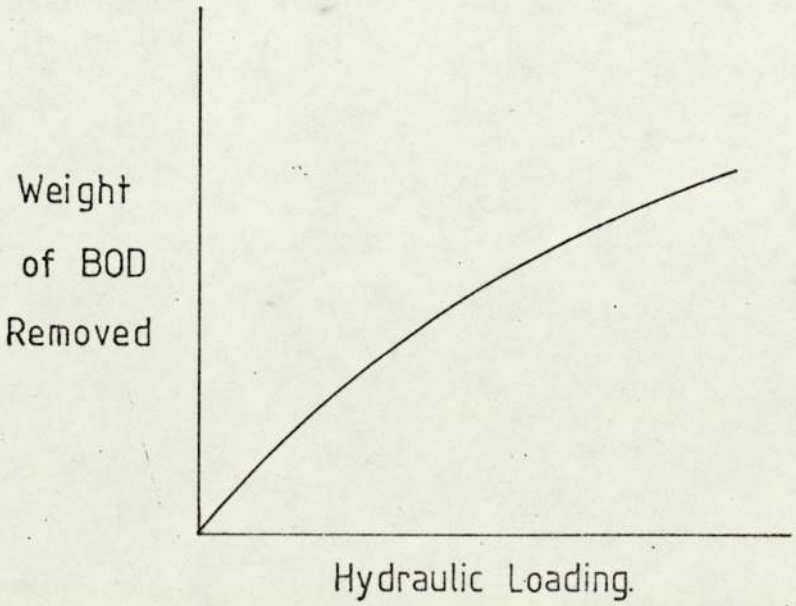


Figure 2.2 Relation between Weight of BOD Removed and Hydraulic Loading.



loading at a given BOD strength results in a decline in the quality of the effluent. This has been observed by Levine et al. (1936), Tomlinson and Hall (1950) and Bruce and Merkens (1970).

Increasing the hydraulic loading whilst maintaining a constant organic load by decreasing the sewage feed strength will, on a theoretical basis, reduce the concentration of food available for diffusion into the biological film hence the rate of BOD removal (that is, the driving force for purification has been reduced).

Much of the early work on the effects of increased loadings has been marred by not separating the effects of hydraulic and BOD loadings. This is particularly true of treatment theories. Rincke and Wolters (1970) clearly distinguish between the two factors. They also advocate the use of the specific surface area as a basis for comparison, rather than the volume of the media, which is in common usage to-day. If the nature of the media has no effect on the biological activity of the film, then all types of media, when under the same loading conditions, with similar retention times, should remove similar quantities of BOD per unit of surface area. This in fact has been shown by studies at the Water Pollution Research Laboratory recorded by Bruce and Merkens (1973), although Banks et al. (1974) found no correlation between specific surface area and BOD removed.

From Chipperfield (1966) and Bruce and Merkens (1973), the saturation loadings and maximum removal values shown in Table 2.2 have been computed in terms of specific surface area. The apparent high efficiency of BOD removal by Flocor E recorded by Chipperfield could be a result of brief primary settlement of the feed. Another reason for the differences shown in BOD removal by Flocor E could

be the nature of the organic waste. It can also be seen that Cloisonyle, although having a high specific surface area, is easily saturated and has a low BOD removal value, in comparison to Surfpac Crinkle Close and Flocor E.

Table 2.2 Observed saturation loadings and maximum BOD removed for various media.

WORKER	MEDIA	SATURATION BOD LOADING ($g/m^2/d$)	MAXIMUM BOD REMOVAL ($g/m^2/d$)
Chipperfield (1966)	Flocor E	70	35
Bruce and Merkens (1973)	Flocor E	53	9.4
Bruce and Merkens (1973)	Cloisonyle	20.5	5.5
Bruce and Merkens (1973)	Surfpac (Crinkleclose)	27	8.8

Early work using synthetic media appeared to indicate the necessity of using tall tower filters to effect good removal values, Chipperfield (1966) and Germain (1966); however, more recent studies comparing the BOD removal per unit volume in a tall tower (7.4m) and a conventional depth filter (2.1 m) of Surfpac (standard) have shown comparable results (Bruce and Merkens 1970).

In practice, the loadings of high-rate filters will be dependent upon the required results. Where a filter is to act as a "roughing" filter to reduce the strength of a trade effluent, high BOD loadings may be employed, since the most important factor may not be the total BOD load of the effluent, but limitations imposed by the site, variations in flow rates, and so on. A new sewage treatment works, needing to comply with the Royal Commission standards and wishing to

produce a fully nitrified effluent is concerned with the BOD strength of the settles sewage applied to the biological filters. It has been shown by numerous studies (Levine et al. 1936, Edmondson and Goodrich (1947), Tidswell (1960), and Hawkes and Jenkins 1964), that the greater the carbonaceous BOD reduction demanded of a biological filter, the less capable the bed is of effecting oxidation of nitrogenous compounds. Hence, when considering using a primary high-rate filter, it may be necessary to employ lower loadings in order to achieve a suitable effluent for application to secondary nitrifying beds.

In order to design a satisfactory treatment works, three factors concerning sludge production need to be ascertained; the volume of sludge, its ability to settle and its dewatering properties. Unfortunately, information about these three factors is limited and also highly conflicting. Chipperfield (1966) stated that the volume of sludge produced is inversely related to the loading, whilst Hawkes and Jenkins (1964) in their studies showed that the concentration of solids in the effluent was related to the loading. Askew (1969) concludes that between 0.2 and 0.3 kg. of sludge are produced per kg. of BOD removed, yet Bruce and Boon (1971) found that 0.6 to 1.0 kg. of sludge are produced per kg. of BOD removed, and state that the percentage volatile matter present was greater than that found in sludge from conventionally loaded filters. In 1973, Bruce & Merkens calculated an average production of 0.755 kg / kg BOD removed, and in 1975, Bruce et al. state that the overall production of sludge was much greater than from a comparable single stage filter.

Considering the settlement of high-rate sludge, Banks et al. (1974) stated that the sludge was difficult to settle, and Tomlinson

and Hall (1950) found that increasing the loading reduced the settleability of the sludge. In contrast to these findings, Chipperfield (1966) and Askew (1969) suggested that high-rate sludges are easy to settle. Levine et al. (1936) found that the percentage BOD removal for a synthetic sewage increased with increasing load and suggested that the filter acted as a colloiding agent; however, Askew (1969) states that sludges from high-rate plastic filters "are wholly of secondary origin but differ markedly from other secondary sludges".

Again, when comparing results obtained concerning the ease with which a sludge may be dewatered, conflict is frequent. Askew (1969) maintains that the sludge is more easily dewatered than other secondary sludges, Eden et al. (1966) consider the sludge not difficult to dewater, Joslin et al. (1971) state that the sludge was easily dewatered. These results contrast to the various studies reported by Bruce et al. (1974) in which the sludges produced were difficult to dewater.

Little attention has been paid to the effect of frequency of dosing to high-rate filters. Bruce and Merkens (1970) compared two frequencies of dosing to large grade slag and granite media. The intervals considered were three and five minutes; no significant differences were apparent in the treatment results. Bruce et al. (1970) compared continuous dosing to a psuedo dosing interval of 2.5 minutes. Again no significant difference was observed in the results. On low-rate filters, the frequency of dosing has been shown to have significant effects upon film accumulation and filter efficiency (Hawkes and Shephard 1970 and Hawkes and Shephard 1972). The frequency of dosing on low-rate filters are of the order 10 - 40 minutes. On such filters the retention times are much greater than

for higher rate filters, as previously mentioned; hence for high-rate filters the frequency of dosing may be expected to be much higher. However, in the two high-rate studies mentioned above, (Bruce and Merkens 1979 and Bruce et al. 1970), the frequency could be too great and greater variations in the frequencies should be examined. Because of the high loadings and particularly the high voidage of high-rate filters, it is quite probable that variation of the frequency of dosing may have a much less important effect upon film accumulation than occurs on low-rate filters.

D. Film Accumulation.

Film accumulation results from an interplay of factors, the strength and hydraulic load of the sewage applied are two important related factors, and also the frequency of dosing, as mentioned previously.

Under low-rate conditions, biological filters have suffered ponding due to to the strength of a feed. Strong sewages will tend to permit rapid growth rates of the bios. If the dosage is such that no endogenous respiration can occur, or the temperature too low to permit an active filter bed grazing fauna, then the biological growth may accumulate, ultimately clogging the interstices resulting in reduced BOD removal. Too high an application rate will induce ponding on low-rate filters.

With high-rate filters which have been specifically designed for high-rate treatment, ponding as a result of film accumulation does not appear to be such a serious problem, although difficulties did arise at Reading (Barraclough 1954).

One reason why film accumulation is not a serious problem on

high-rate filters is the pore sizes. High-rate filters, as previously mentioned, have much larger pores than low-rate filters, hence to block such a filter requires a much greater thickness of film. Such thick films have not been commonly observed on high-rate filters, possibly because the film does not have sufficient mechanical strength to survive high application rates, although evidence provided by Huekelukian (1945) indicates that the flushing action of high flows is insufficient to cause a scouring of the film. Indeed, Heukelukian states "it appears from these results that the volumetric rate of application influences the film accumulation only to a limited extent and that the important factor is the total BOD and suspended solids load applied". These findings have also been confirmed by Tomlinson (1946) and Hawkes (1959).

The nature and condition of the accumulated film also has a significant effect upon its ability to oxidise waste material. This has been described by Hawkes (1961).

The type of waste water to be treated also has a significance upon the development of the film. Dairy wastes and also other strong carbohydrate wastes, cause the growth of a thick fungal film which whilst having a greater depth effecting oxidation than a bacterial film (Tomlinson and Snaddon 1966) can cause ponding difficulties. The biology of high-rate filter film will be referred to later.

Bruce et al. (1970) compared the film accumulation on mineral and plastic media. Whilst the accumulated film on the mineral media was approximately in relation to the specific surface area, (expressed as a percentage saturation of the voids), and similarly on the plastic media, the latter types of media accumulated a much

smaller quantity per unit surface area. This did not appear to affect the BOD removal efficiences, which were related to the specific surface areas. Therefore it seems reasonable to conclude that the performance of the film was not directly related to the biomass. (It should be mentioned that the biological composition of the film was similar on all filters). Bruce (1970) found no significant variation in film thickness with depth, and therefore expressed the results as the average thickness throughout the depth. It was shown that in common with low-rate filters, high-rate filters also increased film thickness in winter, although the effect on efficiency was not so marked, due to the larger pore sizes.

Hawkes and Jenkins (1964) compared the efficiency of double filtration and alternating double filtration. They found that using mineral media of 1" - 2½" grading, film accumulation was greatest on the high-rate primary filter of the double filtration pair during winter months, even though a low frequency of dosing had been employed. Also, the nature of the film differed considerably on the different beds.

E. Temperature and Ventilation.

Temperature and ventilation are factors which can affect the activity of the biological film and as such are factors affecting the purification efficiency of the filters.

Schroepfer et al. (1952) considered the sewage temperature to be a more important factor regulating the bed temperature than the air temperature due to the differences in the specific heat and volumes flowing through the bed. Studies on low-rate filters at the Water Pollution Research Laboratory reported by Bayley & Downing

(1963) have shown such to be the case.

Temperature has an important effect upon biological activity: the higher the temperature the greater the biological activity, and hence the greater the oxidation of the organic waste. As a result of this, film accumulation would be expected to be greatest during the summer months. Such is not the case. Temperatures encountered also have an effect upon the macrofauna of the beds. During winter months the temperature may fall below a critical value preventing the macrofauna from completing their life-cycles, hence their populations are reduced, and they may also be markedly reduced in activity, (Reynoldson 1939 a & b, Thompson 1942, Solbé et al. 1974).

Due to the design characteristics of plastic media, it may be expected that the ventilation may be greater than in mineral media, and that because of the low specific heat and bulk density will tend to have poorer heat buffering capacities than mineral media. Therefore a slightly greater reduction in bed temperature could be expected when the air temperature is particularly low, and also an increase in the summer, if the air temperature is particularly high. In the case of high-rate filters using mineral media, the heat applied to a given mass of media will be greater, but due to the increased pore size of the large media, increased ventilation may increase heat loss, when compared to a low-rate filter.

In contrast to the expectations of Schroepfer et al. (1952), Bruce and Boon (1971) conclude that the effect of temperature on filter performance appears to increase markedly with increased load; whilst results gathered by Banks et al. (1974) suggest that the

importance of temperature as a factor governing BOD removal was less than that observed at the Water Pollution Research Laboratory.

Where a high-rate filter is employed as a primary stage in a multistage treatment of used waters, the drop in temperature of the liquid through the filter and the sedimentation tank may be of great significance. Hawkes and Jenkins (1964) considered that temperature was not an important factor in accounting for the difference between alternating double filtration and double filtration; however, Hawkes in discussion of Bruce et al. (1975) suggested that poor nitrification on the secondary filter of a double filtration plant could be attributed to the heat loss in the high-rate primary filters.

In order that the microbial film may carry out its metabolic activities without impediment, ventilation of the biological beds is necessary to supply sufficient oxygen. The manner in which the beds are naturally ventilated depends upon temperature differences, air density differences and the dimensions of the bed. The problem is complex. Johnson (1952) and Petru (1958) give clear practical and theoretical accounts of the subject. Levine (1940) showed that bottom ventilation or at least a facility for air flow through the bottom of the bed to be of great importance when treating dairy wastes. Truesdale & Eden (1963) studying low-rate filters, considered the natural ventilation to be greatly in excess of the amount required to provide metabolic oxygen.Banks et al. (1974) studying high-rate filters restricted bottom ventilation and observed no deliterious effects. It therefore appears that filters not suffering from too thick an accumulation of film are adequately ventilated.

F. Ecology of High-Rate Filters.

Information concerning the ecology of high-rate filters is severely limited. Most references to the biology of a filter have been incidental and not a primary consideration of the studies being carried out. Early indications from filters (Heukelukian 1945) were that increasing loads to filters resulted in a decrease in the range and populations of the grazing fauna.

From results presented by Reynoldson (1941, 1942) and Thompson (1942) it also appears that the fauna is restricted by high loadings. Reynoldson (1941) showed for a high-rate primary filter at Huddersfield, treating a sewage containing a toxic chemical waste, that the macrofauna was restricted to two species, of which only the insect, Psychoda alternata, was present in significant numbers. A most striking feature of the high-rate filter was the absence of oligochaete worms. Hawkes & Jenkins (1964) also found that there was a comparativly low population of enchytraeid worms in a primary high-rate filter under study. In the case of the latter workers, the period of study of the particular filters was sufficient for several life cycles of worms to have occurred and hence a large population to be present. One possible explanation for the lack of oligochaetes is the size of the media employed. These worms display marked thigmotaxis (Terry 1951) and the large pores present in high-rate filters may not provide suitable habitats to support large populations.

Reynoldson (1942) and Usinger & Kellen (1955) noted a summer film accumulation and decline in the Psychoda alternata populations of high-rate filters. Hawkes & Jenkins (1964) noted a decline in the number of enchytraeids in an intermediate rate primary filter,

with a simultaneous accumulation of septic film. These results suggest that at the peak summer temperatures the activity of the macrofauna cannot cope with rate of film production. They also found a spring time increase in Psychoda, a feature in common with two alternating double filtration beds treating the same sewage. This spring increase was assumed to be at the expense of the enchytraeid population. Anisopus fenistralis larvae were found to be most abundant in late winter. Rincke & Wolters (1970) observed the maturation of a high-rate filter over a period of seven weeks. The growth developed in the following order:- flagellate protozoa, ciliate protozoa, nematodes, sessile ciliate protozoa, and Psychoda larvae. Curds & Cockburn (1970) in a survey of protozoa in high-rate filters found the following ciliates to be present:- Colpidum campylum, C. colpoda, Chilodonella cucullulus, Paramecium caudatum, Epistylis plicatilis, Tachysoma pellionella, and Hemiophrys fusidens. Ingram (1959) also found the ciliates to be the predominant protozoa present. Banks et al. (1974) also mention the presence of ciliate protozoa. In contrast, Bruce and Merkens (1970) and Bruce et al. (1970) found flagellates to be the dominant protozoa, and apart from Opercularia, ciliates were absent. These authors also mention the presence of large numbers of nemotode worms.

Another feature of high-rate filters is the form of the zoogleal film. Reynoldson (1942) reported a species of Oospora (Geotrichum) to be the dominant member of the film. This fungus could be dominant due to the nature of the sewage being treated at Huddersfield. Cooke & Hirsch (1958) using glass slides as a substratum for the development of growths in high-rate filters found that the order of

abundance of fungi was:- Fusarium aquaeductuum, Geotrichum candidum, and Pullularia pullulans. Occasionally in early spring or late autumn, isolated colonies of Leptomitus lacteus were observed. Hawkes & Jenkins (1964) merely refer to the film on high-rate filters at Birmingham as being of a bacterial/fungal nature. Bruce & Merkens (1970) mention the presence of a bacterial and fungal association. The most evident member of the bacterial association was Sphaerotilus paludosus and the fungal member was tentatively described as a species of Subbaromyces. Banks et al. (1974) studying pilot high-rate filters at Ipswich, described the film to be of a bacterial nature.

Algae may occur on the surface of filters. Cooke (1959) considered diatoms and green algae to be the dominant members on high-rate filters in the U.S.A., in contrast to the blue green algae on low-rate filters.

G. Summary.

It has been shown that information concerning the operation of high-rate filters is limited in various aspects and that many of the results so far obtained are conflicting. The significance of retention times on filter performance has not been elucidated. In a qualitative sense, the effects of hydraulic and gravimetric loadings upon filter efficiency have been described, but further results are required to quantify the effects. It appears that high-rate filters using appropriate media do not suffer severe film accumulation in winter, and there is evidence to suggest that the restricted fauna cannot cope with the rate of film production at high summer temperatures.

Knowledge of high-rate filter biology is scanty. The full

community of organisms and their significance have not been evaluated.

It is likely that limits imposed on the quality of effluents entering water courses will become more stringent. In the immediate future, limitations on the concentration of unoxidised nitrogen will most probably be increased, since ammonia at high concentrations is toxic to fish, and encourages primary production, hence imposing a BOD load on the receiving water. To meet more stringent effluent quality controls, it is likely that greater use will be made of double filtration, alternating double filtration and primary filtration before an activated sludge stage. To obtain maximum nitrification, information regarding the permissible BOD loading on secondary filters will be required. This in turn may determine the hydraulic loading of a particular sewage which can be applied to the primary high-rate filter.

3. A REVIEW OF LITERATURE ON THE NITRIFICATION PROCESS AND ITS ECOLOGICAL SIGNIFICANCE.

When biologically oxidisable matter enters a watercourse, the microbial organisms present in the effluent and or the watercourse begin to oxidise the material. This process utilizes the dissolved oxygen in the water and may deplete the dissolved oxygen concentration if the rate of removal is greater than the rate of reaeration. Due to the flow of a river the maximum oxygen depletion will be some distance below the point of effluent discharge. Below this point of maximum oxygen depletion, there is a zone of recovery where the respiratory activity is gradually reduced due to progressive reduction in oxidisable organic matter present. Oxidation of the organic matter results in the synthesis of saprobic organisms; bacteria, fungi and protozoa, some of which form macroscopic growths commonly known as sewage fungus. The development of sewage fungus and the associated oxygen depletion have an adverse effect upon the ecology of a stream (Hawkes 1963).

During the oxidation of organic matter, nitrogenous materials such as proteins and amino acids are converted to ammonia, as an end product. The ammonia is subsequently oxidised to nitrite and then to nitrate (Beckman et al. 1972). This process is known as nitrification; it will further deplete the oxygen concentration in the watercourse. The removal of ammonia is however beneficial. Chlorination of water supplies containing ammonia is more costly and leads to the formation of chloramines which cause tastes and odours of the water (Nicholson 1973). If the water is used as a potable supply then a limit of 0.05 mg/l. ammoniacal nitrogen for treated water and 0.5 mg/l for raw water is advised by the World Health Organisation (1970). Ammonia can also exert a toxic effect upon fish.

The simplest way to remove ammonia is by oxidation to nitrite and nitrate; but increasing the oxidised nitrogen concentration itself can have a deleterious effect on a watercourse. Excessive growths of algae and other aquatic vegetation can seriously alter the flow characteristics of a river, causing a nuisance to agriculture, transport and recreational uses of a watercourse. The growths modify the ecology of the watercourse, directly by the physical effects of excessive growths, and also by causing oxygen depletion of the water at night (Shindala 1972). Algal blooms can also cause difficulties in the treatment of water for potable uses. Nitrogen as nitrate is also toxic to human juveniles, causing the condition methhaemoglobin. Infants are susceptible to excess nitrate in drinking water when the disease is also known as the 'blue baby syndrome'. Therefore the discharge of a fully nitrified effluent whilst avoiding the effects of sewage fungus growth, can cause problems of eutrophication, if no other factor limits growth. Where an effluent is nitrogen rich and/or stream dilution is low, it may be necessary to remove the nitrogenous compounds. The effects of nitrogen in its various forms on streams has been described by Flaigg and Reid (1954).

During the last century, many of the effects of organic pollution on watercourses, outlined above, were being enumerated, (Kolkwitz & Marsson 1908, Kolkwitz & Marsson 1909). It was also known during the latter part of the nineteenth century that deamination of nitrogenous organic constituents occurred in biological filters. Evidence obtained by the Royal Commission on Sewage Disposal indicated that the action of a septic tank was to increase the free ammonia concentration, reduce the albuminoid ammonia concentration and cause

a slight increase in oxidised nitrogen. Watson, carrying out investigations into biological filters at Birmingham in 1906 (Sidwick & Murray 1976 c) notes that 'the greatest reduction in albuminoid ammonia and also in oxygen absorbed figures occurs within the first eighteen inches of the filter bed. Nitrates were not present in any appreciable quantity at a depth of twelve inches; at a depth of three feet, considerable quantities were formed'.

Due to the increased demand for water, treated sewage effluent may form greater than one eighth of a river flow at any one point. Therefore it may be necessary to treat the sewage to greater than Royal Commission Standards both in order to minimize the effect on a river's ecology and to minimize treatment requirements of any abstracted supply downstream.

Where an effluent already attains R.C. Standards for BOD & SS, it is possible to reduce the suspended solids concentration by physical means of tertiary treatment, such as microstrainers (Truesdale et al. 1964). The removal of solids by such a method has an associated BOD removal. However, such tertiary treatment does not have any significant effect upon the nitrogen status of an effluent. For reasons previously outlined, it is necessary to obtain a nitrified effluent at least; due to the increasing re-use of waters, it is likely that nitrogen removal may become necessary. Sewage effluents contain relatively weak concentrations of ammonia and nitrate which render physical methods of nitrogen removal uneconomic. In certain instances where abstraction does not demand a low nitrogen concentration in the water, it may prove feasible to limit ecological difficulties by chemical precipitation of phosphate from sewage effluents. Such occasions are likely to be limited in

number, and generally it will be necessary to produce a nitrogen low effluent. Denitrification occurs bacteriologically when anoxic conditions and a suitable carbon source are available. (Painter 1970, Brezonik 1977, Christensen & Harremoes 1977, Painter 1977).

Many workers have shown that carbonaceous oxidation and nitrification can take place within the same filter, but it is known that the upper region of a filter is the site of carbonaceous oxidation whilst nitrification occurs in the lower region of a filter, (Jenkins 1931, Eckenfelder & Hood 1950, Balakrishnan & Eckenfelder 1969, Beckman et al. 1972, Duddles & Richardson 1974). Barritt in 1933 showed that nitrifying organisms do occur in all sections of a sectional biological filter, although nitrification tended to increase towards the base of the filter. These findings were supported by work reported by Tomlinson (1942); using a six foot deep filter, greatest nitrification was shown to occur between three and five feet below the surface of the bed.

The oxidation of carbonaceous matter and nitrification of ammonia are carried out by two distinct groups of organisms. Carbonaceous oxidation is effected by heterotrophic organisms which utilize complex organic materials directly for incorporation in their development and energy requirements. Nitrification has been shown to be carried out by predominantly autotrophic bacteria requiring simple inorganic nutrients for their metabolism. Autotrophic nitrification involves the oxidation of ammonia to nitrite and then to nitrate; the organisms responsible deriving their energy from these oxidations rather than the oxidation of organic materials. Heterotrophic nitrification can also occur, although such oxidations

are not the sole energy sources for the organisms involved. The literature concerning microbial inorganic nitrogen metabolism has been extensively reviewed by Painter (1970 + 1977), and Sharma and Ahlert 1977). Nitrosomonas (europaea and monocella) and Nitrococcus have been shown to be important autotrophic bacteria in the conversion of ammonia to nitrite (Bergey 1957). Other genera have been suggested but their abilities are questionable; Two genera of organisms capable of oxidising nitrite to nitrate are well established:- Nitrobacter agile and Nitrocystis. The autotrophic conversion of ammonia to nitrite may be expressed as follows:-

$$2NH_3 + 3O_2 \xrightarrow{\text{Nitrosomonas}} 2NO_2^- + 2H_2O + 2H^+ + \text{energy}$$

$$2NO_2^- + O_2 \xrightarrow{\text{Nitrobacter}} 2NO_3^- + \text{energy}$$

A large number of heterotrophic species have been shown to be capable of forming nitrite. Cutler & Crump (1933) cited 104 species which produced low concentrations of nitrite, isolated from biological filters. Fisher et al. (1956) isolated a number of Gram negative rods which converted ammonia to nitrite. However, Eylar & Schmidt (1959) examining 1331 heterotrophic soil isolets, could find none that formed nitrite in significant amounts, Autotrophic nitrifying organisms, in contrast to many heterotrophs, have been shown to have very slow growth rates and also that the yield per energy unit utilised is very low.

The nitrifying ability of a biological filter may be affected by the following factors outlined by Eckenfelder (1961):- the hydraulic load, the organic load, the nature of the sewage, the presence of inhibitors, the volume and type of media, depth of the

filter, ventilation and temperature. Of these factors, the effects of temperature, organic load and hydraulic loading upon nitrification will be discussed.

A. The Effect of Hydraulic Loading on Nitrification.

Edmondson & Goodrich (1947) reported that an increase in hydraulic loading resulted in a decrease in the nitrification achieved by a biological filter. The same effect was also reported by Grantham (1951). Lumb & Eastwood (1958) employing recirculation in a two stage filtration plant found that increasing the hydraulic load to the secondary filter reduced nitrification. Tomlinson (1946) comparing single filtration and alternating double filtration, found that increasing the hydraulic load to a single biological filter caused decreased nitrification through the filter, whilst increasing the hydraulic load to an alternating double filtration system caused a decrease in nitrifying ability of the filter film at all depths within the primary filter, but the decrease was only apparent in the upper three feet of the secondary filter. Hawkes and Jenkins (1964) found that increasing the hydraulic load to a double filtration plant and an alternating double filtration plant also reduced nitrification. Balakrishnan & Eckenfelder (1969) and Duddles & Richardson (1974) both found a trend of decreasing nitrification with increasing hydraulic loading. Bruce and Boon (1970) stated that at high hydraulic loadings ($3m^3/m^3/d$ and greater) nitrification only partially occurred if at all.

The effect of increasing hydraulic load whilst maintaining a constant organic load to a biological filter is to increase the area of carbonaceous oxidation; that is, the depth of heterotrophic film within the filter is increased, reducing the zone of nitrification

(Bruce 1969).

B. The Effect of Organic Loading upon Nitrification.

Generally, it appears that the greater the organic loading imposed upon a biological filter the less the nitrification that occurs. The precise effect of organic matter upon nitrification is uncertain. It is possible that the organic matter has a directly inhibiting effect, and indirect effect of reducing the oxygen available due to the activity of the heterotrophic organisms and also the heterotrophic organisms, due to their far greater growth rate compared to the nitrifiers, physically dominate the filter film excluding the nitrifiers. That the heterotrophic organisms inhibit nitrification by the indirect effect of limiting the oxygen available has been shown by Barritt (1933), Heukelukian (1947), and Tomlinson & Snaddon (1966). Jenkins (1931) employing a sectional pilot biological filter found that glucose did not inhibit nitrification. Similarly, Painter & Jones (1963) using fresh sewage, glucose and peptone, found no inhibition of nitrification. Tomlinson (1942) reported that as the BOD concentration increased nitrification decreased. Heukelakian (1942) stated that nitrification will only occur when the bulk of the carbonaceous material has been removed, and that nitrifiers do not require organic carbon for growth. Lumb & Eastwood (1958) showed that as the BOD concentration of a liquor decreased with depth in a biological filter, nitrification increased. Eckenfelder & Hood (1950) considered the carbon to nitrogen ratio to have a significant effect upon nitrification; nitrification ceasing when this ratio becomes excessive. Painter (1970) suggested that at high C / N ratio heterotrophic organisms develop rapidly, utilizing available ammonia for their own synthesis.

However, in sewage treatment practice, the ammonia concentration is normally sufficient for carbonaceous oxidation and the energy requirements of autotrophic nitrifiers. Beckman et al. (1972) consider the organic carbon concentration to control the population dynamics of heterotrophic bacteria; increasing organic carbon concentration causing the heterotrophic organisms to dominate over nitrifiers. Hawkes (1963) stated that the absence of nitrification in the presence of carbonaceous material is due to the slower growth rate of the nitrifying organisms, causing them to be outgrown by the quicker development of the heterotrophic organisms. This view is supported by work reported by Painter (1970); Nitrosomonas was shown to be capable of growth in 10% dextrose solution when in pure culture.

Bruce & Boon (1971), studying high-rate biological filters, found that increasing the organic loading progressively reduced the degree of nitrification, and that the removal of ammonia at high organic loads may be negligible. However, Duddles & Richardson (1974) on increasing the BOD loading on a two stage filter plant from approximately 0.1 $kg/m^3/d$ to 0.24 $kg/m^3/d$ did not observe any deterioration in nitrification. Bruce (1969) explained decreasing nitrification with increased organic loading by suggesting that increasing competition by the heterotrophic organisms in the lower parts of the filter resulted in fewer autotrophic organisms being present. Bruce et al. (1975) considered that poor nitrification in a two stage biological filtration system was due to excessive BOD loading on the secondary stage. However, Hawkes in discussion of Bruce et al. (1975) considered the BOD concentration of the feed to the secondary filter to be the critical factor. Work reported by Hawkes & Jenkins (1964) showed good nitrification in a double filtration plant where the BOD concentration of the secondary feed

was between 30 and 40 mg / l. The BOD concentrations of the feeds applied to the secondary stage of the filters reported by Bruce et al. (1975) were between 75 and 167 mg / l. Reeves (1972) suggests that the secondary filter of a two stage plant will nitrify successfully where the BOD concentration applied is less than 40 to 50 mg / l. Davies (1973) found that a BOD concentration of greater than 40 mg / l. had an inhibitory effect upon nitrification.

It can be seen that the literature indicates a suppression of nitrification in the presence of organic matter; the autotrophic nitrifying organisms being restricted by the quicker growth of the heterotrophic organisms. Therefore nitrifying organisms are restricted to the lower regions of a filter where the reduced organic concentration allows the nitrifying organisms to compete with the heterotrophic oxidisers.

C. The Effect of Temperature Upon Nitrification.

When considering two stage or multi stage treatment of sewage, the effect of temperature upon nitrification may be of major importance. The effect of temperature upon the growth of pure cultures of nitrifying organisms has been studied by various workers. Buswell et al. (1954) reported the optimum growth of Nitrosomonas to be in the range 30° - 36°C, with no significant growth below 5°C. The temperature range for the growth of Nitrobacter has been reported by Nelson (1931), Deppe & Engel (1960) and Laudelot & van Tichelen (1960). Nelson studied the development of Nitrobacter between 8°C and maximum growth at 28°C, (the effects of higher temperatures were not examined). Deppe & Engel found the optimum temperature to be 34 - 35°C, with no growth below 4°C or above 45°C.

Laudelot & van Tichelen reported the optimum temperature to be 42°C. From these studies it can be concluded that the growth of nitrifiers below 8°C in pure culture is severely restricted. However, it should be noted that these studies refer to the growth of the organisms and not their rate of metabolism; nitrification may still occur below 8°C. The effect of temperature upon nitrification in biological filters has been studied by many workers. Tomlinson (1942), studying a two stage filtration system, found that the nitrifying capabilities of secondary filter film showed seasonal variations; greater nitrification being achieved by the film in the summer than in the winter. Balakrishnan & Eckenfelder (1969) found that the temperature within the range 15°C to 30°C had an important effect upon nitrification. Their results showed that nitrification decreased with decreasing temperature. Solbé et al. (1974) using pilot scale filters innoculated with grazing fauna observed that at temperatures of 7°C, 10°C and 13°C, a decrease in temperature resulted in a decrease in nitrification. Bayley & Downing (1963) and Bruce et al. (1967) reported that biological filter performance varied seasonally in response to the ambient temperature; nitrification being higher in summer than in winter. However, Hawkes & Jenkins (1964) studying double filtration and alternating double filtration found no seasonal variation in the oxidised nitrogen levels of both systems and stated that "it thus appears that nitrification in bacteria beds is not affected by changes in temperature over the range existing in the beds, i.e: between approximately 10°C and 20°C. The reduced nitrification in bacteria beds in the winter when it does occur is probably due to the increased film accumulation". This increased film accumulation

could affect nitrification in two ways; the increased film, being mostly the result of increased heterotrophic growths could eliminate much of the nitrifying population by interspecific competition. Also, the increased film may cause a reduced oxygen concentration in the liquor being treated preventing the activity of nitrifiers. Hawkes (1961), controlling seasonal film accumulation by reduced frequency of dosing, observed that the winter decline in nitrification was reduced. In the work reported by Bruce et al. (1967), it can be clearly observed that nitrification decreased with decreasing temperature, the two minima being coincident, during January - February, whilst the greater film accumulation occurred approximately one month later in both the years reported. Bruce et al. (1975), using pilot scale two stage filtration, suggested that the minimum threshold temperature for nitrification is beneath 10°C. A temperature loss of 4 to 5 centigrade degrees was observed in the sewage during its passage through the primary filter, interstage settlement tank and secondary filter. The poor nitrifying performance of the two stage filtration system compared to a single stage filtration being attributed to this greater temperature loss. However, Hawkes in discussion of Bruce et al. (1975), whilst accepting that temperature of less than 8°C may cause a marked reduction in nitrification as a direct effect of reduced metabolic rates of the organisms, suggested that the poor nitrifying ability of the secondary filters could be related to the organic strength of the feed applied. Duddles & Richardson (1974) found that the effect of temperature upon nitrification increased with increased hydraulic load applied to a two stage filtration plant. It is of interest to note that at a hydraulic loading of 0.3 $m^3/m^3/d$, they achieved

90% nitrification at temperatures as low as 4°C. The effect of hydraulic loading upon the influence temperature exerts over nitrification is considered by Schroepfer et al. (1952). Temperature exerts an effect upon the oxidation of organic matter; decreasing the temperature increases the volume of the filter used for carbonaceous oxidation, reducing the nitrifying zone, hence reducing nitrification. An increase in hydraulic loading also causes a greater quantity of organic matter to be present lower in the filter, similarly reducing nitrification. Therefore, temperature also exerts an indirect effect upon nitrification.

From the literature discussed, it can be seen that temperature effects upon nitrification are complex. In general, it appears that nitrification is severely limited at or below 8°C, which may be of vital importance in two stage filtration plants, where temperature losses can exceed those of single stage systems. The organic strength of sewage applied to filters specifically designed to effect nitrification may have a significant impact. Increasing hydraulic loading to a filter has the effect of reducing nitrification due to increased zone of heterotrophic activity.

In view of the likely effects of temperature, organic strength and hydraulic loading upon secondary filter nitrification, laboratory scale filters were established to determine whether the Hereford high-rate filter effluent could be feasibly nitrified in secondary filters.

4. PILOT HIGH RATE FILTRATION AT HEREFORD.

A. Objectives of the Project.

Hereford sewage treatment works receives a crude sewage of partly domestic and partly industrial origin. The industrial fraction, whilst contributing 25 - 30% of the volume, constitutes approximately 50% of the BOD load to be treated at the works. The major trade effluents include fruit and vegetable canning wastes, effluents from the production of cider and also poultry processing wastes. Cider production and fruit and vegetable processing are seasonal operations which result in wastes rich in organic matter contributing a high BOD to the sewage. Also, the inclusion of these vegetable wastes result in a high carbon to nitrogen ratio. The cider production wastes, in particular, cause difficulties in treating the sewage. The crushing of apples is highly seasonal, particularly strong wastes and greatest flows occurring between October and January.

Due to the low temperatures, the strength of the waste and the high C/N ratio, the development of fungal growths is encouraged on biological filters. This can lead to ponding problems and a deterioration in the quality of the final effluent.

In view of the nature of the sewage, and a need to increase the capacity of the works, the possibility of two stage treatment was considered where the first stage would be high-rate filtration. As information concerning the performance of high-rate filters was limited, a pilot scale investigation was initiated at the Hereford sewage treatment works.

The purpose of the investigation was to determine whether two

stage filtration using high-rate primary filtration was feasible for the treatment of Hereford sewage, possibly resulting in an improved effluent quality, reduced operational difficulties and reduced capital expenditure on extending the sewage works.

The project also included more fundamental objectives. Various types of media suitable for high-rate filtration were to be tested in order to obtain information about the comparative performances of the media and the relative economics of constructing full scale filters of each type of media. The effects of various loadings and frequencies of dosing were to be investigated.

Also, an objective of the project was to assess the degree of purification necessary in a high-rate primary filter to ensure a fully nitrified effluent from the secondary stage. The temperature loss through the various high-rate filters was to be monitored in order to determine the likely operational temperatures of secondary stage filters, since evidence from previous two stage filtration studies indicate that nitrification difficulties might be encountered in the secondary stage during winter months.

Published information concerning the ecology of high-rate filters is extremely limited. Previous studies only mentioning the flora and fauna of filters in qualitative terms as incidental observations. It was therefore considered useful to obtain data concerning the comparative ecologies of the various media employed.

B. Plant Description.

The pilot scale filters were constructed by modification of two existing octagonal filters which had previously been employed for experimental work at Hereford. In order to obtain filters of 2 metres

in depth, it was necessary to raise the height of the brick octagonal filters using concrete blocks. One tank was divided into eight equal segments providing a surface area of 1.9 m^2 for each filter. The divisions were constructed using shuttering, (an impervious ply boarding used in the construction industry), with kerb stones situated at the base of the boarding to ensure complete separation of the individual effluents. The screed bases of the filters were finished to ensure free drainage of the effluent to the effluent sumps, with no standing effluent at the base, as shown in figure 4.4. Drainage tiles were placed in the bases of the filters. The effluents were collected in small sumps constructed outside the main tank structure as shown in figure 4.1. These sumps were built to facilitate sampling of the individual effluents, by either manual or automatic techniques.

In order to ensure adequate ventilation within the filters, 63.5 mm diameter uPVC pipes were inserted in the corner of each filter as shown in Plate 4.4, with the upper end extending above the retaining walls, and the lower end terminating at the level of the drainage tiles.

As previously mentioned, one tank was divided vertically into eight equal radial segments; this tank being used to house four types of mineral media. The second tank was divided in a similar manner, but instead of being divided into eight equal segments was divided into six segments. (It had been decided at an early stage, after consultations with the manufacturers of Flocor, I.C.I. Limited, that in order to obtain a representative packing of the media within the octagonal structure, the filter volumes needed to be double the size used for the mineral media). Four of the segments within the second tank were of the same dimensions as the segments built to house the

mineral media. However, the remaining two segments which were diagonally opposed, each occupied a quarter of the total available surface area; that is, twice the size of the other four segments. These two filters housed the modular Flocor plastic media under test. The two types of Flocor used were Flocor E and Flocor M. The base of the segment used to house Flocor M was raised by 200 mm using a galvanised steel mesh of 25mm aperture. This action was taken in order to obtain an equivalent total surface area of media to a random plastics media, (Biopac 50), used to fill two of the smaller segments within the octagonal tank. The bases of all the segments contained drainage tiles and were constructed in a similar fashion to the segments of the other octagonal tank, having sloping bases, individual effluent sumps and ventilation shafts as previously described. The two larger segments had two effluent sumps each.

Prior to installing the mineral media and the random plastics media, a 2 metre deep 37.5 mm diameter hollow aluminium shaft was installed vertically in each filter, in such a position that it would eventually be surrounded by a minimum radius of 300 mm of the media packed into each filter. The shafts were placed in an identical position in each filter in order that they would be subjected to the same irrigation of sewage at the surface of the filter. (The tops of these shafts are visible in plates 4.4, 4.5, 4.9 and 4.10). The shafts were mounted in a manner to allow free drainage from the base, with large rubber bungs fitted to the tops. These shafts were used to carry out neutron scatter determinations of the moisture retained by the filter films at any depth. The technique will be described in detail in chaper 6, section BII.

Also installed in a similar manner to the aluminium tubes, were three galvanised perforated steel shafts per filter. These shafts were of 1.8 m depth and 225 mm internal diameter. Only four filters of mineral media had the shafts installed as indicated in figure 4.1. The purpose of these shafts was to permit access to the media at any depth within the filter. In order to ensure media packing within the shafts representative of the rest of the filter, larger diameter shafts are to be preferred. However, it was felt that larger shafts might have a significant effect upon the filter performance. The shafts were perforated in order that the media packed within the shafts would be in intimate contact with the rest of the filter media to permit maximum colonisation of the media by the film and its grazers. The perforation employed was 19 mm diameter; this being considered adequate to allow colonisation of the media, without permitting any structural damage to the shafts or angular parts of the media to become trapped in the perforations. Three shafts were inserted in each filter in order that a full recolonisation of the sample media could occur between sample periods. Initially, bags made of $\frac{1}{4}$" nylon shrimp netting were tried as possible containers for the media. However, although the shrimp netting allowed excellent packing of the media within the shafts, difficulties were encountered in removing the bags. Angular pieces of media tended to penetrate the perforations of the steel shaft, chaffing the nylon netting and causing serious destruction of the bag. Therefore the media used in the shafts was contained in five plastic baskets of 220 mm diameter, constructed of $\frac{3}{4}$" mesh 'Netlon'. The basket at the surface of the filter was of 200 mm depth whilst the other four baskets were 400 mm in depth, (fig. 4.5). The baskets were lowered into the shafts by means of four lengths of

polypropylene baler twine attached to the open upper edges. Five baskets were inserted into each shaft as a compromise between the desired number and practical considerations. It is standard engineering practice to allow the depth of any insert within a cylindrical shaft to be twice the diameter of the shaft to avoid the insert jamming across the shaft. This would have meant that only four baskets could have been inserted into each shaft. It was considered probable that the nature of the film would alter markedly within 450 mm, particularly near the surface of the filter. Therefore the surface basket was constructed of 200 mm depth since this basket could easily be removed manually, extracting the individual pieces of media if necessary. The remaining four baskets were built 400 mm in depth, equal to twice that of the surface basket. The bed containing the mineral media was packed with four different types of media; nominally 89/50 mm and 125/75 mm granite and two similar grades of blast furnace slag. The physical properties of the media employed are detailed in chapter 5. Diagonally opposed pairs of filters were filled with the same media; one of each pair containing the three galvanised shafts previously described. Duplicate filters were used in order to determine whether the variation in performance between the various media was significant or whether it was due to natural variation between filters. The duplicates were sited diagonally opposite in an attempt to prevent any maldistribution of sewage to the filters or the effects of the prevailing winds leading to erroneous conclusions concerning any particular medium's performance.

Due to the physical dimensions of each filter and the possibility of displcaing and damaging both the aluminium tube and the biological shafts, much care was taken when installing the media in each filter.

The media was individually placed manually; it was necessary to use a mobile crane with a dustbin attached to its jib to lift the media into each filter. Immediately prior to its placement, the media was thoroughly washed, and collected as randomly as possible from a well mixed pile of the media. Because of the weight of the mineral media, each filter was filled in rotation, increasing the depth by approximately 300 mm at each filling to prevent distortion of the shuttering dividing the filters.

The other octagonal tank was filled with plastic media. The four smaller filters being used for the random plastics media, Biopac 90 and 50. Diagonally opposed filters were filled with the same media. Due to the low bulk density of both types of Biopac, the media could be installed by tipping bags full into the filters; after installing approximately every 500 mm of media, large boards were placed on the surface of the media and these were gently bounced upon in order to tamp the media into a stable packing arrangement. Biopac 90 and 50 take their names from the physical sizes of the media. The media consist of hollow plastic cylinders respectively 90 and 50 mm in diameter and length. The structure of the individual units is shown in plate 4.3 and can be seen in the packed filters in plate 4.4.

Flocor E, a modular plastic media consisting of corrugated sheets, (shown in plate 4.1) was packed into one of the larger segments in the second tank. Each module was 1.2 m in length, 0.6 m in depth and 0.6 m in width. The lowest layer of the media was of a slightly different nature, although presenting a similar surface area for colonisation. A thicker and more rigid laminar sheet of plastic was attached to each module as a vertical support;

these modules are known as Flocor ES. The purpose of the additional strengthening is to ensure that when a heavy film had developed on the upper layers of the media, physical distortion of the modules would not occur. Flocor M, a similar modular media of greater specific surface area (135 m^2/m^3), shown in plate 4.2, was used to pack the other large segment. As previously mentioned the base of this segment was raised by 200 mm in order to obtain a total surface area of media equivalent to that of the two filters containing Biopac 50. Due to the greater structural rigidity of Flocor M compared to Flocor E, identical units of Flocor M were packed throughout the depth of the filter. Because of their modular structure, it was not feasible to use the biological shafts previously described in the Flocor E and M filters. Samples of the media and associated film had to be obtained by different methods. At three depths within each filter, namely 0 - 200 mm, 600 - 800 mm and 1200 - 1400 mm, smaller subunits of each type of media were installed. These subunits were installed by cutting standard Flocor units into smaller pieces. In the case of Flocor E these units were 300 mm x 300 mm x 200 mm, whilst for Flocor M they were approximately 300 mm x 200 mm x 200 mm. At the surface of the filter four units cut from one standard module were installed. The purpose of the four units was to allow recolonisation between sampling intervals. At 600 mm - 800 mm depth another four similarly dimensioned units were installed. These units were positioned so that removal of film (during sampling) from the units above would not affect the quality of the sewage that they received. In order to remove these units for examination, a complete standard module from the layer above had to be lifted out from the surface of the filter using two "Mole" wrenches at diagonally opposed corners.

To remove samples of the media from the third depth via the surface of the filter would have required disturbance of several modules of the media above, which might seriously affect the performance of the filter. Therefore an alternative method was employed. Only one small unit was installed at the 1200 - 1400 mm depth adjacent to the side wall of the octagonal tank. A rectangular hole was cut in the tank wall at the position of this sample unit in order that it might be extracted laterally for examination. To prevent excess ventilation through this aperture polystyrene blocks were cut to fit the hole as completely as practicable. These insulating blocks were held in position by an oversize board of shuttering attached to the external surface of the wall.

Two aluminium tubes used for film moisture content determinations were installed in each filter, similarly positioned to those installed in the random mineral and plastics filters. The tubes were inserted by being hammered directly through the media from the surface. Little effort was required for this operation and minimal damage was incurred by the media, (plate 4.5).

Settled sewage was applied to the surface of the filters by Simon Hartley rotating four arm distributors; one to each octagonal tank. The central vertical support shaft was sited at the centre point of each tank, being grouted and bolted in position. Trays were placed on the surface of the filters in various positions to collect distributed sewage in order the check that the central shaft was vertical and that an even distribution of sewage was obtained. Each arm was supported by means of a galvanised wire stay attached to the top of the central shaft and approximately two thirds the length of each arm from the central shaft. Minor adjustment to

ensure that each arm was horizontal could be obtained by slackening or tightening a bottlescrew on each stay. To ensure that the four arms radiated at right angles horizontally to each other from the central shaft, galvanised steel stays were connected between each arm. The jets on the distributor arms were staggered to ensure full coverage of the filter surface, although due to the octagonal shape of the tanks used, a small area adjacent to the ventilation pipes did not receive the same cover as the rest of the bed surface. To further facilitate adequate distribution of sewage to the filter surface stainless steel splashplates were fitted below each jet to increase the area covered, shown in plates 4.9 and 4.10.

In order to provide a uniform frequency of dosing, the distributors were motor driven. The drive from the electric motor was transmitted to the distributor arms by means of a chain. The sprocket sizes on the final drive and driven shaft could be varied in order to obtain a variety of dosing frequencies. In order to provide adequate distribution of the sewage at various flow rates two opposite arms on each distributor were provided with valves. At low flow rates these valves could be closed, therefore only using two arms hence increasing the force with which the sewage impinged on the splashplates providing a wide spray area; the frequency of dosing could be maintained by altering the sprocket sizes on the chain drive.

Sewage was provided to the experimental plant via a "Mono" pump sited adjacent to the main works primary settlement tanks collecting settled sewage from the collection chamber. The pump was capable of providing 200 m^3/day under the site conditions prevailing. In order to maintain a constant flow to the filters,

a header tank was installed between the two octagonal tanks, where the surface of the sewage in the tank could be maintained constantly at 1.3 m above the surface of the filters. The tank volume was 2.4 m^3. Sewage entered the base of the tank via a 75 mm diameter uPVC pipe and entered each distribution system via two 75 mm diameter uPVC pipes similarly through the base of the tank. Any sewage lost over the weirs at each end of the header tank whilst maintaining the constant head was run to waste. In order to vary the flow to each distributor, a ball valve was installed in each line from the header tank. The pipe from the base of the header tank to each distributor ran through the octagonal retaining wall and then along a shuttering division between two filters, hence preventing any disturbance to the filter media packing and filter performance. In order to determine the retention times of the various filters, part of the pipework between the header tank and distributor arms was duplicated as shown in figure 4.2 and plate 4.6. This provided a means of inserting a known volume and concentration of tracer into the distribution system, and hence to the surface of the beds, with the minimum of disturbance to the flow rate.

In order to monitor the sewage flow rate, initially two venturis were installed in the pipework between the header tank and the distributors; the flow being measured as a function of the pressure drop across the venturi. The pressure difference was converted into an electric signal via a transducer. The signal was then fed into an integrating recorder. Unfortunately the system proved unsuitable for this application; the pressure either side of the venturi was transmitted to the transducer via 6 mm diameter "Bundy" tubing. This tubing quickly developed a film on its internal surface and

affected the pressure transmission. Also, the venturi itself presented too great a restriction on the flow rate, which could only be overcome by either raising the header tank, or increasing the bore of the pipework and the venturi. Due to both these problems, this method of flow measurement was abandoned early in the project. It was replaced by four Water Research Centre 10 litre tipping trough recorders, as shown in plate 4.7. These troughs could be calibrated for the volume of sewage required to cause them to overbalance and tip out their contents. Each tip was registered via a magnetic reed switch and integrating recorder. Electric power for the system was supplied by a 12v DC battery, kept charged by a 240v AC battery charger on a time switch. The four tipping troughs employed were specifically built to fit into the effluent channels, under the individual effluent sumps. To ensure an accurate measurement of the effluent flow from the sumps, the sump outfall weir required modification to permit its contents to flow directly into the trough. Because of the difficulty in moving the troughs from one effluent sump to another and also the modifications required, it was decided that two diagonally opposed effluents would be monitored continuously on each bed.

The temperature of the sewage in the header tank and within each filter was monitored, using Foster Cambridge resistance probes. These probes were constructed of 570 mm long hollow steel tubes containing the resistance wires. Prior to installing the probes, tests were carried out to determine what depth of the probe required immersing in the sewage to ensure that the temperature recorded accurately reflected either the sewage or the bed temperature. In the case of the header tank, the probe was mounted vertically above

the surface of the sewage with 250 mm of the probe immersed in the sewage. Previous reports have indicated that the temperature within a filter bed may vary with depth. In order to ascertain whether any variation occurred in the filters used in this project, holes were drilled through the 200 mm octagonal retaining walls at three depths within each filter. The three depths of 200 mm, 1000 mm and 1800 mm from the surface of the filters were identical for all the filters except for the Flocor M filter where the two lowest positions were 1600 mm. The variation of temperature observed with increasing depth of the filter is discussed in chapter 6. The 13 mm diameter probes were installed after placement of the various media. In order to insert the probes into the filters, it was necessary to drive a 16 mm diameter steel rod through the media. In the cases of the mineral media, vigorous striking of the rod by a lump hammer was required. The rod was driven into each filter approximately 50 mm further than required to insert the probe. Great care had to be taken over the positioning of the drill holes in the cases of the filters containing the perforated steel shafts to ensure that the probe would pass directly between the shafts and not through or directly adjacent to a shaft. In total, 17 temperature probes were used; one for the incoming sewage in the header tank and one for each filter. However, only a three channel chart recorder was available to monitor the output from the probes. One channel continuously recorded the header tank temperature, whilst the other two channels were fitted with eight-position switches which allowed any one of the eight probes to be monitored. As a result, one filter temperature from each octaganal bed could be monitored oontinuously, with the facility of manually switching a desired probe into the recorder channel.

The Cambridge Clearspan recorder was capable of plotting temperatures within the range 0 - 30° C. No facility was available to calibrate each probe output, although initial tests showed that the temperatures recorded by different probes were accurate. In order to prevent any variations in resistance due to differing lengths of coupling wires to the probes, compensation wires were installed, and all wiring was screened to prevent any external interference. The chart recorder was provided with a heater to prevent problems of condensation during cold weather.

Automatic sampling was provided by three Bestel Dean samplers. The sewage supply was sampled using a standard 24 x 250 ml bottle sampler. The sampler incorporated a facility to ensure that the 25 mm internal diameter heliflex tubing and the internal pipework of the sampler were thoroughly purged by fresh sewage before the sample was taken. A maximum purge time of 12 minutes was available although in practice a time of 3 minutes was found to be adequate. The 24 bottle sampler shown in plate 4.8 worked in the following manner:- either by switching the sampling procedure on or by setting up the sample timer, the initial sample would be delivered into bottle number one, after purging the pipework for a desired interval. On completion of the first sample, the turntable on which the bottles were mounted rotated so that the delivery tube was positioned between the first and second sample bottle; this ensured that any drips from the delivery tube did not contaminate either sample. The sample interval timer then came into action. This timer could be set for a time interval varying from five minutes to four hours between each sample. In practice this was usually set to 55 minutes in order to provide 24 hourly

samples of the sewage feed. On completion of the sample time interval, the turntable would rotate to place the second bottle beneath the delivery tube, and the previously described routine would be repeated. On filling the 24 bottles the sampler would then switch off, and would not restart until manually reset. To prevent problems due to condensation and also freezing of the samples a small electric heater was installed in the base of the sampler cabinet, which could be switched on during cold weather. To increase the flexibility of sampling the cabinet was controlled by a 7 day, 24 hour timer governing the mains supply to the unit. This was considered necessary to obtain 24 hour sample periods during weekends and other unmanned periods greater than 24 hours.

To sample the effluents of the 16 filters, two purpose built 8 bottle samplers were used. These differed from the standard 24 bottle unit in various ways. Only eight canisters were present on the turntable. The sample bottles could contain a maximum volume of five litres. One sampler was allocated to each octagonal tank to sample the eight filter effluents. The samplers produced a composite sample of each effluent in a sample bottle, delivering 250 mls on each sampling. The purge timer and interval timer were capable of the same variations as the 24 bottle sampler. However, at each sample time, eight separate samples were taken of the filter effluents. The eight samples were taken sequentially, being delivered by the same delivery tube, with a purge of the tubing and associated pipework between each sample; the whole sequence taking 35 minutes when a purge time of 3 minutes was used. After taking the eight samples, the turntable stopped in a position such that the delivery tube was midway between sample bottle number 8 and number 1. These eight bottle samplers differed from the 24 bottle

sampler in that they would continue to sample until manually switched off. In order to obtain a sample of each effluent, sumps as shown in plate 4.7 were constructed. These sumps accumulated solids. To obtain a representative sample of the effluent from these sumps a purge time of 2.5 minutes minimum was found to be required. Therefore in practice a three minute purge time was employed.

Seven day, 24 hour time switches were installed in the mains supply to each sampler to obtain weekend samples. A heater was also installed in the base of each sampler cabinet to prevent condensation difficulties and freezing of the collected samples.

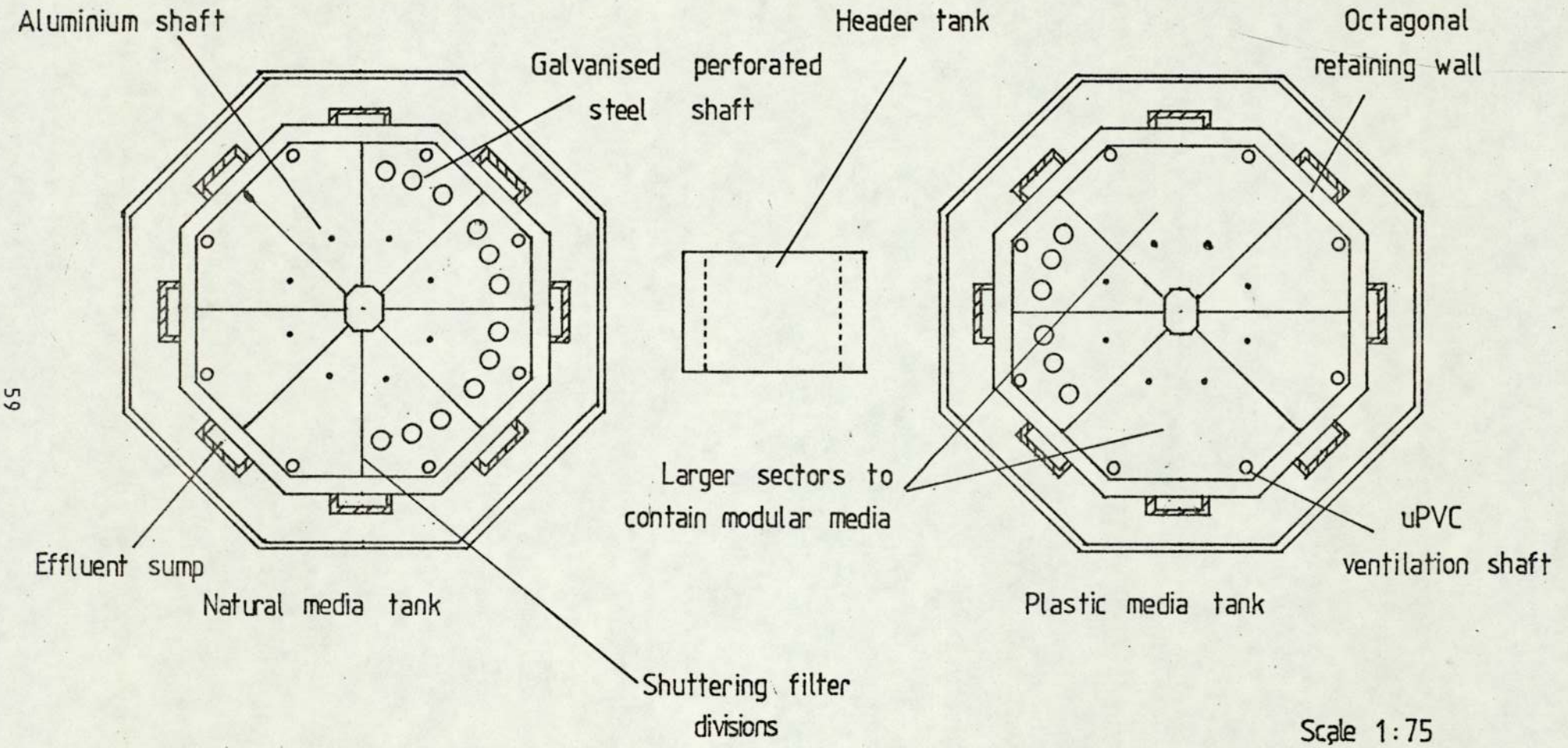


figure4.1 PLAN OF PILOT HIGH RATE FILTRATION PLANT

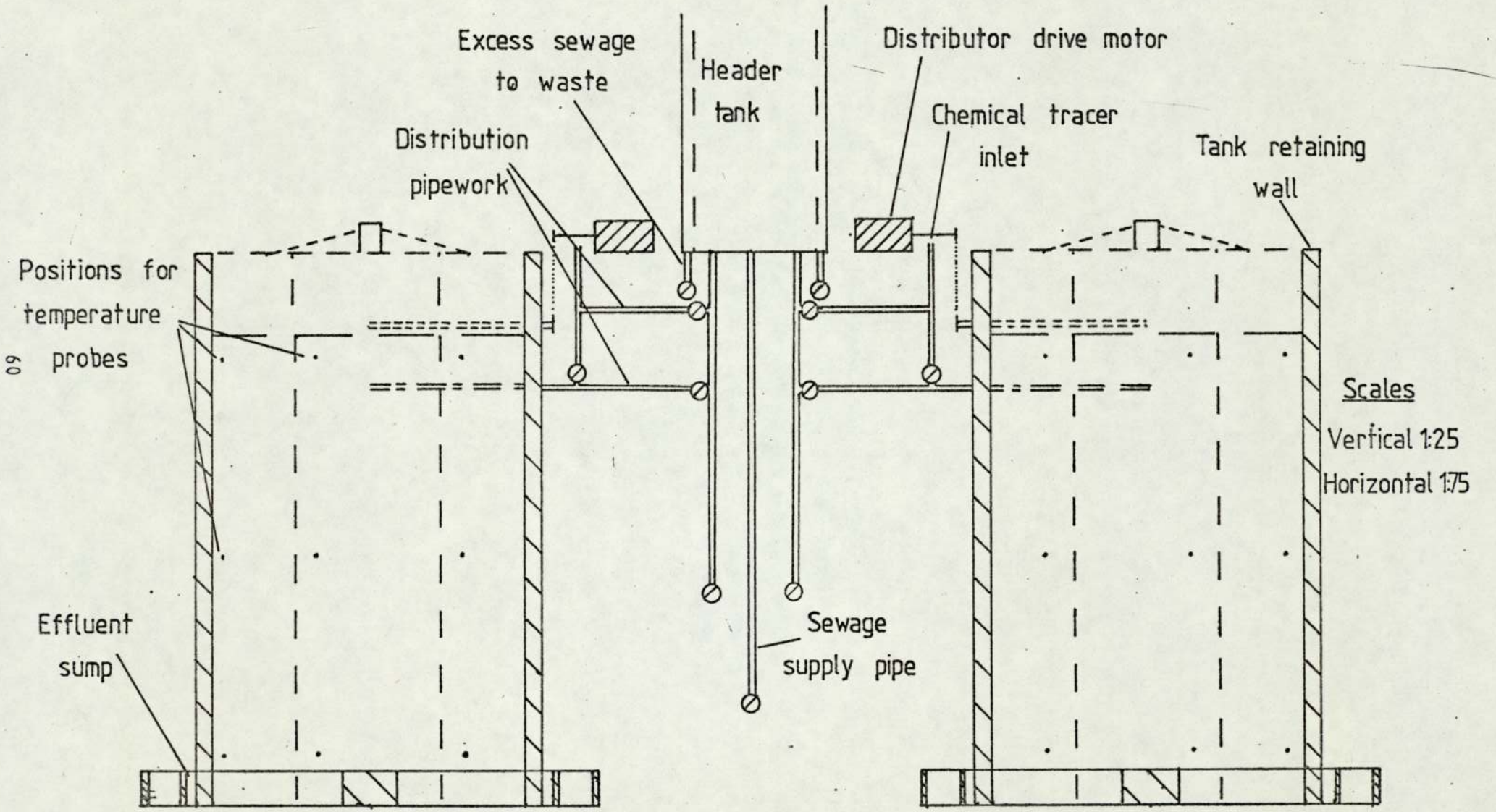


figure 4.2 PROFILE OF PILOT HIGH RATE TREATMENT PLANT

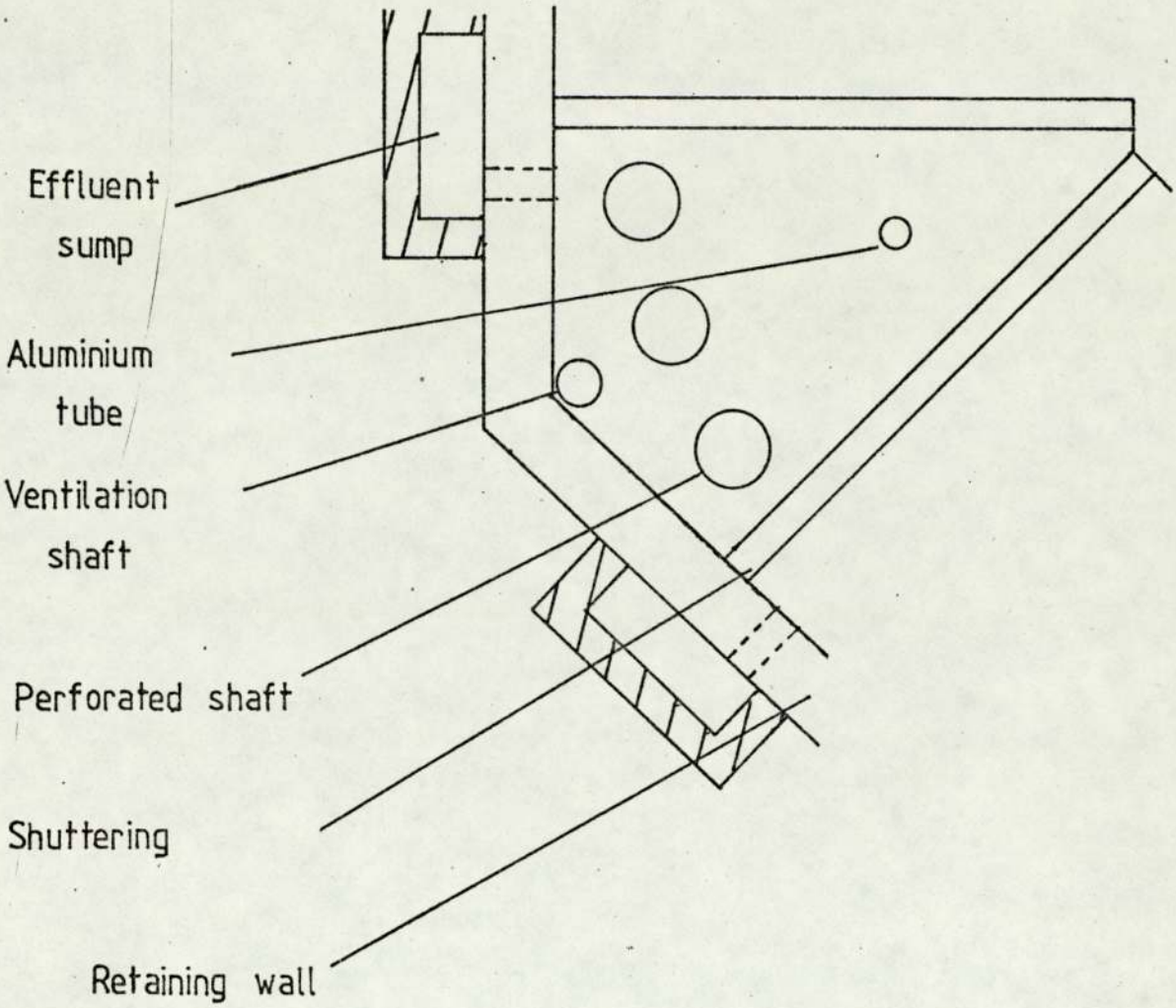


figure 4.3 PLAN OF SECTOR DETAIL

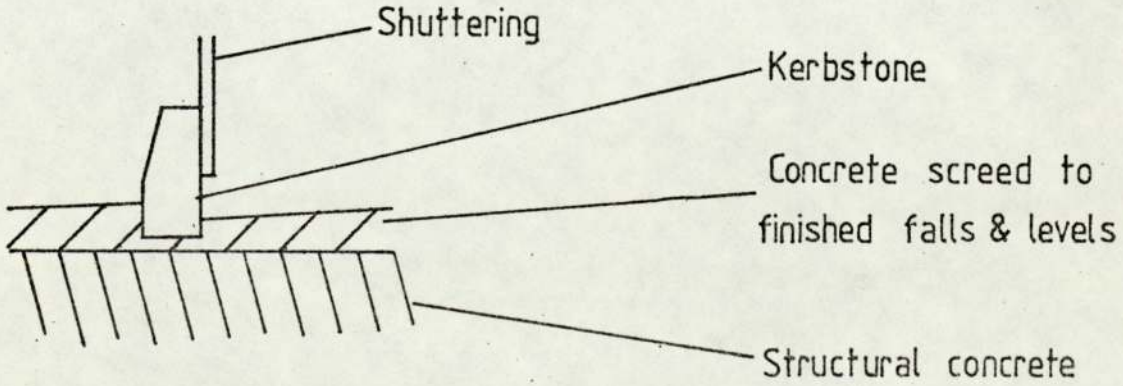
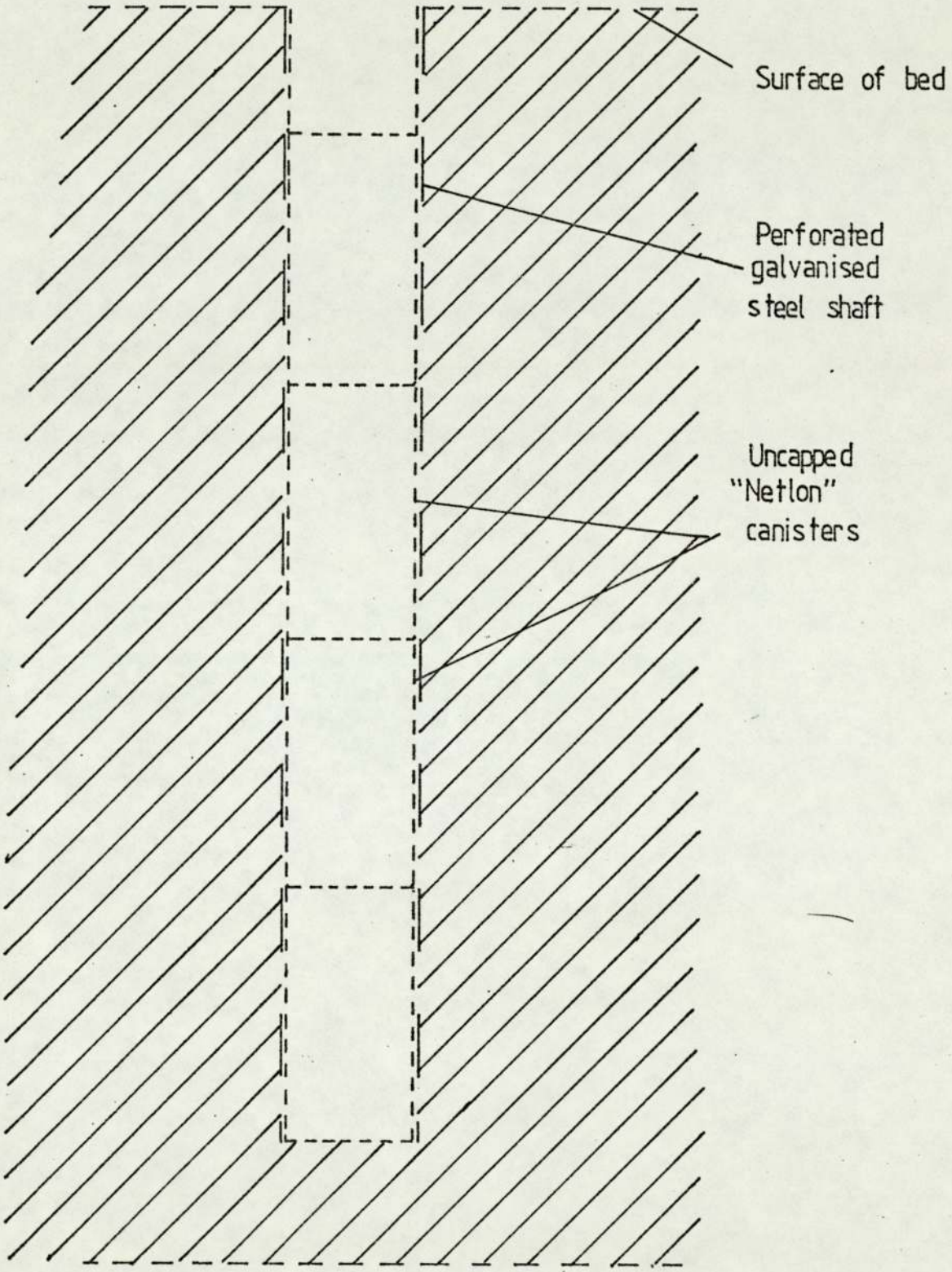


figure 4.4 DETAIL OF SEALED PARTITION BASE



PLAN OF BIOLOGICAL SHAFT

10cm.

(Canisters raised by attached polypropylene twine.)

figure 4.5

Plate 4.1 A Single Module of Flocor F

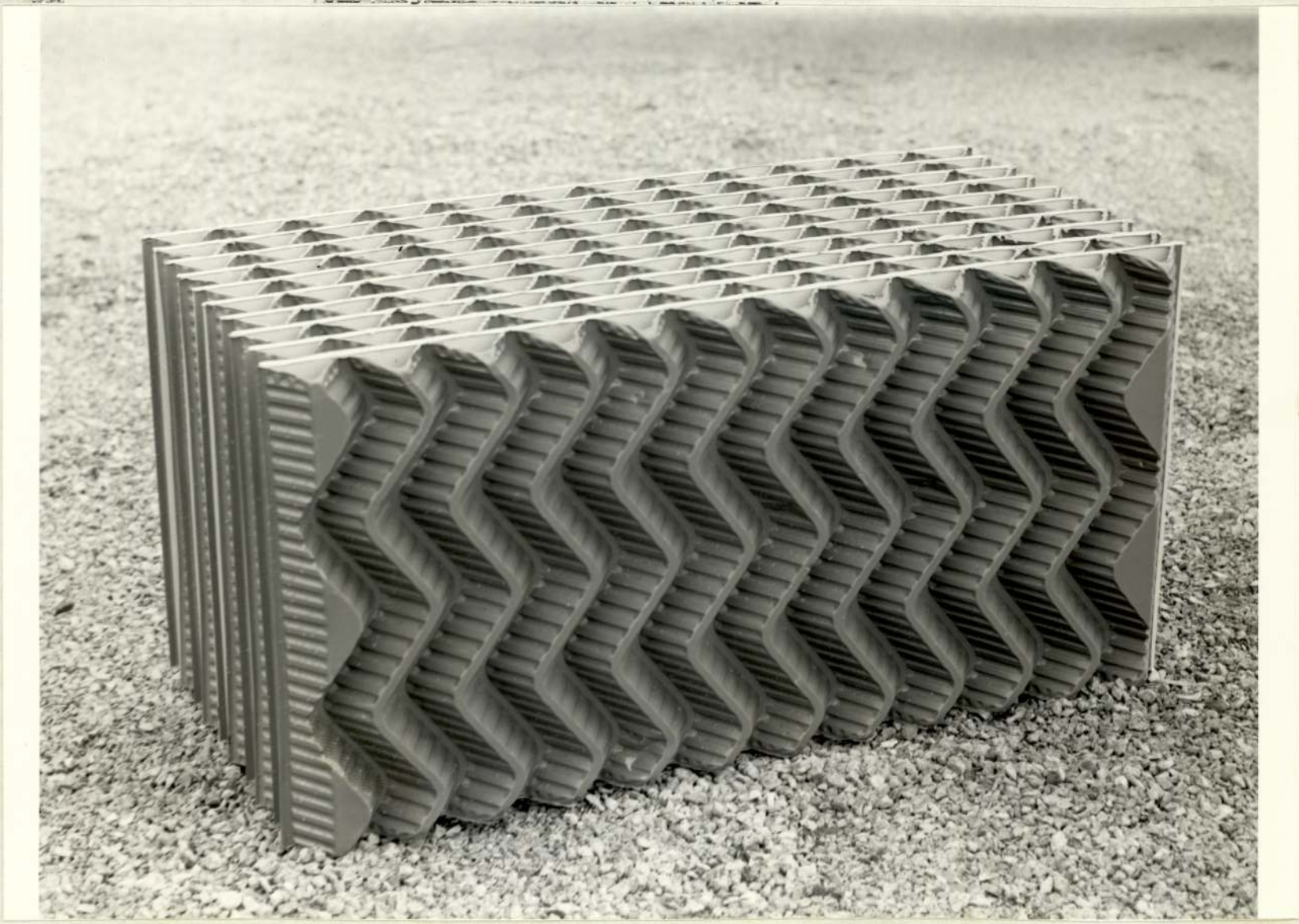


Plate 4.2 A Single Module of Flocor M.

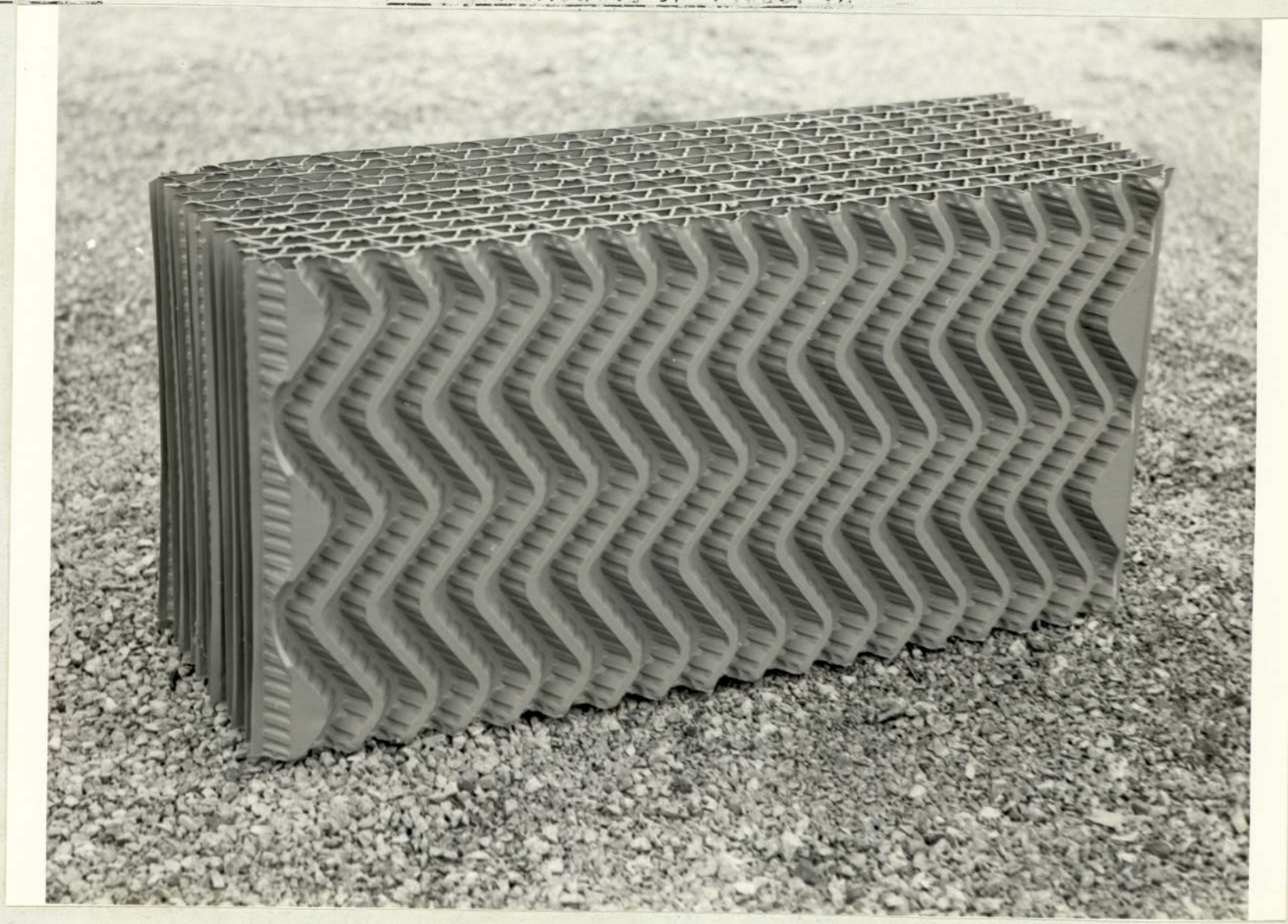


Plate 4.3

Biopac 90

Biopac 50

Plate 4.4 Ventilation, Neutron and Biological Access Shafts.

Plate 4.5 Distribution System to Filters.

Plate 4.6

Header Tank

Distribution

Pipework.

Plate 4.7

Flow Recording

Timing Trough.

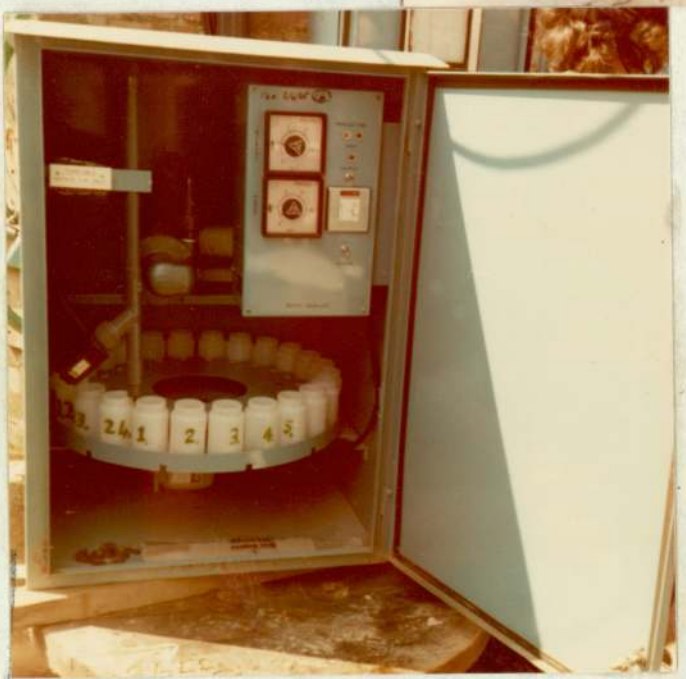


Plate 4.8

24 Bottle Sampler

Plate 4.9 Distributor Jets and Splash Plates.

Plate 4.10 Surface View of the Mineral Media Filters.

5. PHYSICAL CHARACTERISTICS OF THE MEDIA USED.

In order to establish the characteristics of the various media to correlate with their differences in performance, several physical tests were carried out on the mineral media to determine their gradings, stabilities, specific surface areas, void capacities and retention times devoid of film.

Since the plastic media were of known regular dimensions, the grading test was not applicable. Also due to their design, the plastic media had known specific surface areas and hence were not assessed in the manner of the mineral media. However, their void capacities and retention times under the dosing regime employed were assessed.

A. Grading of the Mineral Media.

The gradings of the mineral media for use in high-rate filters is not specified in British Standards, consequently the grade of media used is currently a matter of agreement between supplier and contractor. In order to obtain comparative data on the granite and blast furnace slag, the gradings shown in tables 5.1 and 5.2 had to be complied with. In order to analyse the media the methods outlined in British Standard 1438 (1971) were followed. Standard sieves were used for the grades 63.5 mm and less, whilst steel meshes for the 150 mm, 125 mm, 100 mm and 75 mm, were fabricated. In order to determine the flakiness indices of the media, hardboard templates were constructed by inference from the size ratios described in the standard.

For the 125 / 75 mm media, approximately 200 kg. were used in the test, and 100 kg. for the 89 / 50 mm media. These samples being random subsamples of roughly one cubic metre of thoroughly mixed media.

I Results.

Table 5.1 - Sieve Analysis of 89 / 50 mm Mineral Media

Sieve (mm)	Suggested Passing*	Granite*	Slag*
100.0	100	98.0	89.8
76.0	45 _ 55	38.0	39.3
63.5	0 _ 10	4.8	12.0
50.0	0	0.5	2.2

(*Results expressed as percentages of sample by weight)

Table 5.2 - Sieve Analysis of 125 / 75 mm Mineral Media

Sieve (mm)	Suggested Passing*	Granite*	Slag*
150.00	100	100	97.5
125.0	75 _ 85	85.9	75.0
100.0	35 _ 45	38.3	37.1
76.0	0 _ 10	3.2	7.8
63.5	0	0.7	2.9

(*Results expressed as percentages of sample by weight)

Table 5.3 - Flakiness Analysis of the Mineral Media

Type of Media	Flakiness*
125/75 mm Granite	5.0
125/75 mm Slag	2.5
89/50 mm Granite	12.1
89/50 mm Slag	7.4

(*Results expressed as percentages of sample by weight)

II Discussion.

From tables 5.1 & 5.2, it can be seen that the large media complied fairly closely to the suggested gradings. However, the 89/50 mm media showed deviations from the specifications. The granite media contained a greater proportion of small sizes. The media were accepted since it was considered that these deviations could be expected in standard commercial practice.

All the media complied with requirements of B.S. 1438 for flakiness; the 89/50 mm granite showing the greatest degree of flakiness.

B. Sodium Sulphate Soundness of the Media.

Mineral media can be subject to breakdown, when used in filter beds, through various causes such as flaking due to incipient cracks, the effects of a particularly strong waste, or the varying thermal expansion coefficients within a piece of the media.

In order to avoid such breakdowns, media to be used in biological filters should undergo the Sodium Sulphate Soundness Test, described in British Standard 1438 (1971), which endeavours to simulate harsh conditions similar to those which media in filters might have to endure. Both the Granite and the Blast Furnace Slag were subjected to the test as described in B.S. 1438 (1971).

I Results.

The results are presented below in Tables 5.4 & 5.5, the original data being given in Appendix 5.1

Table 5.4 - BS. 1438 Sodium Sulphate Soundness Test Results on Blast Furnace Slag.

No. of pieces tested	40
Original Sample Weight	6464.7 g.
Mean Weight	202.0 g.
Final Sample Weight	6365.3 g.

8 pieces disintegrated during the test.

2 pieces lost greater than 10% of the mean weight during test.

Therefore 10 pieces failed, i.e: 25%

Overall weight loss of samples 1.5%

Table 5.5 - BS. 1438 Sodium Sulphate Soundness Test Results on Granite Media.

No. of pieces tested	40
Original Sample Weight	9375.2 g.
Mean Weight	234.4 g.
Final Sample Weight	1994.3 g.

31 pieces disintegrated during the test.

1 piece lost greater than 10% of the mean weight.

Therefore 32 pieces failed the test, i.e: 80%

Overall weight loss of the sample 78.8%

II Discussion.

From tables 5.4 & 5.5, it can be seen that both types of media

failed the test. Analysis of the raw data tabulated in Appendix 5.1 shows that the granite media survived well until the tenth cycle, after which disintegration occurred with increasing frequency. Visual inspection of the granite before the test indicated no incipient cracks or tendency to crumble. The granite was also very resistant to fracture on being struck heavily. In the case of the blast furnace slag, the disintegration was more gradual and less severe as compared with the granite.

At the end of the test period, after a 24 hour wash cycle and a 4 hour drying, it was noticed that sodium sulphate crystals still formed on the surface of the media. In order to remove all traces of the sodium sulphate within the media, it was necessary to carry out three washing and drying cycles.

It is pertinent to note that in BS 1438 (1971), users of the sodium sulphate soundness test are asked to forward results to the British Standards Institute, so that modifications may be made to the test if necessary. From the results presented, it would appear that the test is extremely severe and that a reduction in the number of cycles employed (to perhaps ten or less), and/or a reduction in the temperature used for drying might improve the suitability of the test.

C. Specific Surface Area.

Due to the irregular shapes of the mineral media, the surface areas are difficult to assess. Schroepfer (1951) and Truesdale et al. (1961) used a paint dipping method, which assumes that a uniform coat of paint can be obtained on the stone surface. Harrod & Hall (1962), in attempting to measure the surface area of aquatic plants, used a solution of teepol on the plant surface, and assumed that a

uniform film had been obtained. Calow (1972) used a modification of these methods to assess the surface areas of stones in littoral zones. In this method, the stone is covered with a latex solution in order to form a mould of the stone. This mould is then removed and the inside coated with teepol solution. The weight of teepol solution used is compared to the amount required to cover a known surface area.

The method employed by Schroepfer (1951) and Truesdale et al. (1961) gives credible values for the surface areas of stones and appears to be reproducible; nevertheless, as mentioned by Truesdale et al., this method takes no account of the smaller pores, which are filled with the paint during the dippings. The method employed by Calow might conceivably lead to greater accuracy since the latex rubber mould can take up the shapes of the small pores.

In this project, the specific surface areas of the mineral media were assessed during the paint dipping method described by Truesdale et al. (1961). The paint used was a red oxide Trimite 85/GP1 described by the manufacturer as an air drying red oxide primer suitable for dipping. This paint was also used by Truesdale et al. (1961).

A standard volume, 0.3696 $m.^3$, of each grade of media was used. This volume, after noting Bruce (1968), was considered large enough to obtain a representative packing and grading of the media, whilst providing a sufficient number of pieces to be painted.

The pieces of media used to fill this volume were randomly gathered from approximately 1 m^3 of media. Prior to paint dipping, the media were thoroughly washed, allowed to dry and then the individual weight of each piece recorded. The amount of paint taken

up was assessed in two different ways. The media were individually dipped into a paint reservoir of known weight for 30 seconds, and then allowed to drain over the reservoir for 2 minutes, after which the reservoir was re-weighed.

The media was allowed to dry overnight, and the weight of the painted media recorded. This procedure was repeated three times. In order to assess the weight of paint taken up by unit surface areas of the media, 6 wooden blocks of three known surface areas were similarly dipped and their uptake recorded.

I Results.

The results presented in tables 5.6 & 5.7 are the summed weights of paint taken up. The results were calculated on the total weight of paint rather than the individual weight increases in order to minimize the effect of individual uptake variations on the final results for the specific surface areas.

The specific surface area data in table 5.7 were obtained by dividing the respective cycle paint weight increased by the specifuc paint uptake for the wooden cubes for that cycle.

Table 5.6 - Weight of Paint Taken up/m^2 by the Wooden Blocks.

Cycle No.	Wet Paint Used (g/m^2)	Paint Used (Dry Weight)(g/m^2)
Cycle 1	426.82	109.44
Cycle 2	445.06	260.83
Cycle 3	525.32	284.55

Table 5.7 - Paint Uptake and Specific Surface Areas of the Four Mineral Media.

Media	Cycle	Wet Paint Uptake(g)	S.S.A. (m^2/m^3)	Mean S.S.A. (m^2/m^3)	Dry Paint Uptake(g)	S.S.A. (m^2/m^3)	Mean S.S.A. (m^2/m^3)
Large	1	621.0	39.37		289.5	71.57	
Granite	2	693.0	42.13	39.03	375.5	38.95	37.64
(125-75mm)	3	697.5	35.92		382.0	36.32	
Small	1	762.0	48.30		280.7	69.40	
Granite	2	1013.0	61.58	57.64	463.8	48.11	49.68
(89-50mm)	3	1042.5	53.69		539.0	51.25	
Large	1	609.0	38.61		268.5	66.38	
Slag	2	610.5	37.11	32.95	351.5	36.46	34.80
(125-75mm)	3	617.0	31.78		348.5	33.14	
Small	1	1014.0	64.28		442.5	109.40	
Slag	2	1058.5	64.35	64.18	535.0	55.50	59.17
(89-50mm)	3	1243.0	64.02		661.0	62.85	

II Discussion.

Observation of table 5.6 showed that the uptake of paint by the wooden cubes on each cycle differs; the uptake being greater each successive cycle. This trend was most marked between cycles 1 & 2 in the case of the dried paint weights. In this case the reason could be twofold. Firstly that the previous paint layer itself increased the area to be covered and secondly that the dried paint surface provided a more suitable surface for the adhesion

of paint. The first explanation would apply to an increase between any successive cycle, but is somewhat negated by the effect of paint occluded pores.

Another point of interest is that the weight ratio of wet paint/ dry paint (table 5.8), decreased each cycle. This indicates that the thinners used did not evaporate to the same extent, i.e: some of the thinner was retained within the layers of paint; a greater concentration being retained the thicker the layer of paint. This would indicate that perhaps insufficient drying time had been given for the cycles. The manufacturers advised that the majority of the thinner should be evaporated in 4 to 5 hours. Between each cycle there was a minimum drying period of 24 hours, in a well ventilated and heated room, therefore it is unlikely that the media was insufficiently dried between each cycle; rather that the thicker the layer of film created, the greater the retention capacity of the paint.

Table 5.8 - Ratio of Wet/Dry Paint Uptake.

Media	Cycle	Wet Paint(g)	Dry Paint(g)	Wet/Dry Ratio
Large	1	621.0	289.5	2.145
Granite	2	693.0	375.5	1.846
(125-75mm)	3	697.5	382.0	1.826
Small	1	762.0	280.7	2.715
Granite	2	1013.0	463.8	2.184
(89-50mm)	2	1042.0	539.0	1.933
Large	1	609.0	268.5	2.268
Slag	2	610.5	351.5	1.737
(125-75mm)	3	617.0	348.5	1.770
Small	1	1014.0	442.5	2.292
Slag	2	1058.0	535.0	1.978
(89-50mm)	3	1243.0	661.0	1.880

Whilst carrying out the test, it was noticed, particularly in the case of the blast furnace slag, that occasionally pores of various sizes did not fill with paint, whilst other pores had been completely occluded. These occurrences will cause inaccuracies in the final result. In order to minimize the effect of incomplete surface cover, the media were kept immersed in the paint for 30 seconds. Also, after weighing the wet media, the pieces were carefully placed on a 20 mm steel gauze, to allow any further drainage of excess paint and also minimize the point of contact with the media. It was noticed that many pieces of both types of media, particularly of the larger grading, had natural resting positions which could allow excess paint to accumulate in the hollows on the uppermost surface of the piece. This lead to inaccuracies in the determination; in order to prevent such inaccuracies being carried forward from one cycle to the next, the pieces were, as far as practicable, placed on the gauze such that the upper surface did not accumulate large excesses of paint. Wide variations can be seen in the determinations of specific surface areas. However, these results appear to be in accord to results obtained by Schroepfer (1951) and Truesdale et al. (1961).

Table 5.9 - Specific Surface Areas Recorded for Various Media.

Media		S.S.A. (m^2/m^3)
(1) Rock of size	76.7 mm.	51.8
(1) Rock of size	69.9 mm.	55.7
(2) Slag of size	63.5 mm.	108.2
(2) Clinker of size	63.5 mm.	122.6
(2) Rock of size	63.5 mm.	90.5

(1) from Schoepfer (1951)

(2) from Truesdale et al. (1961)

Comparing the specific surface areas of the two larger media to the gradings shown in table 5.10, it can be seen that the granite had the greater S.S.A., but that it also had the greater fraction of large pieces. This, in practice, is unlikely to occur particularly when the porous surface of the blast furnace slag is taken into consideration.

Considering the two smaller media, the granite had a larger fraction of 100 mm.to 76 mm.pieces, yet the blast furnace slag had a greater percentage of 63.5 mm. - 50.0 mm. pieces. As can be seen from the table 5.10, the S.S.A. of the granite media was less than that for the slag, as might be expected, considering the results of the grading tests and the nature of the two media's surfaces.

These specific surface areas for the mineral media are compared to the values for the four plastic media used in the project in table 5.10.

Table 5.10 - Specific Surface Areas of the Media Used.

Media		Specific Surface Areas m^2/m^3
125/75 mm.	Slag	34.62
89/50 mm.	Slag	61.68
125/75 mm.	Granite	38.33
89/50 mm.	Granite	53.66
Flocor E		85
Flocor M		135
Biopac 90		85
Biopac 50		124

D. Void Capacities.

The void capacities of the random media, both mineral and plastic, were assessed at the same time that the neutron scatter calibrations were made of the media.

The media were packed into a 50 gallon drum, 575 mm diameter and 900 mm depth. After packing the drum to the brim with media, the volume of water required to fill the void spaces was measured.

In order to carry out neutron scatter calibrations and void capacities of the modular Flocor E and M, a rectangular tank of known volume slightly greater than that of a standard Flocor E module (600 mm x 600 mm x 1200 mm), was used, in a similar manner to that described for the cylindrical tank.

I Results.

Table 5.11 - Percentage Void Capacities of the Media Used.

Media	% Void Capacity
89/50 mm Granite	50.9
125/75 mm Granite	50.9
89/50 mm Slag	47.4
125/75 mm Slag	51.7
Biopac 50	90.5
Biopac 90	94.8
Flocor E	97.9
Flocor M	95.6

II Discussion.

From tables 5.11, the most obvious differences between the various void capacities is that between the mineral and the plastic media. The mineral media have void capacities of approximately 50%, whilst the

plastic media have void capacities of approximately 95%.

Considering the random media, for particles of a given shape, the void capacity of the packed bed is independent of the particle size; therefore any variations in void capacity between different gradings of like media must be related to the different particle size distributions and variations in particle shape. The two granite media showed no difference in void capacity, but the blast furnace slag did differ in their void capacities. This suggests that the granite media were of similar particle distributions in each grade and of a similar shape. The difference between the blast furnace slag void capacities could be explained by the differences between the particle size gradings - the larger 125/75 mm grade having a much greater large particle fraction.

Considering the Biopac 90 & 50 media, the larger media has a greater void capacity. This could in part be due to the thickness of the material of the individual units, which is the same for both types. This argument could also be extended to the modular Flocor media. The Flocor M, having a greater volume of plastic per unit volume of the filter bed, hence reducing the void capacity.

The values determined for the void capacities of the mineral media are similar to those obtained by Schroepfer (1951),Truesdale & Eden (1963), Wukasch & Bloodgood (1966), Bruce (1968) and Bruce & Merkens (1970).

The value obtained for Flocor E (97.9) was in good agreement to that found by Bruce & Merkens (1970), namely 98%.

E. Sewage Retention Times.

The significance of sewage retention times within filters and

the various physical parameters which affect the retention times have been discussed in Chapter 2.

The application of sewage to filters causes the development of a complex biological film on the surface of the filter media; the major floral components of the film being bacteria and fungi. The nature and extent of the biological film both have an effect upon the residence time. The residence time of sewage within a filter can itself have an effect upon the degree of biological purification occurring.

In previous studies, various methods of determining the retention times of filters have been described. The methods can be broadly divided into two classes. One such method involves the application of a known quantity of tracer to the surface of the filter over a given time. The concentrations of the tracer emerging from the filter over a given time are then determined, and a tracer concentration - time curve plotted. The retention time of a filter can then be expressed as a function of the curve, (Eden, Brendish & Harvey, 1964). Tracer techniques suffer from specific practical limitations. The purpose of adding a tracer to the applied sewage is to observe the flow of the sewage through the filter, but a tracer may not behave in the required manner. The use of cations as tracers suffers from the capacity of the filter and filter film to selectively adsorb and absorb the cation, hence delaying its flow through the filter. Ammonium salts and organic tracers may suffer destruction within the filter which reduces the quantity recovered in the effluent. Simple anions such as chloride, bromide and iodide may also be adsorbed within the filter thus delaying the exit of the tracer. Certain radioactive tracers have been proposed for tracing techniques within filters, due to the simplicity of detection, their relatively inert activity within

the filter and also the small quantity which need be applied to the surface of the filter, thus minimising the disturbance of the sewage flow (Eden & Melbourne 1960, Meltzer 1962, Eden et al. 1964).

The second class of determining filter retention characteristics is that of determining volume of water within a filter by studying its drainage characteristics, (Meltzer 1962, Tariq 1975). This method involves the suspension of routine operation whilst the amount of water draining from the filter is assessed.

In this study, the retention time characteristics of the filters was determined using a known quantity of sodium chloride as the tracer, (with the addition of fluorescein to give an immediate visual indication). Whilst it was appreciated that radioactive tracer methods would provide a more accurate picture of the flows through the filters, practical limitations precluded their use.

Initially, fluorescein tracer was added through the additional purpose built pipework between the header tank and the distributor arms. However, the tracer was found to be unevenly distributed over the surfaces of all eight filters, via the two filter arms in operation. An alternative method was therefore sought. It was found that by applying the tracer to one of the distributor arm weir-boxes, with practice, a fairly even dosing of the tracer could be achieved over the surface of a single filter. Whilst this method was highly subjective and led to some loss of the tracer, it was the only practical solution available.

Immediately the tracer was first added to the sewage in the weir-box, effluent samples were taken. During the first 20 minutes after applying the tracer, effluent samples were taken every 30 seconds, then at minute intervals for the next 10 minutes, and thereafter at

5 minute intervals. Samples of the sewage were also taken at 15 minute intervals in order to determine the background chloride levels.

The concentration of chloride in the sample was then determined in the laboratory by duplicate titration against standardised silver nitrate solution using potassium dichromate solution as the end point indicator, (Analysis of Raw, Potable and Waste Waters, H.M.S.O. 1972, P.73). In view of the large number of samples to be analysed and the time taken for each titration, a chloride electrode was purchased which allowed the chloride determination to be carried out in approximately half the number of man-hours required for the titration method. However, the electrode method of determination was only feasible when it was possible to carry out the analysis on the same day that the samples were collected. Storage of the samples caused the production of sulphide which severely interfered with the electrode response.

After analysis, the data was then fed into a computer at the University of Aston for the calculation of the quantity of chloride emitted from a filter after a given time. From these results it was possible to plot a tracer time curve using log probability axes. The characteristics of the curves obtained were then described by their 16 and 50 percentile times. That is, the times after which 16 and 50 percent of the recovered tracer had left the filter in the effluent, (as described by Eden et al. 1964).

I Results.

Table 5.12 - Results of Retention Time Tests on Clean Media Devoid of Film. (May 1975).

Media	16% ile	50% ile
125/75 Slag	2.2	5.5
125/75 Slag (biol)	2.0	4.75
89/50 Slag	3.6	7.7
89/50 Slag (biol)	1.8	4.75
125/75 Granite	0.75	2.0
125/75 Granite (biol)	0.7	2.1
89/50 Granite	1.5	4.0
89/50 Granite (biol)	1.4	3.4
Biopac 90	0.25	1.7
Biopac 90 (biol)	0.5	1.7
Biopac 50	1.2	2.8
Biopac 50 (biol)	0.8	2.7
Flocor E (1 c.w.)	0.65	1.6
Flocor E (2 c.w.)	0.7	1.7
Flocor M (1 c.w.)	0.65	1.8
Flocor M (2 c.w.)	0.65	2.0

((biol) refers to the sector incorporating the biol. shafts).

Percentile time in minutes.

The percentile retention times shown in table 5.12 relate to the media devoid of film with a dosing regime of once every two minutes; the mineral media was subjected to a hydraulic load of 2.8 $m^3/m^3/d$, and the three plastic media Flocor E, Biopac 50 and Biopac 90, to a load of 5.6 $m^3/m^3/d$. The other plastic media, Flocor M, due to the reduced depth of the filter, was subjected to 6.2 $m^3/m^3/d$.

II Discussion.

The data in table 5.12 indicates that the larger grades of natural media have reduced retention times when compared to the small grades. This is probably related to the surface area of the media available for the liquid to be retained on by adsorption and surface tension effects. However, using the four values for the 16 percentile and the 50 percentile retention times for each type of media, the correlations with the specific surface areas in table 5.12 were found.

Table 5.13 - Correlation Coefficients of Retention Times to S.S.A.s.

Media	16%/SSA Corr. Coeff.	50%/SSA Corr. Coeff.
Small Granite, Large Granite	.99	.97
Small Slag, Large Slag	.42	.47

It must be remembered when considering table 5.13 that only four values are involved in calculating each correlation coefficient. Nevertheless, a difference is shown between the granite and slag media. In the most part this is related to the high variation between the determinations of the retention times for the duplicate sectors. The greater variation compared to the granite media could be due to two particular factors. The blast furnace slag retention times are greater than those for the same grading of granite media, therefore any similar percentage variation will result in a greater absolute value. The surface of the slag differs from the granite in that many of the pieces have pores of various dimensions. This will increase the retentive capacity of the filter when compared to the granite and explains the larger percentile retention times. It is

unlikely that each dosing of sewage to the surface of the filter will follow the same route through the filter. The liquid retained in these pores may therefore not be diluted by every dose of sewage. This will increase the variation in time over which the tracer emerges.

The percentage retention times of tracer in the Biopac media followed a similar trend to that shown for the two grades of granite and blast furnace slag. The results show little variation, particularly the 50 percentile times. This is due to the uniformity of the media providing regular pore sizes. It is interesting to note that the modular Flocor media did not show any difference in 16 percentile retention times even though the specific surface areas of E and M differ by 50 m^2/m^3. However, it should be remembered that, due to the reduced depth of the Flocor M filter, the hydraulic loading to the M media in terms of volume of liquid to the volume of media was greater. Nevertheless, when observing the 50 percentile times it can be noticed that the retention time for Flocor M was greater than that for Flocor E. The corrugations of the Flocor M sheets are smaller than those for Flocor E and it is likely that more liquid may be retained in these dips as small droplets.

From the plots of the log chloride concentrations versus time curves shown in Appendix 5.2, the application of each dose of sewage to the filter can be seen to increase the concentration of tracer recovered in the effluent. This peak concentration also corresponded to the peak effluent flow rate. The increase in concentration is presumably because retained tracer in certain areas of the filter may only be flushed out at high flow rates.

The variation in the flow rate and concentration of the tracer also account for the poor estimated recovery of tracer; a mean flow

being used to calculate the quantity of tracer in the effluent.

The retention times of the filters were assessed at later dates at the same loading but with various accumulated thicknesses of film. The results are presented and discussed in chapter 8.

6. DESCRIPTION OF THE ANALYTICAL METHODS EMPLOYED ON THE HEREFORD HIGH RATE FILTER PROJECT.

A. Chemical Analyses of Sewage Feeds and Filter Effluents.

The sewage applied to the filters and the effluents, whether manually snap sampled or collected by automatic samplers, were composited into 500 ml ground glass stoppered stock bottles; all aliquots for the various analyses being obtained from these bottles.

I Suspended Solids.

Suspended solids analysis was carried out using the filtration method described in the 'Analysis of Raw, Potable and Waste Waters' (H.M.S.O. 1972, P.40); the method was modified in certain aspects and is further detailed in appendix 6.1

Three part 7cm. diameter Hartley funnels were employed using Whatman GF/C glassfibre filter papers. Prior to the analysis of the pilot plant sewage and filter effluents, whilst instructing the technician in various analytical techniques, the loss in weight of numerous Whatman GF/C papers (previously dried to 105°C for a minimum of 1 hour), on washing was recorded. In no instance did the loss in weight after washing and drying at 105°C exceed 1 mg. The average weight of the clean dried papers being 200 mg each. Therefore the error in using unwashed filter papers for the solids determination would not exceed 0.5%, (the average weight loss was 0.2%). However, it was also noted at this time that the GF/C papers lost an appreciable weight after being dried at 105°C for one hour and being allowed to cool in a dessicator.

In view of the large number of samples to be processed each day, the pre-washing of the filter papers was dispensed with but the filter

papers were individually dried out on watch glasses at 105°C and cooled in a dessicator before being weighed and used.

In order to minimise the time required and space needed for filtration of the samples, the Hartley funnels were not individually mounted on Buchner flasks. A system was developed which allowed the simultaneous filtration of twelve samples. Figure 6.1 indicates the various components used. To regulate the vacuum applied to each of the two 'Vulcathene' manifolds a valve was installed in each suction line. This permitted filtration of samples in one manifold whilst replacing the Hartley funnels on the other manifold. Less than six samples could be filtered on one manifold by simply removing the base of the unrequired Hartley funnels from the manifold and inserting a rubber bung in the hole remaining. The system also minimised the time required to drain the Buchner flask of filtrate since one large flask could be used, requiring infrequent emptying. The Edwards vacuum pump installed was capable of displacing large volumes of air through the twelve filters when almost drained and could comfortably maintain a strong vacuum. To prevent the pump exerting too great a vacuum on the filter papers, a valve was installed between the pump and the Buchner flask. Further adjustments in the pressure could be made at the valve to each manifold. Further reduction in the time required for filtration of the samples was obtained by transferring the 100 ml aliquots from the stoppered bottles into 250 ml beakers, thus allowing individual topping-up of the Hartley funnels when necessary, rather than slowly releasing the 100 ml samples from a pipette into the funnels as they emptied; (7 cm Hartley funnels hold approximately 50 ml of sample above the paper).

Much consideration was given to settlement of the samples. The

Figure 6.1 Suspended Solids Filtration System.

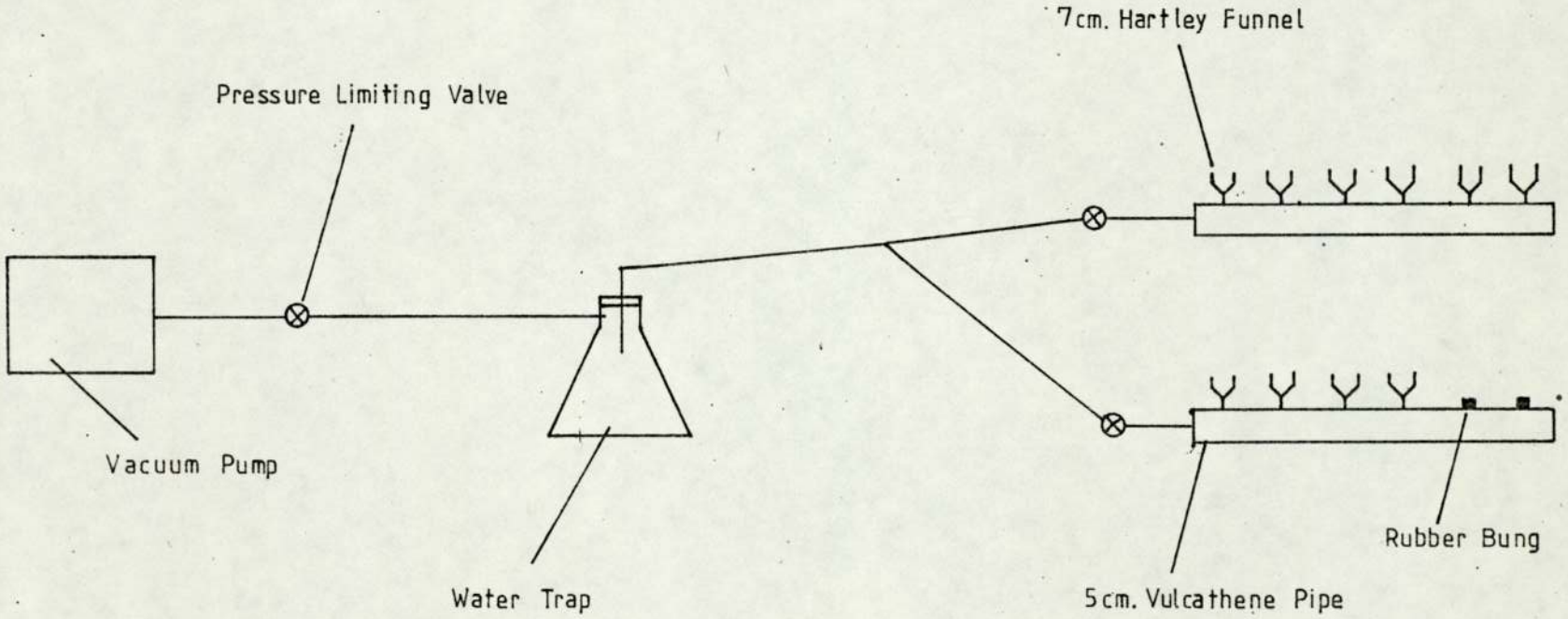
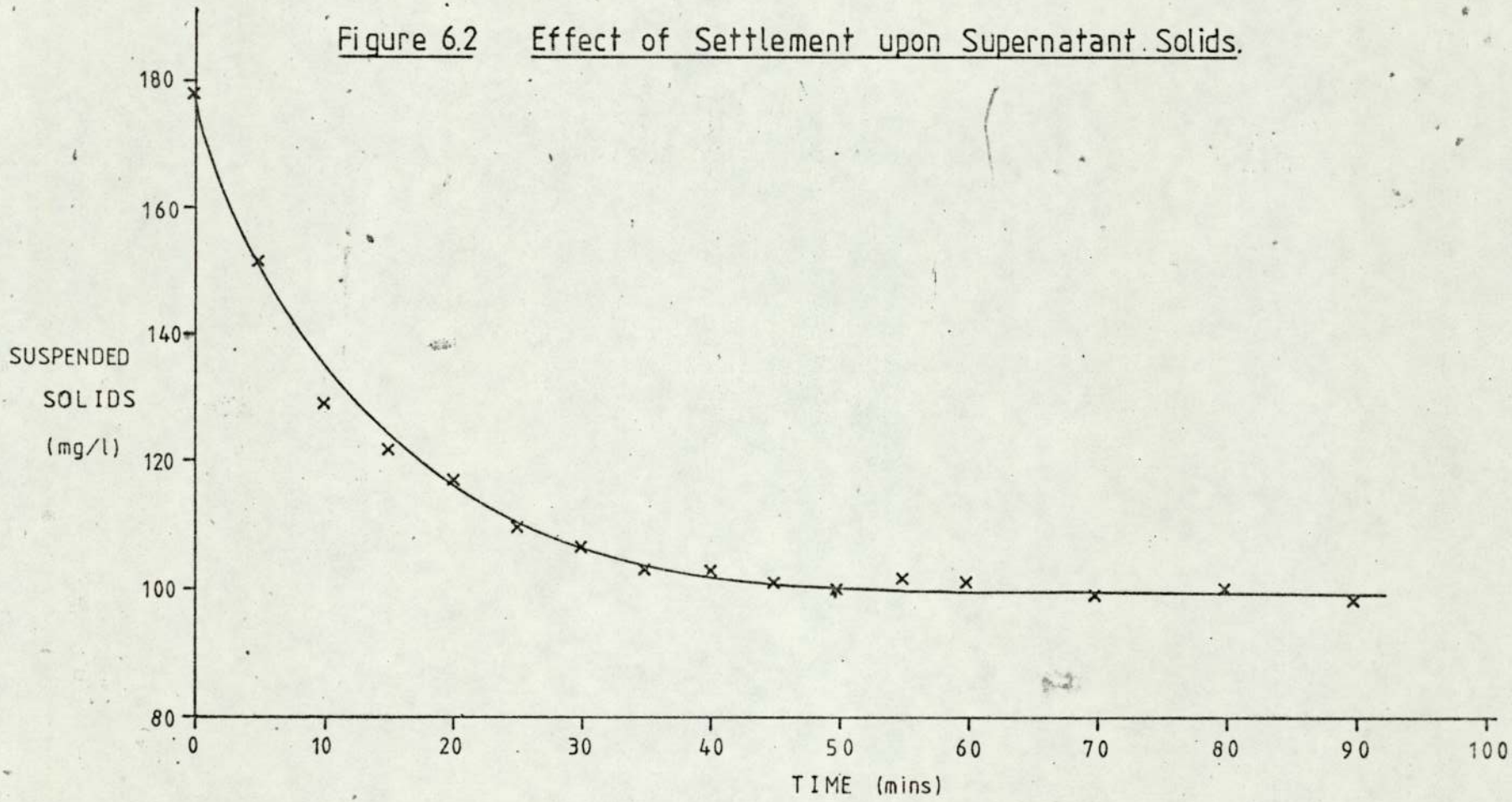


Figure 6.2 Effect of Settlement upon Supernatant Solids.



objective of sample settlement should be to simulate the action of secondary settlement tanks, in order that the overall process efficiency may be determined. The settlement of solids has been shown to be affected by temperature and variations caused by draughts. The first intention was to settle 2 litres of sample in tall form beakers in a shed used solely for sample settlement. However, practical difficulties were envisaged which prevented the use of this system. A minimum of 17 samples had to be transported from the pilot plant to the laboratory daily. Two litre samples caused difficulties in the collection of the samples, their transport, and storage at $4^{o}C$. Insufficient space was available in the laboratory to store equipment, reagents and sundry items. If sample settlement was to be carried out in the shed provided expressly for this purpose, then the equipment used for routine analysis in the laboratory needed reorganising between each type of analysis (in order to accommodate less frequently used equipment); which would have been unsatisfactory due to the time consumed and the increased likelihood of damage to the equipment. Difficulties were also envisaged in transferring the samples between the shed and the laboratory during the winter months. An alternative method of sampler settlement was therefore deemed necessary.

Trials were carried out on the rate of sample settlement in 500 ml stock bottles, and the variations in settlement caused by temperature and vibration of the working surfaces. As may be observed from figure 6.2, the initial rate of sample settlement was rapid and gradually reduced. It was found in practice that the supernatant withdrawn after one hour varied little from a supernatent withdrawn after three hours; however, after only 30 minutes settlement, a

supernatent sample contained appreciably greater quantities of solids than a supernatent after one hour's settlement. It was therefore decided to allow one hour's settlement before withdrawing an aliquot of supernatent. Variations in temperature and vibrations experienced in the laboratory had little effect upon the rate of settlement in the 500 ml stock bottles.

The extraction of the settled sample also presented difficulties. Since the sample settling in the stock bottle would have greater solids concentrations the greater the distance from the surface of the sample, it was necessary to extract aliquots from a standard depth. In order to meet this requirement, the aliquots were withdrawn using a 100 ml pipette and pipette filler. The pipette was lowered to a standard depth in the sample bottles by attaching a plyboard restraint to the pipette which prevented it being lowered any further into the bottle.

In view of the different nature of the filter effluents to the applied settled sewage, a reassessment of the settlment procedures was to be carried out after a period of filter maturation.

II Biochemical Oxygen Demand.

Five day biochemical oxygen demand determinations were carried out using the method described in the 'Analysis of Raw, Potable and Waste Waters' (H.M.S.O. 1972), employing the modified Winkler determination of dissolved oxygen (see appendix 6.2). However, in one procedure the method was modified as detailed below.

The composite samples were stored in 500 ml stoppered glass bottles as mentioned previously. The samples were stored overnight in a refrigerator at $4^{o}C$, and then allowed to attain room temperature before use. BOD determinations were made on both shaken samples and

on aliquots of the settled samples. The settled samples being withdrawn from the 500 ml bottle by the same method and from the same height as described for the suspended solids analysis. However, instead of mixing the sample in aerated diluent water in a manner described in 'Analysis of Raw, Potable and Waste Waters' (H.M.S.O. 1972), separate aliquots were pipetted into two 250 ml ground glass stoppered bottles, with the diluent water being carefully poured into the bottle from the tap of a 10 litre aspirator. Whilst it was realised that this procedure could introduce greater variation in the two diluent samples obtained, it was preferred due to the convenience and speed of sample preparation. Prior to the start of the pilot filters, comparative tests were carried out on the two methods. It was found that whilst the sample could be carefully mixed into a standard volume of diluent water before being poured into two 250 ml bottles, air became entrained in the diluted sample when pouring into the 250 ml bottles which was not always removed by tapping the sides of the sample bottle allowing air bubbles to escape before placement of the stopper, thus introducing errors into the BOD determination. Less variability was found using two separately withdrawn aliquots of the sample and the addition of diluent water to each bottle. (The latter method was also quicker to carry out). The diluent was carefully poured down the sides of the glass bottles to minimise agitation and entrainment of gaseous oxygen. The bottles were filled to the brim with diluent water, sharply tapped on their sides and left to stand to allow any excess gaseous oxygen to escape before being stoppered.

One bottle of each sample was then placed in an incubator and maintained at 20°C for 5 days. The other sample was immediately

pickled using the Pomeroy-Kirschman modification of the Winkler method. The amount of iodine liberated was then determined by a duplicated titration of 50 ml sample aliquots in control flasks with N/80 sodium thiosulphate. Weekly checks were made on the strength of the thiosulphate by replicated titration of a standard solution of N/40 potassium iodate. If the sodium thiosulphate strength had decreased greater than 0.6% then a fresh stock was prepared before titration of the samples. Replicate variation of titration of the standard iodate solution was 0.2%. It was considered desirable to titrate both the 1 day dilutions and the 5 day dilutions with the same preparation of sodium thiosulphate. In order to preserve the reagent it was stored in blackened bottles during use and kept refrigerated between the two sets of titrations.

In order to obtain an accurate end point for the thiosulphate titration, soluble starch with urea was used as an indicatorreagent, since it was found to have a sharper end point than soluble starch, providing less variable end points.

Initially problems were encountered with the consumption of 1 mg/l of oxygen over 5 days in the diluent blank. In order to overcome this error the following precautions were instigated and maintained throughout the study. The diluent water was made using freshly prepared distilled water and the nutrients added immediately before use. The nutrient stock solutions were kept refrigerated. The diluent water was prepared in 10 litre polythene aspirators and was aerated for one hour followed by one hour's settlement before use. Aeration was carried out using an electric induction pump which drew air through a cottonwool filter to minimise the effects of any atmospheric pollution. During summer months it was found that the distilled water in the laboratory was frequently warmer than 20°C. In order to cool the distilled water, the 10 litre

aspirators were filled the day before use and kept in a refrigerator overnight. Removing the aspirators early in the morning before use and the effect of aeration and standing to reduce supersaturation of the diluent water was found to raise the temperature to within 3°C of 20°C. To prevent any bacterial development in the diluent aspirators, after use each aspirator was thoroughly washed out with distilled water and 1 ml of hypochlorite solution added as a sterilant. The aspirators were then returned to the refrigerator, and only drained of the sterilant before use. The aspirators were then washed out several times with distilled water to prevent any sterilant carry-over. Particular attention was paid to ensuring that the tap was thoroughly rinsed.

Titration of the 50 ml sample aliquots was carried out using a Grade A 25 ml automatic levelling and refilling burette, which was marked in 0.02 ml divisions. Between uses the burette was always left charged with N/80 sodium thiosulphate which was drained and washed using fresh thiosulphate before use.

After duplicated titration of the sample, the 250 ml bottles were washed out twice with tap water and finally once with distilled water.

Occasionally, due to plant difficulties, or additional sampling, it was not possible to titrate the samples the day that they were pickled. Tests were therefore carried out to determine whether storage of the pickled samples affected the titration and hence the BOD's. Table 6.1 shows the effect of storing pickled samples. It can be seen that there is an increase in the dissolved oxygen result obtained when the sample is stored. However, it should be noticed that the increase is only significant between immediate titration and

18 hours storage. Further storage did not cause any significant increase in the thiosulphate required to satisfy the liberated iodine. It was therefore concluded that an error of approximately 5.7% was introduced by storage of the picked samples and that such storage should be avoided whenever possible.

Table 6.1 - The Effect of Pickled Sample Storage Time on Dissolved Oxygen Titrations.

Date	Time	Bottle No.	Titre 1. (mg/l D.O.)	Titre 2. (mg/l D.O.)	Mean D.O. (mg/l D.O.)
3/5/75	15.00	1	8.00	8.02	
		2	8.02	8.04	
		3	8.04	8.04	8.0275
		4	8.04	8.02	
4/5/75	08.30	5	8.50	8.48	
		6	8.39	8.44	
		7	8.37	8.39	8.3925
		8	8.28	8.28	
4/5/75	15.45	9	8.21	8.27	
		10	8.38	8.36	
		11	8.30	8.32	8.2925
		12	8.22	8.27	
5/5/75	15.30	13	8.50	8.50	
		14	8.35	8.32	
		15	8.50	8.48	8.4250
		16	8.36	8.38	

* Bottles labelled after being randomly filled.
At 0.1% level of probability, random plot analysis of variance indicates L.S.D. of 0.3208 mg/l D.O.

Therefore, only 3/5/75 15.00 samples differ significantly by 5.7%.

Allyl thiourea was not used to suppress nitrification in the BODs performed at Hereford on the high-rate filter feed or effluents since

it was considered unlikely that nitrifying bacteria would be present in significant numbers in the effluent. However, the extent of nitrification in the high rate primary filters was also to be monitored, and the use of allyl thiourea could be implemented at a later date if found necessary. Several references were found relating to the effect of nitrification on BOD determinations and the onset of nitrification. Apart from river water and final effluent samples, it was generally shown (Sawyer & Bradney 1946, Hurwitz et al. 1953, Buswell et al. 1954, and Wheatland & Smith 1955) that nitrification did not occur to any significant extent during 5 day BODs.

III Chemical Oxygen Demand.

Chemical oxygen demand (COD) analyses were carried out on the sewage fed to the high-rate filters and their effluents using the method described in 'The Analysis of Raw, Potable and Waste Waters' (H.M.S.O. 1972, Pps.121-122), taking 5 ml samples, (see appendix 6.3 for details of this method). The samples were withdrawn from the 500 ml sample bottles by pipette as previously described.

On occasions when the samples consumed greater than 40% of the dichromate, repeat analyses were carried out using 1 ml samples and adding 4 ml of distilled water to the reflux flask in order to maintain the sulphuric acid concentration. After being refluxed for 2 hours, (ensured by the use of a timer on the heating mantles), 45 ml of distilled water were added by being poured down the reflux condenser and the flask contents allowed to cool in cold water.

The amount of dichromate remaining in the flasks was determined by titration with acid N/8 ferrous sulphate solution, using 1 drop of ferrous phenanthroline indicator. A 10 ml 0.02 ml graduated automatic

refill burette was used to titrate the ferrous sulphate. If the blank titres varied by more than 0.8% from the control figure, duplicated blank refluxes were carried out to determine whether the result was a random error, or due to an error in the analysis.

Chloride levels in Hereford settled sewage were found to be commonly slightly in excess of 100 mg/l. It was therefore decided that 0.2g of mercuric sulphate should be added to the contents of each flask including the blank before refluxing in order to suppress chloride interference.

Prior to commencing the study, brief tests were carried out on the effect of acid concentration, reflux temperature and time, sample storage and the age of the reagents on the accuracy of the chemical oxygen demand determinations.

Initially, using the method outlined in 'The Analysis of Raw, Potable and Waste Waters' (H.M.S.O. 1972), the effect of reflux temperature and time were studied. Table 6.2 indicates the effect of temperature on the destruction of dichromate; unfortunately, a suitable thermometer was not available at this time and therefore the temperatures used were assessed by the intensity of the electric coil colour in the heating mantles, the vigour with which the flask contents boiled and the setting of the variable rheostat.

Table 6.2 - The Effect of Temperature on Dichromate Destruction.

	Simmering	Continuous Boiling	Agitated Boiling
Dichromate Loss	2.73	2.93	3.82

Results expressed as mean (of 6) percentage loss from the mean of 6 unheated samples.

From the table it can be seen that the temperature at which the

flask contents were refluxed had an effect upon the amount of dichromate destroyed. It was therefore considered good practice to maintain the flasks in a state of gentle boiling/simmering for this project.

The effect of time of reflux is shown in table 6.3. From the table it can be seen that the longer the reflux period, the greater the dichromate destroyed. In order to obtain an accurate and reproducible time period the heating mantle was wired through a time switch cutting off the power supply after 2 hours.

Table 6.3 - The Effect of Reflux Time on Dichromate Destruction.

	120 mins.	135 mins.	150 mins.
Dichromate Loss	2.74	2.91	3.15

Results expressed as mean (of 6) percentage loss from the mean of 6 unheated samples.

The test on the effect of reflux time was carried out with the samples being boiled gently.

From table 6.4 the effect of various acid concentrations on the destruction of dichromate may be observed.

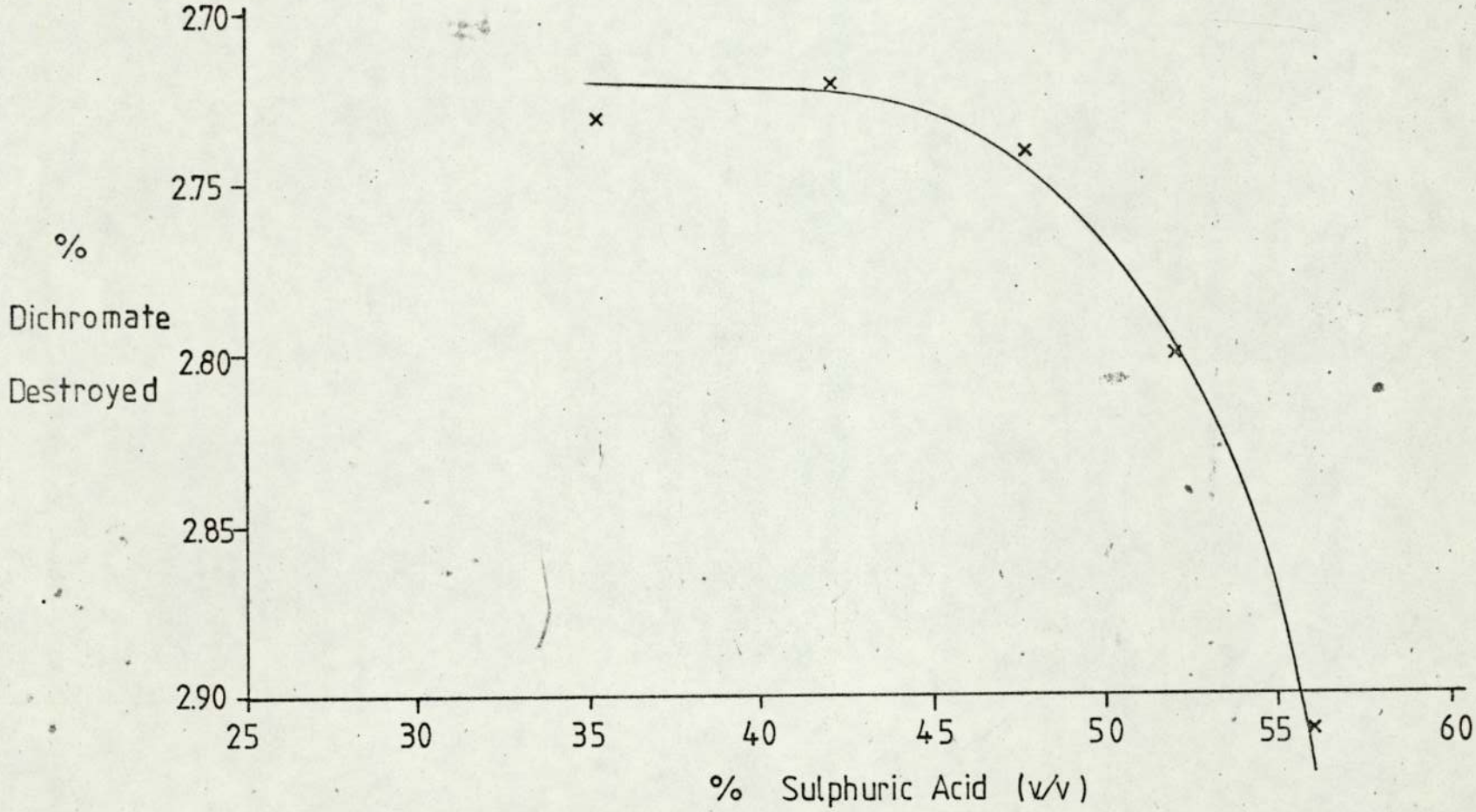
Table 6.4 - The Effect of Sulphuric Acid Concentration on Dichromate Destruction.

Percent H_2SO_4 (v/v) Present	35.3	42.1	47.6	52.2	56.0
Percent Dichromate Destroyed	2.73	2.72	2.74	2.80	2.91

Results expressed as mean (of 6) percentage loss from the mean of 6 unheated sample titres.

From figure 6.3 it can be seen that when the acid strength exceeds approximately 42% v/v concentration a significant increase occurs in the destruction of dichromate. Since the proposed method for

Figure 6.3 Effect of Acid Concentration on Dichromate Destruction.



COD determinations uses an acid concentration of 47.6 % v/v, strict control appeared to be necessary on the titration of acid into the reflux flasks.

In the three tests mentioned above, the loss of dichromate has been expressed as the percentage lost when compared to the titration of unheated blank samples. In practice the consumption of dichromate by a sample is considered to be the amount of dichromate removed after reflux of the sample compared to the loss of dichromate from a refluxed blank containing 5 ml of distilled water instead of the sample, therefore the destruction of dichromate due to the conditions of the test rather than the sample is compensated for.

The results of these three tests were in close agreement with analytical tests carried out by Stones (1974). The most noticeable difference being that the onset of destruction of dichromate occurred at a slightly lower acid concentration in the Hereford tests, (approximately 42.5 % v/v) than in the tests carried out by Stones (50 % v/v).

Brief tests to determine the stability of the acidified ferrous sulphate solution indicated that the reagent should be prepared weekly and kept refrigerated when not in use. The ferrous sulphate slowly oxidised if kept under ambient temperatures in the laboratory for greater than two weeks.

The dichromate solution was found to be stable for long periods if kept refrigerated when not in use. However, it was decided that the reagent should be prepared fortnightly and kept refrigerated.

Sample storage was shown to have a marked effect on the COD determination and was considered a serious cause for concern. Table 6.5 indicates the results of a test into the effects of sample storage.

The settled sewage sample taken was subdivided into three 500 ml stoppered bottles allowing approximately 50 ml of air space at the top of the bottle. Prior to taking the 5 ml aliquot for COD analysis, the bottles were thoroughly shaken. The three bottles were then kept under different conditions, one being kept in shade in the laboratory, one refrigerated and another incubated at 20°C.

Table 6.5 - Effect of Sample Storage on the Chemical Oxygen Demand.

Hours Stored		0.75	2.75	5.75	24.75	49.75
5°C	1	1400	1510	1290	1240	1200
	2	1420	1320	1350	1280	1150
20°C	1	1400	1390	1440	1300	1160
	2	1380	1410	1350	1280	1200
Laboratory (ambient)	1	1320	1340	1260	1100	990
	2	1390	1470	1350	1170	1050

COD in mg/l

As a result of the test on the effect of sample storage it was decided that it was necessary to refrigerate the samples for the minimum possible period before analysis. In view of the sampling routine to be established, the samples were commonly stored for 16 hours.

IV Ammoniacal and Oxidised Nitrogen Determinations.

Samples of Hereford high-rate filter settled sewage supply and filter effluents were taken weekly to be analysed for ammoniacal and oxidised nitrogen, in order to determine whether any ammonification and/or nitrification occurred within the filters. 25 ml of the composited samples were transferred to 25 ml screw topped universal bottles, to which were added 5 drops of concentrated hydrochloric acid from a Pasteur pipette. The hydrochloric acid was included to prevent any further biological activity in the samples which might affect the nitrogen status. The samples were then kept refrigerated until required for analysis.

The addition of concentrated hydrochloric acid to preserve samples was studied to determine what effects it had upon inorganic nitrogen by C.R. Kneale (1975). It was found that the method prevented any significant change in the inorganic nitrogen status. Additional periodical checks were carried out during the current study to ensure that no significant change did occur.

Analysis was carried out at the University of Aston using a Technicon AutoAnalyzer. The colorimetric methods employed for both the ammoniacal and the oxidised nitrogen have been described by Chapman et al. (1967) and are outlined in appendix 6.4. The method used for the oxidised nitrogen included both nitrous and nitric forms. Since the filters were to be employed as a primary biological treatment stage, it was considered unlikely that any nitrification would occur, although it might be possible for slight nitrification to occur during periods of weak settled sewage.

Consideration was given at the outset of the study to the effects of solids in the samples on the concentrations of ammonia and oxidised

nitrogen. It is possible that ammonia in particular might be adsorbed on to the surface of the solids particles. Samples of both shaken and settled composite samples were therefore analysed for their ammonia and oxidised nitrogen content. From table 6.6, it can be seen that the inclusion of solids had an insignificant effect upon the concentrations observed. Statistical analysis of the data indicated that there was no significant difference between the samples of the settled or shaken sewage feed or primary filter effluent at the 1% level of probability.

Table 6.6 - The Effect of Suspended Solids on Inorganic Nitrogen.

		Shaken Sample	Settled Sample
Oxidised Nitrogen (mg N/1)	mean	14.160	14.135
	S.D.	0.0598	0.0489
Ammoniacal Nitrogen (mg N/1)	mean	10.3925	10.4000
	S.D.	0.0494	0.0538

S.D. - Standard Deviation.

(results are the means of 20 samples).

V. Phosphate Analysis.

The samples collected for oxidised and ammoniacal nitrogen analysis were also analysed for total inorganic phosphate using the Technicon AutoAnalyzer. The method employed was developed by Technicon; an outline of the method is included in appendix 6.5. The reducing agent employed was amino - naphthosulphonic acid.

Phosphate analysis was carried out to provide supplementary information on the condition of the filters and to observe the concentration variations in the sewage.

B. Physical Measurements on the High-Rate Filters.

I Temperature Measurements.

The equipment used to monitor the temperature of the sewage applied to the filters and the filter bed temperatures at three depths within each filter have been described in detail in Chapter 4.

Prior to the application of settled sewage to the filters, a study was made of the temperatures observed at three levels in one filter, namely the Biopac 90 filter containing the biological sample shafts. The three levels were 200 mm, 1000 mm and 1800 mm from the surface of the bed.

Without any sewage applied to the filters, the familiar sinusoidal temperature changes throughout a twenty four hour period were observed. This diel curve was followed by the temperatures at all three depths within the filter. However, there were differences in the amplitude of the curve and the mean temperature recorded at each depth. The surface measurement (200 mm) showed the greatest fluctuation during the period, having both the maximum and minimum temperatures recorded. The centre probe showed a reduced amplitude in its cycle, fitting within the curve traced by the surface probe. The probe situated at the base of the filter (1800 mm) recorded a further reduced amplitude in its curve; its minimum temperature being comparable to the surface minimums, but the maximum value being much lower, therefore showing a lower mean temperature.

The filter appeared to gain solar heat in a similar fashion to the ground, but lost its heat in a slightly difference manner. The cooling appeared to occur most at the surface and the base of the filter, causing the centre of the bed to be the warmest area at night. The surface of the filter could lose its heat by convection and radiation,

the centre by convection and conduction, whilst the base of the filter could lose its heat by conduction and.convection.

The filter surface temperature will fall once the air temperature is less than that of the filter. The heat will be lost from the surface of the bed by radiation into the atmosphere, convection due to ventilation through through the filter and also due to air currents moving across the surface of the filter.

The centre of the filter will begin to lose heat by conduction once the temperature of the surrounding media becomes lower than that of the centre of the bed. The centre of the filter can further lose heat to the ventilating air. At night when the air temperature falls below the temperature of the filter, any air passing through the filter will gain heat at the expense of the filter temperature. The base of the filter may also lose heat due to ventilation. The media at the base of the filter becomes colder than the media at the centre of the filter. If the ventilation of the filter occurred in an upwards direction the temperature difference between the air and the media at the base of the filter causes heat to be transferred to the air. As the air rises through the filter, the temperature difference between the media and the air diminishes causing a smaller heat loss from the centre of the bed. The media at the base of the filter may also suffer a heat exchange with the base of the filter. However, the similarity of the minimum temperatures recorded in the media at the surface and base of the filter indicate that ventilation must be the prime cause of the heat loss, with the other effects contributing only minor transfers of heat.

The application of sewage dramatically altered.the observed diel temperature patterns of the dry filter. At a flow of 6 $m^3/m^3/d$ and a dosing frequency of two minutes, the previous diel pattern was greatly

modified. In general, the centre of the filter during application of sewage became the warmest zone of the filter, and the base of the filter was warmer than the surface, at the minimum temperatures. At the minimum temperatures recorded, the centre of the filter was again the warmest zone on three days, but however, on two days became cooler than the surface of the filter. It thus appears that the temperature patterns may also be confused by the prevailing weather. Unfortunately, the air temperature and wind conditions were not recorded at the time of these observations; therefore it is extremely difficult to derive a satisfactory explanation of the observed temperature changes.

Table 6.7 - Temperature Variations at Three Filter Depths.

	Upper Probe		Centre Probe		Lower Probe		
Date	Max.	Min.	Max.	Min.	Max.	Min.	
11/6/75	30+	-	17.6	-	15.7	-	
12/6/75	30+	10.7	18.2	12.6	15.5	10.7	
13/6/75	30+	11.0	25.9	13.2	18.3	11.2	
14/6/75	27.6	13.0	27.3	15.5	18.0	13.9	Without Sewage
15/6/75	20.5	10.6	15.7	13.4	13.6	12.0	
16/6/75	18.0	4.9	18.9	8.3	17.7	6.8	
17/6/75	19.0	13.7	19.3	15.8	18.4	14.9	With Sewage
18/6/75	18.3	13.9	19.5	17.0	18.3	16.2	
19/6/75	19.1	13.2	15.9	13.8	13.9	13.0	
20/6/75	19.2	12.0	15.0	14.2	15.0	12.0	

Temperature in ^{o}C.

For routine purposes, it was decided that the daily maximum and minimum temperatures of one filter of mineral media and one filter of plastic media would be recorded and a weekly average produced. The influent temperature was also recorded continuously and a weekly average of its daily temperature maxima and minima calculated. Also during the day comparative filter temperatures of all 16 filters were to be made, and from the results any possible diel patterns and comparative temperature information obtained. A difference in temperature between filters might explain a difference in performance.

II Measurement of Filter Moisture Content using a Neutron Probe.

As previously mentioned in chapter 4, the purpose of neutron scatter determinations of the filters at various depths is to detect indirectly the amount of film accumulation at that depth. The neutron probe consists of a source of a highly excited neutrons;the source used in this project contained a radioactive mixture of americium and beryllium. The neutrons emitted from such a source have a high energy content. Such neutrons are preferentially moderated by hydrogen atoms in association with oxygen in water molecules (Burn 1961). The bonding of hydrogen in organic matter and the supporting media, whether plastic or mineral, does not slow down or reflect the neutrons in the same manner. The neutrons are therefore reflected in proportion to the quantity of water present at a particular position within the filter. The neutron probe which is lowered to the desired depth within a filter also contains a detector specific to the reflected slow neutrons. Therefore, the probe provides an indirect method of determining the biomass at any given depth.

In this study, the instrument used was a Pitman portable probe designed for field determinations of soil moisture contents. The

neutron source and detector were contained in a stainless steel cylinder which could be lowered into the filter to the required depth through aluminium shafts which had been previously inserted into the filters. The cylinder was supported by a cable through which electric power and the detector output were conveyed. This cable was fed through a meter in the head of the instrument, marked off in centimetres, which indicated the distance the probe was lowered from its moderator shield. Also in the head of the instrument was a digital display ratescaler which could show the number of counts received per second from 0 to 999. The ratescaler was provided with two periods of operation. The number of counts received over a given time period of either 16 or 64 seconds could be assessed. The count period was initiated by operating a start switch, but the period was automatically halted after 16 or 64 seconds, whichever had been selected. The number of counts recorded in the interval was then divided by the number of seconds of operation to give a display of the number of counts per second. In dry media without any film, the number of counts per second was about 10 to 100, whilst in saturated media the counts were between 900 and 1000 per second; therefore the instrument provided a wide range of values for determining the moisture content.

In view of the random nature of radioactive emissions, in order to obtain an accurate value of the moisture content, either the number of counts and/or the period over which the observations are made should be as large as possible. Due to the difficulties involved with the authorised storage of radioactive materials and their transport, it was necessary to determine the moisture content of all 16 filters at every desired depth in one day. This requirement dictated the number of counts possible and the length of the counting

period. In practice, it was found that 4 replicate 16 second counts were in close agreement, and therefore 4 such counts were made at each depth in the routine estimation of the moisture content. In order to eliminate the effect of radioactive source decay over time causing inaccurate determinations of moisture content, the absolute ratescaler output was not used for the calibration curve of moisture content versus counts per second, but instead a ratio of the recorded counts per second within the filter media to the number of counts obtained by the detector when the source emission was observed within its moderator shield, (Bell and Eeles 1967). This ratio would be unaffected by any radioactive decay of the source. In practice this meant that at the outset of any moisture determinations, the shield count had to be made; to provide an accurate value for this denominator, four 64 second recordings were obtained and their average value used in the production of the ratios.

Prior to using the neutron scatter probe in the filters, calibration curves for the various media had to be constructed. In order to carry out the calibrations on the random media, a representative sample was placed in a 50 gallon steel oil drum, with an identical aluminium shaft to those used in the pilot scale filters placed in the centre of the drum. The drum was also provided with a tap at the base to facilitate drainage of the water. Previous studies (Marais and Smit 1960, Burn 1961), had indicated that similar oil drums provided a sufficient diameter of media about the aluminium shaft (600 mm) to avoid introduction of errors due to any edge effects. Investigations carried out by various workers (Mortier and de Boodt 1956, Marais and Smit 1960, Burn 1961, and Harvey et al. 1963) have shown that the number of slowed neutrons detected by the probe was not directly proportional

to the moisture content, but traced a curve, particularly deviating from a linear relationship at very low moisture contents; however, at higher moisture contents the calibration curve tends towards a straight line. In order to obtain intermediate moisture contents between freely drained and saturated media, various methods such as the inclusion of sand to occupy approximately 50% of the voidage have been used. However, to carry out such operations accurately imposes many practical difficulties and is very time consuming. Due to these difficulties and the nature of the calibration curves, only three points were used in this study to obtain the calibration curves. The three points used were air dry media, freely drained media and saturated media. It was found that there was little difference between the counts obtained using air dry media and freely drained media. Whilst carrying out this exercise, it was also possible to obtain the void capacities of the various media, by measurement of the amount of water required to fill the oil drum after the media had been inserted; the values obtained for the void capacities are recorded in chapter 5.

The two modular media, Flocor E and Flocor M, could not have calibration curves determined using an oil drum, therefore an alternative method was employed. For this purpose, a steel tank which could contain more than one complete module was used. The effective media diameter was greater than 600 mm, and the void capacities of the media were also determined at this time.

When the sewage was first applied to the pilot filters, it was possible to carry out neutron scatter moisture determinations on the freely drained media. It was found that the results obtained agreed closely to the counts recorded for the freely drained media in the oil drum. The values only deviating at the surface of the filters and the bases of the filters. All the calibration work in the oil

drum was carried out midway between the surface and the base of the drum. At the surface of the filter less counts were recorded than in the oil drum. This edge effect was due to the proximity of the air above the filter minimising the moisture surrounding the probe. At the base of the filters, higher counts per second were observed than in the oil drum. This was due to the presence of water on the concrete base of the filters and the water retained within the porous clay drainage tiles.

After initial calibration of the media, all further data processing was carried out with the extensive use of the computer facilities at the University of Aston. It had been decided that for 14 of the 16 filters the moisture contents would be determined at 14 depths within the filter. The first depth was 100 mm from the surface of the filters. The next 3 depths were at 50 mm increments from the surface, then at 450 mm and thereafter at 200 mm increases in depth. The surface of the filters were most intensively studied since it was considered that most film accumulation and variation would occur at the upper regions of the filters. For the two aluminium shafts in the Flocor M media, moisture observations were only taken at 13 depths identical to those for the other filters; but due to the lesser depth of the filters the lowest readings for the other filters were not possible.

The calibration curve for each media was expressed in mathematical terms and entered into a specifically developed computer programme to obtain a direct print out of the moisture content at each depth and also to provide a graphical output of the moisture profile within each filter. Whilst the neutron scatter probe was in use, the four counts at each depth in the filters were directly entered onto

coded data sheets. Overnight, the data was then entered into the computer and final output received the following morning. The development of this programme dramatically minimised the processing time and operator time requirements. A copy of the graphical output for the freely drained media is shown in appendex 8. ; the deviations of the observed moisture contents at the surface and the base of the filters may be seen in the diagrams.

III Retention Time Determinations.

The significance of sewage retention times within filters has been discussed in chapter 2, whilst the practical aspects of the determinations carried out at Hereford have been discussed in chapter 5.

The results of initial retention time observations are also shown and discussed in chapter 5. One of the objectives of the project was to endeavour to relate the retention times, neutron scatter moisture determinations and film accumulations as assessed by analysis of film developed within the baskets in the biological shafts. Therefore at the outset of the project, it was intended that quarterly retention time determinations, and quarterly determinations of film accumulation would be carried out during the project; with the intention of carrying out the retention time analysis directly before assessing film accumulation in order to obtain the two sets of results whilst the filters were maintained under similar conditions. Neutron scatter observations were to be made monthly.

However, for various reasons including such problems as discontinuous sewage supplies, lack of manpower and transport difficulties, it was not possible to carry out as many retention time or film accumulation determinations as projected. The results of retention time and neutron scatter moisture content determinations are

presented in chapter 8.

The amounts of film accumulated in the various filters at different times during the project are shown in chapter 8.

C. Biological Analysis of Filter Film.

In order to obtain samples of the filter media from various depths in each filter, three galvanised perforated steel shafts were inserted in one of the duplicates of each filter. Five 'Netlon' baskets containing the media were then inserted in each shaft. The dimensions of the shafts and baskets have been described in chapter 4 and diagrams of their positions in the filters and profile are shown in figures 4.3 and 4.5.

The two modular media, Flocor E and Flocor M, could not have samples of the media removed from the various depths in the same manner and therefore alternative methods were employed. These methods have also been detailed in chapter 4.

The sample shafts were only installed in one of each pair of filters which permitted assessment of whether the presence of the shafts had a significant effect upon the performance of the filter. Initial indications from the retention time determinations of the 'clean' media (see chapter 5) would suggest that the shafts did not have a significant effect upon the flow characteristics. Three shafts were placed in each filter in order that the media contained in the baskets would have sufficient time between sampling periods for full recolonisation to occur. At the outset of the project it was intended that observations of the filter media would be carried out every 3 months, therefore each shaft would have 9 months for recolonisation and maturation to occur.

When baskets of the filter media and associated film were removed from the steel shafts they were taken to the Hereford laboratory for determination of the amount of wet film present, the total and volatile solids content of the film and for identification and enumeration of the macroscopic grazers. The nature and relative abundance of the microscopic flora and micrograzers was also carried out on subsamples of the filter film.

Prior to removal of the baskets of media, the sewage supply was disconnected for approximately 60 minutes to allow excess water to drain from the film. Immediately after removal from the shafts, the baskets were placed in large rigid polythene containers to minimise the loss of film in transit to the laboratory. In the laboratory, the media and basket were weighed using a spring balance. After removing all the film from the basket and media, and repacking the basket with media, the weight was again recorded. By subtraction, the amount of film in the known volume could be obtained. However, this weight was only used as a check on the amount of film recovered, since a significant amount of film could develop on the surfaces of the basket.

After the initial weighing, the media was removed from the basket and placed on a large tray. Most of the film was then removed from the pieces of media by scraping the individual pieces with a scalpel. After being scraped, the pieces were then carefully washed in equipment which allowed collection of the washings which were then sieved. To the film collected in this manner, the scrapings were also added and weighed. The film scrapings commonly constituted 90 - 95% of the total weight collected. This weight being taken as the total wet weight of film present in the known volume of media. The film

attached to the 'Netlon' basket being washed off and discarded.

In the cases of the two modular media, slightly different methods of film recovery were required. The subsection of the media was weighed complete with its attached growth and then carefully scraped with scalpels to remove as much film as possible. Test tube brushes and toothbrushes were then used to remove further film from the more inaccessible corrugated surfaces of the media. Additional film was also collected by careful washing of the module. However, it was not possibe to collect all the film successfully in this manner. Strenuous and repeated washings with hot water were required to clean the plastic surfaces thoroughly. Therefore, in order to obtain the weight of film supported by the media, the difference in weights between the subunit and its attached film and the weight of the clean media were recorded.

The collected film was then thoroughly mixed and subsamples taken for subsequent analysis. 10 grams of the wet film were weighed on to a watchglass and placed in an oven at 105°C for determination of the total solids. After drying in the oven overnight, the watchglass and film were placed in a dessicator to cool to room temperature. The weight of film was then determined. In order to obtain the volatile solids content of the film, the film dried to 105°C was then transported to the University ofAston where it was placed in a muffle furnace at 500°C for two hours. After cooling in a dessicator, the remaining ash was weighed. The difference in weight between 105°C and 500°C was then taken to be the weight of the volatile solids present in 10 grams of wet film. The method of volatile solids determinations is described in

'The Analysis of Raw, Potable and Waste Waters', H.M.S.O. 1972, P.42.

In practice, it was found that the variety and number of macrograzers present in the filter film varied significantly between filters and times of sampling. In view of the number of samples to be processed, it was necessary to vary the weight of film used for this analysis. It was found that the number of dominant grazers which could be counted in approximately 30 to 45 minutes was 100 to 500. Such a population was found to be commonly present in 10 grams of wet film. However, on occasions it was necessary to reduce the weight of film to 5 grams.

After being thoroughly mixed, the sample of film used for this analysis was weight out on to a petri dish, where the film was teased apart as much as possible using tweezers. The film was then transferred to a large white tray (approximately 600mm by 400mm) and washed using polythene washbottles full of water. It was found that surrounding the pieces of film with water encouraged most of the macrograzers to travel to the surface of the film; but enchytraied worms tended to burrow into the film which then required further careful teasing apart. The macrograzers were identified with the aid of Water Pollution Research Technical Paper No. 9., Department of Scientific & Industrial Research, H.M.S.O. 1946, Scientific Publication No.22, Freshwater Biological Association 1971.

A further subsample of the collected filter film was subjected to microscopic examination to identify the floral components and obtain a subjective assessment of the abundance of each component.

At the same time, identification and subjective abundance assessments of the protozoa and rotifers were carried out. The ciliated protozoa were identified with the aid of Water Pollution Research Technical Paper No. 12., Ministry of Technology, H.M.S.O. 1969.

In order to assess the microscopic members of the community ten separate mounts of the filter film from each basket of media were observed and the relative abundance of each community member assessed. An aggregate abundance scale was then formed of the ten mounts. The scale was as follows:- rare, occasional, frequent, common and abundant.

In addition to these observations of the protozoa present in the filters, occasional samples of the filter effluents were taken by W.R.C. staff for analysis of the protozoan contents at Stevenage. The results of these observations are also included in chapter 8.

7. PHYSICO CHEMICAL PERFORMANCE OF HEREFORD PILOT SCALE HIGH RATE FILTERS

A. Introduction

Three automatic samplers, described in chapter 4, were installed to take samples of the settled sewage feed and the sixteen effluent samples. The sampler used solely for the settled sewage feed contained 24 250 ml bottles. It was decided that for routine purposes one sample would be taken every hour. The individual samples could then be bulked into one sample for any given period. As previously described, the other two samplers formed bulked effluent samples for each of the filters. Again for routine purposes, it was decided that hourly samples would be taken. Because of the more complex pipework and manifold arrangements of these samplers, a minimum purge time of three minutes was necessary to ensure complete clearance of the previously accumulated solids and effluent from the system. Particular attention was paid to the effluent sumps at the base of each filter. Solids often tended to accumulate in these sumps. In order to remove these solids and prevent an unrepresentative sample being taken, the 25 mm heliflex pipes were mounted in a manner which positioned the end of the tube at the base of the sump. It was found that within the three minute purge time the accumulated solids had been removed from the sump and that a volume of effluent greater than three times the volume of the sump had been drawn up the sample delivery pipework. To obtain samples for a given period over weekends, the samplers were governed by 7 day timeswitches.

At the outset of the project, a weekly sampling programme was prepared with the intention of providing sufficient laboratory time for the analysis of the samples within 24 hours of collection.

In order to ensure that the samples were stored for the minimum period, the 24 hour day was split into two periods; namely a daytime period of 8 hours between 10.00 and 16.00 and a nighttime period of 16 hours between 17.00 and 09.00. This meant that the samples generated during the day could be removed after 16.00, taken to the laboratory, bulked and placed in a refrigerator overnight to reduce deterioration of the sample. The samples taken overnight could be removed after 09.00, bulked and analysed the same day.

The sampling programme drawn up is shown in appendix 7.A.1. From the programme it can be seen that there were three sample days, Tuesday, Thursday and Sunday. The two weekday sampling periods were for 24 hours starting at 10.00, therefore two sets of samples were generated each weekday. At the weekend only the daytime period was sampled. This decision was necessary due to the workload imposed on the laboratory. As well as the weekend samples on Monday, dissolved oxygen titrations of the BOD samples had to be carried out.

In order to determine the overall loading of the filters, as distinct from comparative performances, bulked daily samples of the settled sewage feed were also taken for COD and suspended solids analysis; the 24 hour day being split in the aforementioned manner.

In addition to these analyses at the Hereford laboratory, samples of the settled sewage and filter effluents were taken weekly to the University of Aston for ammoniacal and oxidised nitrogen analysis.

Unfortunately, difficulties immediately arose in maintaining this sampling programme due to frequent malfunction of the automatic samplers. All three samplers contained solenoid valves to regulate the liquor flows within the samplers. These valves were frequently jammed at various openings by mineral matter and humic solids alike.

The 24 bottle feed sampler did not break down as frequently as the other two samplers. After repeated thorough overhauls on site and also modifications by the manufacturers, this sampler ceased to present problems.

However, due to the complexity of the two 8 bottle samplers, extreme difficulty was encountered in keeping them in service. Eventually, after having been shortcircuited and rewired several times, the manufacturers removed the samplers from the site for major design modifications. Due to these difficulties, it was necessary to resort to manual sampling of the effluents every hour. This meant that overnight and weekend sampling of the effluents had to be abandoned; overnight sampling was discontinued in February 1976. Due to prolonged delays in the modification of these samplers, after having been returned to site, it was decided that their use be completely abandoned.

The taking of effluent samples manually every hour caused a greatly increased workload for the technician. Approximately two hours each sample day were lost because of this sampling. This additional workload had a far greater impact than simply the loss of two hours, since it was necessary to alter the routine of the laboratory analysis to accommodate taking the samples at fixed time intervals. Therefore, after February 1976, only two daytime sample periods were used each week.

Initially, settled sewage was pumped from the old primary settlement tanks of the main treatment works at Eign. Numerous teething problems were encountered with the supply such as the blockage of the suction tube with gross solids (caused by overloading of the primary settlement tanks) causing evacuation of the 75 mm heliflex

tubing which frequently collapsed, particularly during periods of high temperatures and strong sunlight. Another difficulty was the splitting of the pressurised uPVC supply pipework. However, the initial difficulties were overcome and the basic design problems eliminated.

The sewage works was undergoing major extensions at this time, which had the unfortunate consequence of disrupting the settled sewage supply to the pilot plant. As a result of the disruptions, the project had to be carried out using four differing qualities and quantities of sewage. Unfortunately, it was not possible to split the study into four equal periods under comparative environmental conditions. The physico chemical results reported in this section have therefore been grouped into the four periods of the study. The conditions pertaining during each period are detailed in the four following subsections.

A list of the abbreviations used to code the different filter media in the following tables and the symbols used to denote the filters in the following figures has been included in appendix 7.A.2. A timetable of the four periods of study of the pilot scale high rate filters, indicating the loadings applied to the filters, has been included in appendix 7.A.3.

B. Period I: 16 June 1975 to 16 November 1975

During this period of study when sewage was first applied to the filters, the supply was taken from the overloaded primary settlement tanks of the old works. Because the settlement tanks were overloaded and the screens in poor condition, gross solids frequently blocked the inlet to the Mono pump tubing, supplying the experimental filters' header tank. This had the initial effect of reducing the available supply for the filters and ultimately total blockage of the tubing which caused its evacuation and sometimes its collapse. Modifications to the tubing inlet to increase the surface area of screening and regular cleaning of this screen permitted a more constant supply to be obtained.

I. Results

i) Flow Results:-

During the initial trial period, the nominal flows were 2.8 $m^3/m^3/d.$ for the natural media and 5.6 $m^3/m^3/d.$ for three of the plastic media. In view of the reduced depth of the Flocor M filter, and the distribution system employed, this filter received a nominal flow of 6.2 $m^3/m^3/d.$

The weekly mean flows received by the filters are shown in appendix 7.B.1. It can be seen that for the natural media during the period the average flow of 2.83 $m^3/m^3/d$ was only fractionally higher than the nominal 2.80 $m^3/m^3/d$; however the plastic media received appreciably less than the nominal flow at 5.03 $m^3/m^3/d$ rather than 5.60 $m^3/m^3/d.$ Closer examination shows that there were wide variations in the weekly average flows and also between the flows recorded by the two troughs to each tank. The main reason for the

variations has been mentioned previously, namely the blocking of the screen to the pumped supply. Difficulties were also encountered with the integrating recorders for the tipping troughs. It can be seen that during the first week and the last three weeks of the period one or more of the recorders were out of action. Two problems in particular caused either irregular recordings or no recording for the tipping troughs. During this period of the study, the recorders were each powered by two 4.5 v dry cell batteries. These batteries tended to discharge slowly and it was difficult to check their condition; hence the periods where there are no flow records. The other problem which led to poor flow records was a malfunction of the magnetic reed switches which did not always open and close each time the trough tipped. If the magnet was not fastened to the tipping trough in the correct position, it was possible for no make and break or several make and break contacts to occur every time the trough tipped out its contents. This problem was gradually overcome by operator experience of the system.

The marked difference in flows recorded for tank A for the week ending 13/7/75 was due to the electric motor driving the distributor arms burning-out. This happened on the 12/7/75 causing the arms to halt in such a position that much of the sewage was applied to the filter over the second tipping trough. As a temporary measure until the motor could be replaced on 18/7/75, the chain drive was removed which allowed the distributor arms to rotate as a result of reaction drive. From 12/10/75 to 16/11/75, much of the flow variation was due to unavailability of settled sewage for the pilot plant. On 30/9/75 new filter beds on the Rotherwas site were commissioned; and much of the crude sewage at Eign inlet works was diverted to new primary

settlement tanks at Rotherwas, leaving insufficient sewage flow through the old primary settlement tanks to cover the experimental plant pump inlet.

ii) Temperature Results:-

Appendices 7.B.2 and 7.B.3 show the weekly meaned maximum and minimum temperatures and the comparative bed temperatures. Weeks 14/9/75, 21/9/75 and 28/9/75 did not have the daily maximum and minimum temperatures recorded due to problems of instability in the chart recorder. Moisture within the cabinet and dirt on a slide wire were affecting the continuous readings. In appendix 7.B.3, there are five weeks when no comparative data were recorded. The first week and the last two weeks of missing data were due to an excessive analytical workload and plant maintenance which prevented the comparative temperatures being measured at 12.00 hours daily. The middle fortnight of absent data was due to the recorder difficulties previously mentioned.

For reasons which will be explained in the discussion of the temperature data, in order to obtain more comparative data of the daily maximum and minimum temperatures of the plastic and mineral media, the temperature probes constantly monitored were changed. One probe was situated near the base of the clockwise second part of the Flocor M filter (FLM 2cw), whilst the other probe was situated near the base of the 89/50 mm blast furnace slag filter containing the biological shafts (SS biol).

iii) Routine Analytical Results:-

Appendices 7.B.4 to 7.B.9 show the weekly averaged data for this operational period. The averaged results shown in these tables only

include sampling periods when it was possible to collect a complete set of data for any one type of analysis; however it should be remembered that the weekly averages do not necessarily include the same number of sample periods. It can be noticed that no results are present in any of the tables for the week ending 20/7/75. This was due to difficulties with the automatic samplers, which meant that no complete sets of samples were obtained during any of the five sample periods during that week. Analytical results for the weeks ending 12/10/75 and 19/10/75 are also absent. No samples apart from daily feed samples were collected during this fortnight whilst examination of the film in each of the filter media types was being conducted. It may also be noticed that no complete COD data is presented for the weeks 3/8/75, 26/10/75, 2/11/75 and 9/11/75; the reason for incomplete data for these periods was the number of COD analyses required each week. Only a mantle for heating six flasks at any one time was available; therefore it was extremely difficult to heat more than 18 samples daily including a blank.

In appendix 7.B.4 showing the BOD results for the period, averaged data for the week ending 28/9/75 has been omitted. During that week, due to difficulties with the automatic samplers, no complete set of BOD data was obtained.

Appendices 7.B.8 and 7.B.9 showing the results of the ammoniacal and oxidised nitrogen refer only to one sample period per week; normally the overnight period Tuesday to Wednesday. Nitrogen analyses, which were carried out at Aston University, were not begun until the first week of September 1975.

II. Discussion of Physico Chemical Data for Period 1

During this maturation period for the filters, the collection of analytical data was seriously affected by teething problems with the pilot plant equipment. Many of these difficulties have been explained in the results section. Further difficulties were encountered as a result of the extensions being carried out to the sewage works.

From appendix 7.B.1, it may be seen that there were appreciable variations in the weekly flows applied to the filters; these variations being particularly pronounced during the first two months of operations. The reduction in the volume of settled sewage applied to the plastic media filters during November 1975 being due to the limited quantity of settled sewage available at the Eign works.

Table 7.1: Weekly Averaged Daily Maximum and Minimum Temperatures (16/6/75 - 16/11/75)

	Max.	S.D.	Min.	S.D.	Fluct^{n}.	S.D.
Feed	15.48	4.46	14.17	4.24	1.32	0.35
B90 (FLM 2cw)	14.61	4.56	12.88	4.27	1.72	0.63
LG (SS biol)	14.13	4.83	12.37	4.78	1.75	0.44

Temperatures in ^{o}C.

From table 7.1, it can be seen that the average maximum and minimum temperature of the settled sewage in the header tank during the complete period was 15.48^{o}C and 14.17^{o}C respectively, with a mean daily fluctuation of 1.32^{o}C. Both types of media had lower average maximum and minimum temperatures during the period than the applied feed. The plastic media filters (B90 and latterly FLM 2cw) which were continuously monitored showed higher temperatures than the two

mineral media filters observed (namely LG and SS biol). Both the maximum and minimum temperatures were greater by approximately 0.5°C. This result may be explained by the greater flow of sewage applied to the plastic filters which prevented their temperature deviating to the same degree as the mineral media filter temperatures from the applied sewage temperature.

The mineral media filters when compared to the plastic media filters had far greater heat masses present and also more restricted ventilation due to the limited void capacities. Due to these two factors, it may be expected that the mineral media filters would display more limited daily fluctuations in temperature than the plastic media filters. However, from observations of table 7.1, it can be seen that the mean daily fluctuations were similar although their standard deviations differed; that is, the variation in the daily fluctuation was slightly more restricted in the mineral media filters. It would therefore appear that the higher sewage application rate to the plastic filters counteracted this effect.

From figure 7.1, it can be seen that the temperature of the sewage declined from a summer maximum of approximately 20°C to 7.5°C during this period. It can also be seen that the maximum and minimum temperatures of the two filters under constant surveillance also declined in a similar fashion; this suggests that the reduced volume of settled sewage available during late October and November 1975 did not directly affect the plastic media filters' temperatures. However, the decline in the meaned maximum and minimum temperatures of the settled sewage during October and November 1975 may be as a result of the increased retention time provided for the sewage in the primary settlement tanks, although the temperature of the sewage may be

expected to decline at this time of year in any case.

Turning to the comparative temperature data presented in appendix 7.B.3, the filters which displayed the highest and lowest weekly meaned temperatures in each tank have been indicated. Examination of the highest and lowest temperatures shows that the duplicate filters did not display similar trends. These observations are borne out by analysis of variance conducted on the data which showed that the duplicate filters varied significantly in temperature. The statistical analysis also indicated that the variation in temperature from week to week was highly significant.

Table 7.2: Mean 12.00 hrs. Filter Temperatures (16/6/75 - 16/11/75)

SG biol	LS biol	SS	LG	B50 biol	B90 biol	FLE 2cw	FLM 2cw
13.97	13.82	14.02	13.53	14.61	14.19	14.26	14.81
SG	LS	SS biol	LG biol	B50	B90	FLE 1cw	FLM 1cw
13.78	14.01	14.01	13.98	14.82	14.74	14.69	14.77

L.S.D. @ 10% Probability Level = 0.33°C.

Examination of table 7.2 shows that overall there was no filter which had significantly the highest or lowest temperature, although the mineral media tended to have the lower temperatures with the 89/50 mm Granite and the 125/75 mm Slag showing the lowest temperatures. The two Biopac media tended to have the highest temperatures.

The variation in the temperatures recorded for the duplicate filters has been shown to be significant. This result leads to the question of why the duplicates varied.

Table 7.2 which shows the mean of the daily filter temperatures taken at 12.00 hrs. indicates that certain filters were quite consistently cooler than other filters within the same tank. In tank A

containing the natural media, filter LG was consistently the coolest for five consecutive weeks. In tank B filters B90 biol and FLE 2cw were generally the coolest. By observation of figure 4.1 it can be seen that the coolest filters were those which received the least solar radiation, and that their low temperatures were not related to the nature of the media. These filters had their surfaces shaded for the greater part of the daytime, whilst the warmest received the most sunlight at midday. The temperature probes were situated at the base of each filter and in fact the probes' exteriors received sunlight in inverse proportion to their temperatures. This would indicate that the surface temperature is important in determining the filter temperature.

This effect was noticed in October 1975 and, as a result, the probes used to constantly monitor the two tank temperatures were changed to those in SS biol and FLM 2cw. From October 1975 until the end of the project these probes were employed for this purpose.

Turning to the chemical analysis of the applied sewage and the filter effluents during the period, table 7.3 gives a summary of the average values found for the parameters. It should be recalled that the data presented refers to that collected during the comparative sampling periods and the values for the sewage should not be considered as the overall loadings applied during the period. From the last column in the table, it can be seen that only the midday temperatures of the filters showed significant differences between the replicate filters. This difference has already been explained to be as a result of the location and configuration of the filters. The filters did not show any significant differences in the values for any of the other parameters. Time can be seen to cause

Table 7.3 Analysis of Variance of Physico Chemical Data from Hereford High Rate Filters(Period 1.16/6/75-16/11/75)

	LG	SG	LS	SS	B50	B90	FLE	FLM	L.S.D.
Midday Temp. (^{o}C)	13.753	13.877	13.918	14.015	14.718	14.465	14.477	14.791	(R) 0.117 (M) 0.233 (T) 0.340
Nominal Flow ($m^3/m^3/d$)	2.8	2.8	2.8	2.8	5.6	5.6	5.6	6.2	-
Actual Flows ($m^3/m^3/d$)	2.83	2.83	2.83	2.83	5.03	5.03	5.03	5.59	-
BOD Applied (mg/l)	315.7	315.7	315.7	315.7	315.7	315.7	315.7	315.7	-
BOD Removed (mg/l)	212.91	233.19	228.49	222.99	223.91	218.63	204.86	214.03	(M) 13.86 (T) 20.79
Effluent BOD (mg/l)	102.86	82.58	87.28	92.78	91.86	97.13	110.91	101.74	(M) 14.54 (T) 21.80
Percent BOD Removal	67.4	73.9	72.4	70.6	70.9	69.3	64.9	67.8	-
Sludge Production (g/g BOD removed)	0.90	0.77	0.97	0.75	0.68	0.74	0.81	0.82	(T) 0.381

Table 7.3(cont.). A of V of Physico Chemical Data from Hereford High Rate Filters. (Period 1, 16/6/75 -16/11/75)

	LG	SG	LS	SS	B50	B90	FLE	FLM	L.S.D.
Unsettled Effluent SS (mg/l)	168.59	150.93	176.98	144.66	127.97	134.95	143.80	137.35	(M) 34.417 (T) 53.040
Settled Effluent SS (mg/l)	53.53	50.86	51.17	46.82	55.08	51.31	56.41	57.17	(M) 5.61 (T) 8.65
COD Applied (mg/l)	410.2	410.2	410.2	410.2	410.2	410.2	410.2	410.2	-
COD Effluent (mg/l)	154.88	149.35	147.17	136.97	137.45	148.97	150.24	148.02	(M) 11.88 (T) 16.27
COD Removed (mg/l)	255.30	260.83	263.02	273.22	272.74	261.22	259.94	262.17	(M) 11.88 (T) 16.27
Percent COD Removed.	62.2	63.6	64.1	66.6	66.5	63.7	63.4	63.9	-

significant variations in the filter effluent qualities; however, by referring to the weekly averaged data in appendices 7.B.4 to 7.B.9, it may be seen that there was no consistent trend in the values of the parameters; therefore the variation with time was essentially a result of random variations in the applied sewage quality and quantity. Figures 7.2 to 7.11 which show the data of appendices 7.B.4 to 7.B.7 in graphical form clearly indicate that there was no overall trend in the data, apart from the first fortnight's performance when there was an improvement in the COD and BOD removal abilities of the filters.

Comparing the effluent qualities of the mineral and the plastic media filters, it can be seen that the mineral media filter effluents tended to have greater stability in their quality. This stability was not as a direct result of the variations in the flows of settled sewage. In the case of the plastic media filters, the standard deviation of the flow data was only 12% of the mean, whilst for the mineral media the variation was 38% of the mean which would suggest that the mineral media filters might show the greater instability in their effluent qualities. However, it should be recalled that in volumetric terms, the plastic media filters did receive 1.78 times the sewage applied to the mineral media filters per cubic metre. It is possible that this higher loading might account for the instability, although unlikely since in terms of the specific surface areas of the various media the organic loadings were comparable.

Figures 7.6 and 7.7 show that the weight of sludge produced per unit of BOD removed by each filter. It can be seen that the trends and the values shown for all the filters are similar, the major differences in production appearing to occur in the mineral media filters during the week ending 5/10/75. However, it should be noted

that this was an isolated incident which was most probably related to the nature of the sewage applied to the filters during that week. The routine analysis did not show any marked deviation apart from the low BOD concentration applied and present in the effluents. On 30/9/75, there was a reduction in the quantity of sewage available at Eign due to commissioning of the Rotherwas works; this increased the retention time of the sewage in the primary settlement tanks and also led to periods of insufficient supply to the experimental plant.

Further consideration of table 7.3 shows that the filters consisting of the 125/75 mm graded granite had the lowest temperatures, the lowest BOD removal of the natural media filters, and consequently the highest BOD concentration in the effluent. Next to the 125/75 mm slag, the large grade of granite media filters had the highest sludge production per unit of BOD removed, although the solids present in the effluents were not particularly high. The 125/75 mm granite also had the highest COD concentrations in their effluents.

The Biopac 50 filters tended to have low solids production and concentration of COD in their effluents. Whilst the BOD concentrations of the Biopac 50 effluents were not particularly low; due to the low solids production in the filters they tended to produce the lowest weight of sludge per gram of BOD removed.

As a result of the high settleable solids production, the 125/75 mm slag filters had overall the highest sludge production per gram of BOD removed.

It can therefore be seen from table 7.2 that of the mineral media, the two larger grades of slag and granite tended to have the lower performances in terms of BOD and COD removal and solids production, of which the 125/75 mm granite filters were worst. Considering the

plastic media filters, it can be seen that the random media filters, particularly Biopac 50, tended to provide a greater removal performance than the two modular Flocor media. Therefore, overall it can be seen that the 125/75 mm granite media filters gave marginally the worst performance of all the filters under the conditions provided.

No one type of media gave the highest performance in terms of effluent quality, with the Biopac 50 and the 89/50 mm slag filters achieving better quality effluents than the other filters in most parameters.

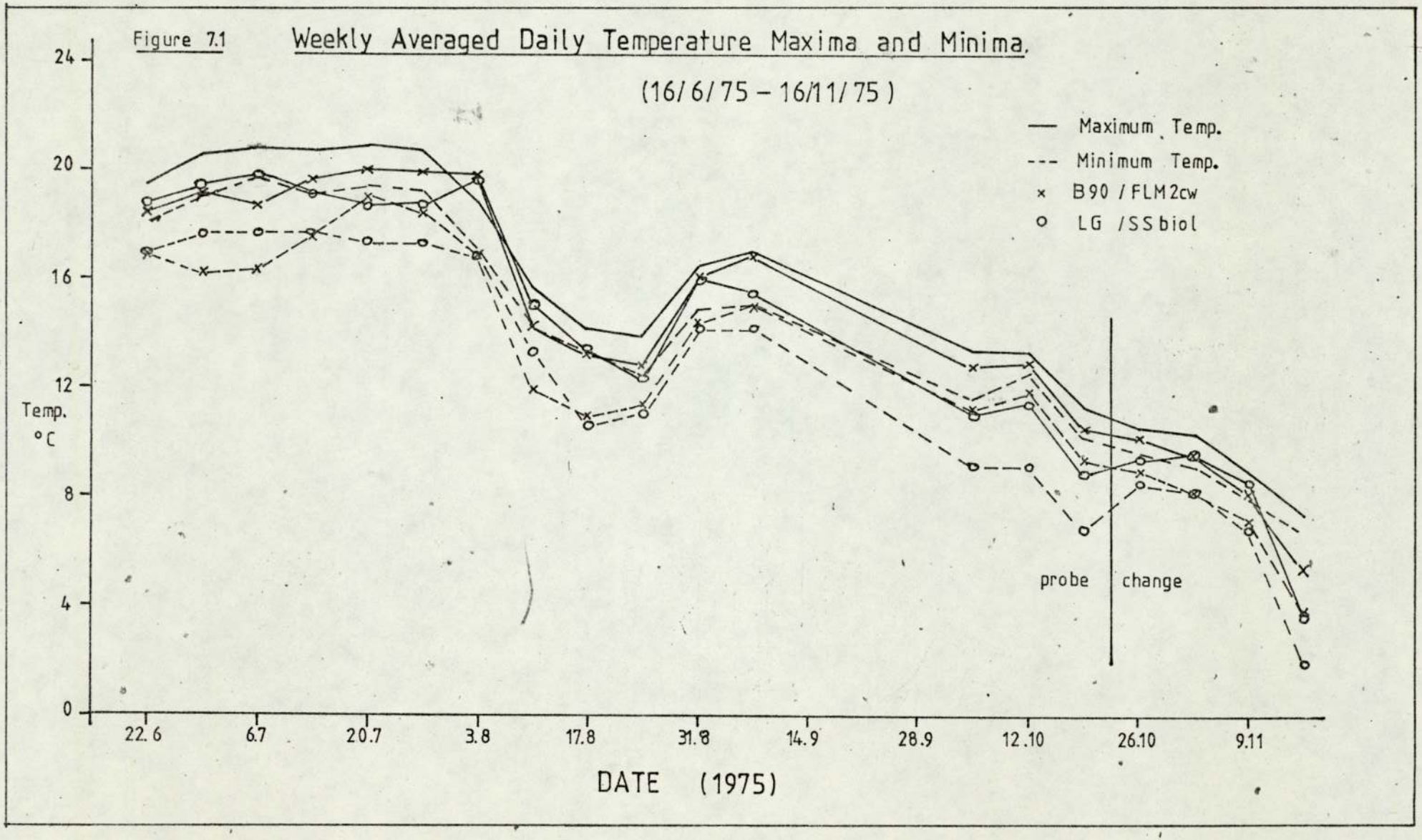


Figure 7.1
Weekly Averaged Daily Temperature Maxima and Minima.
(16/6/75 – 16/11/75)
Maximum Temp.
Minimum Temp.
B90 / FLM2cw
LG / SS biol
probe change
Temp. °C
0
4
8
12
16
20
24
22.6
6.7
20.7
3.8
17.8
31.8
14.9
28.9
12.10
26.10
9.11
DATE (1975)

Figure 7.2 Settled Sewage and Mean Filter Effluent BOD Concentration.

(mineral media) (16/6/75 – 16/11/75)

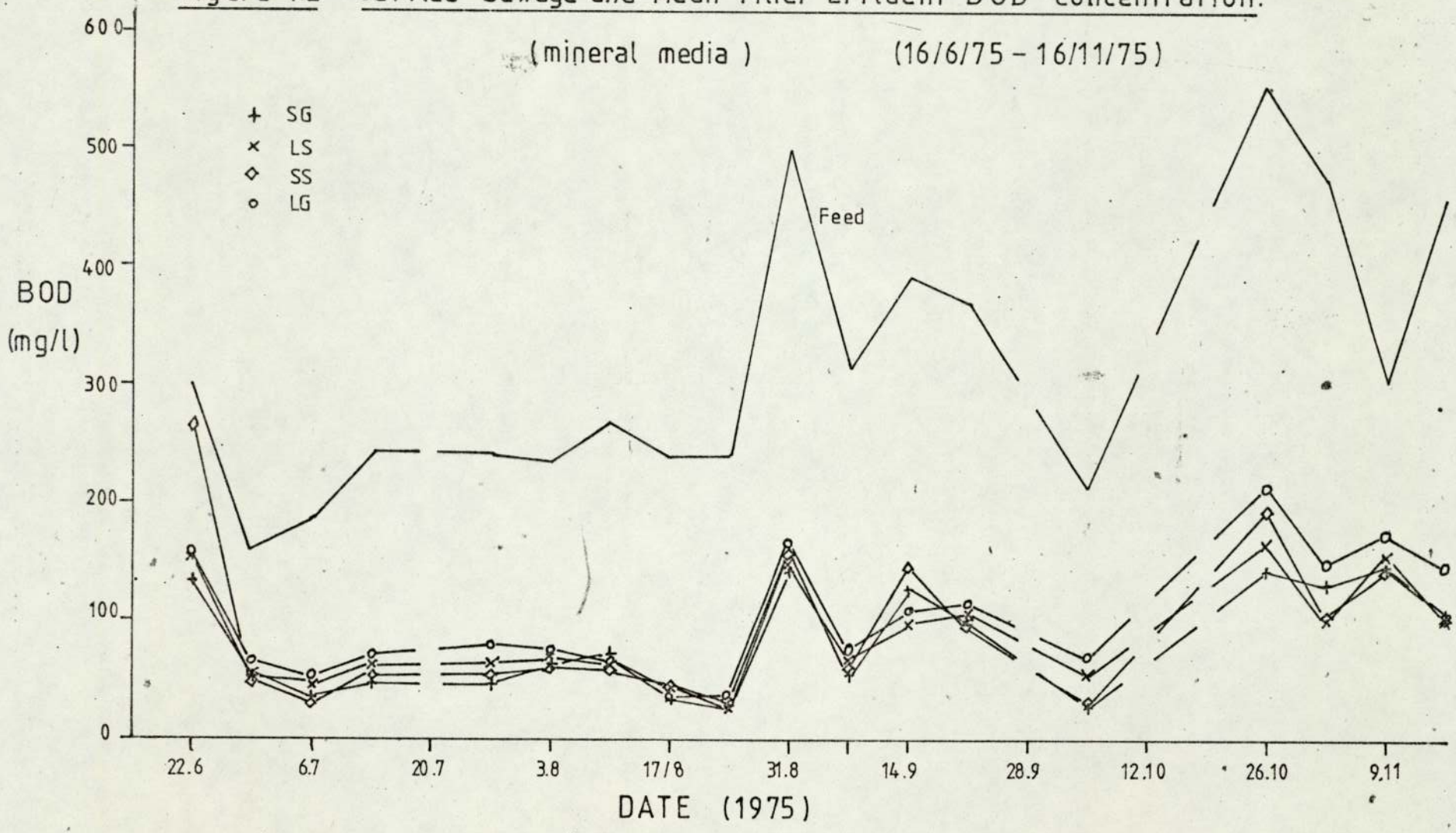


Figure 7.3 Settled Sewage and Mean Filter Effluent BOD Concentration.

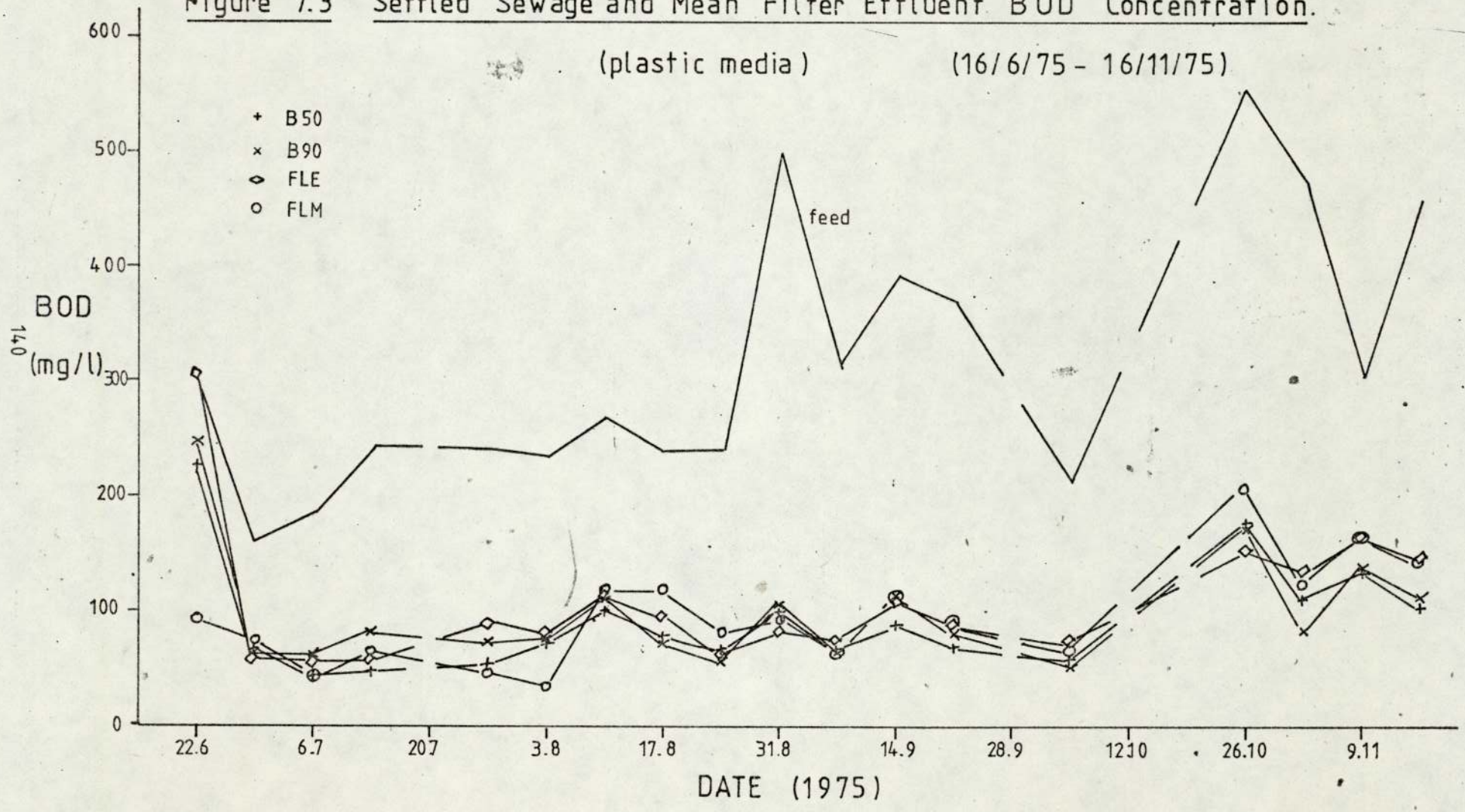


Figure 7.4 Percentage BOD Removals of the Mineral Media Filters.

(16/6/75 – 16/11/75)

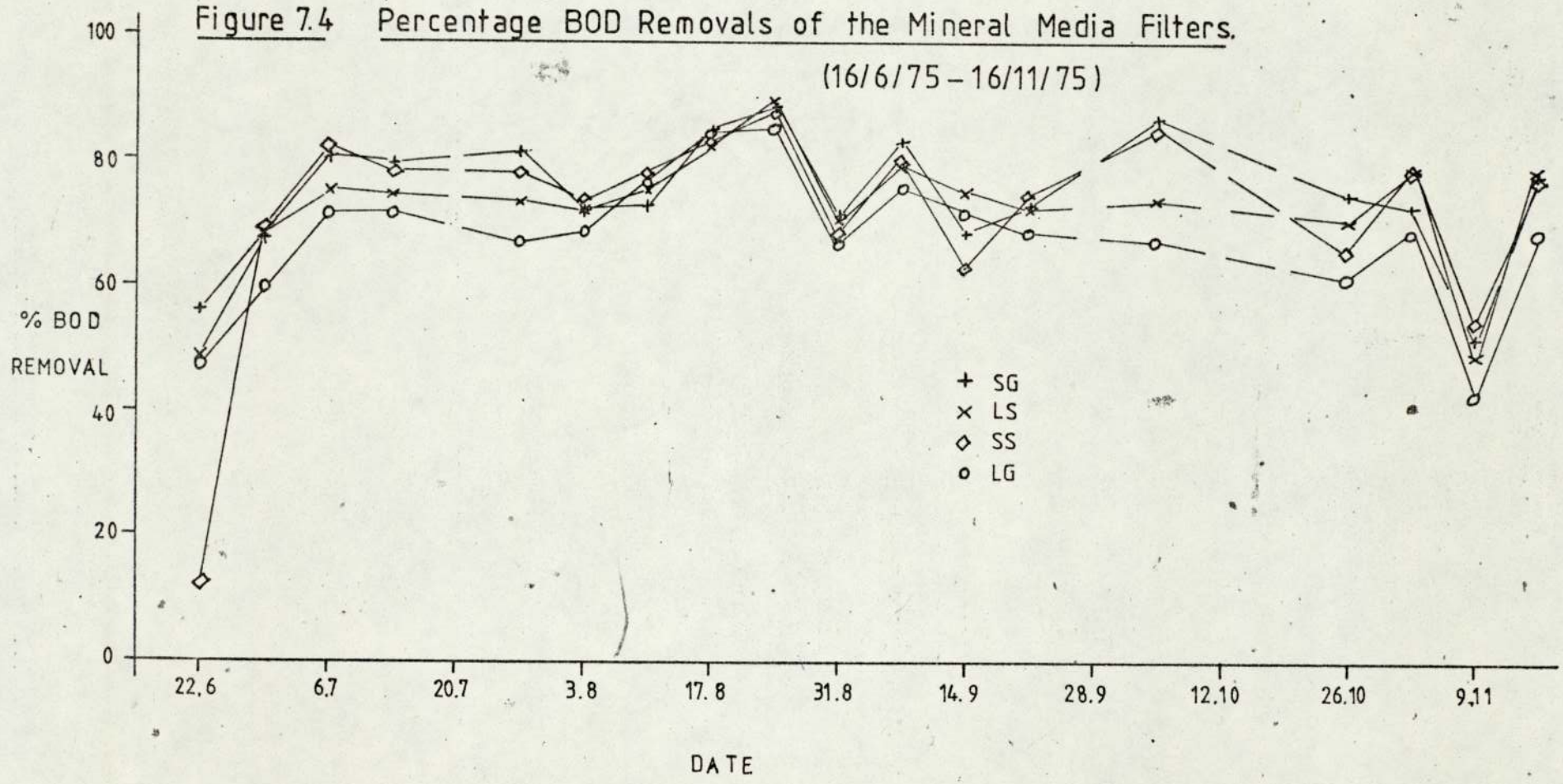


Figure 7.5 Percentage BOD Removal of the Duplicate Plastic Filters.

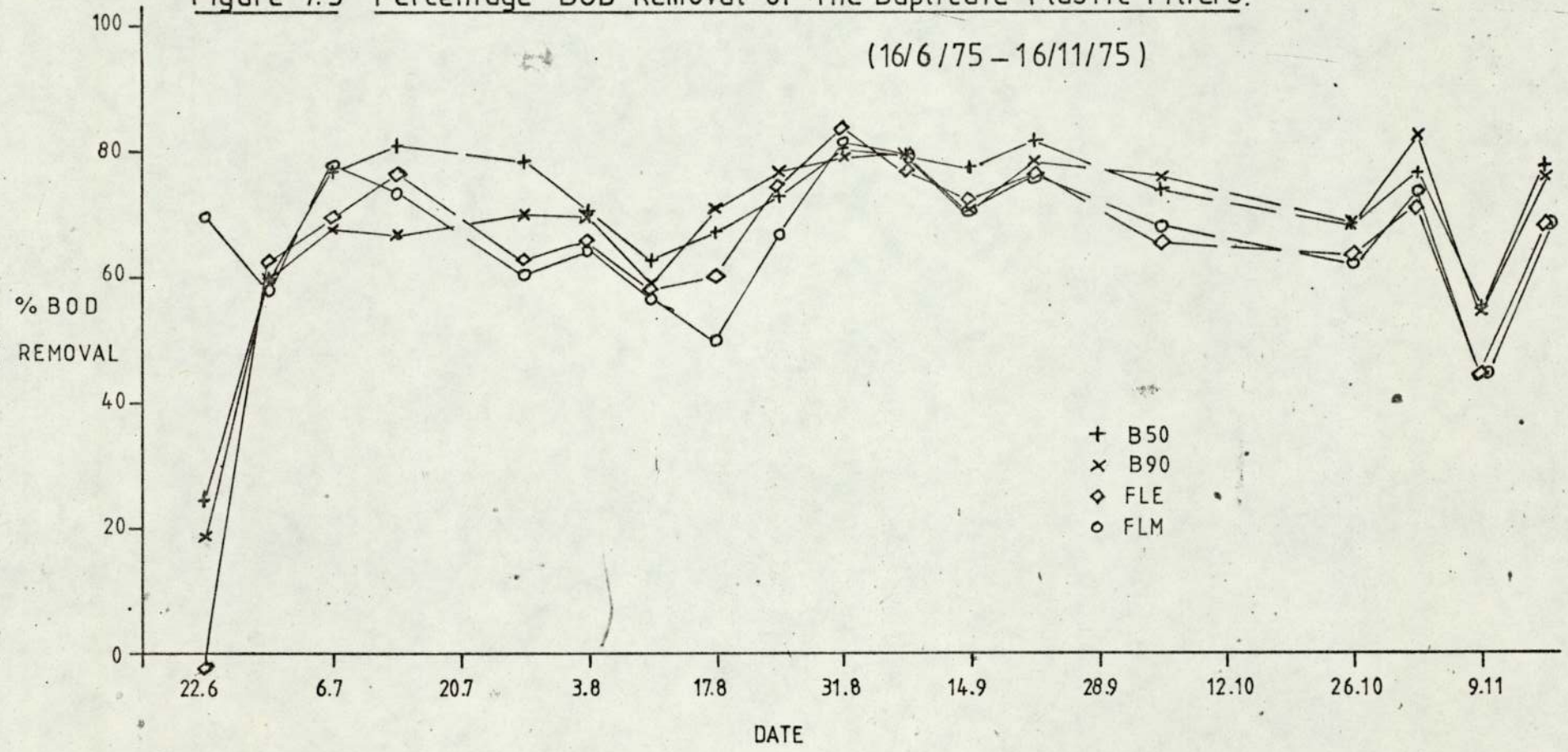


Figure 7.6 SLUDGE PRODUCTION/BOD REMOVAL RATIO FOR MINERAL FILTERS.

(16/6/75 - 16/11/75)

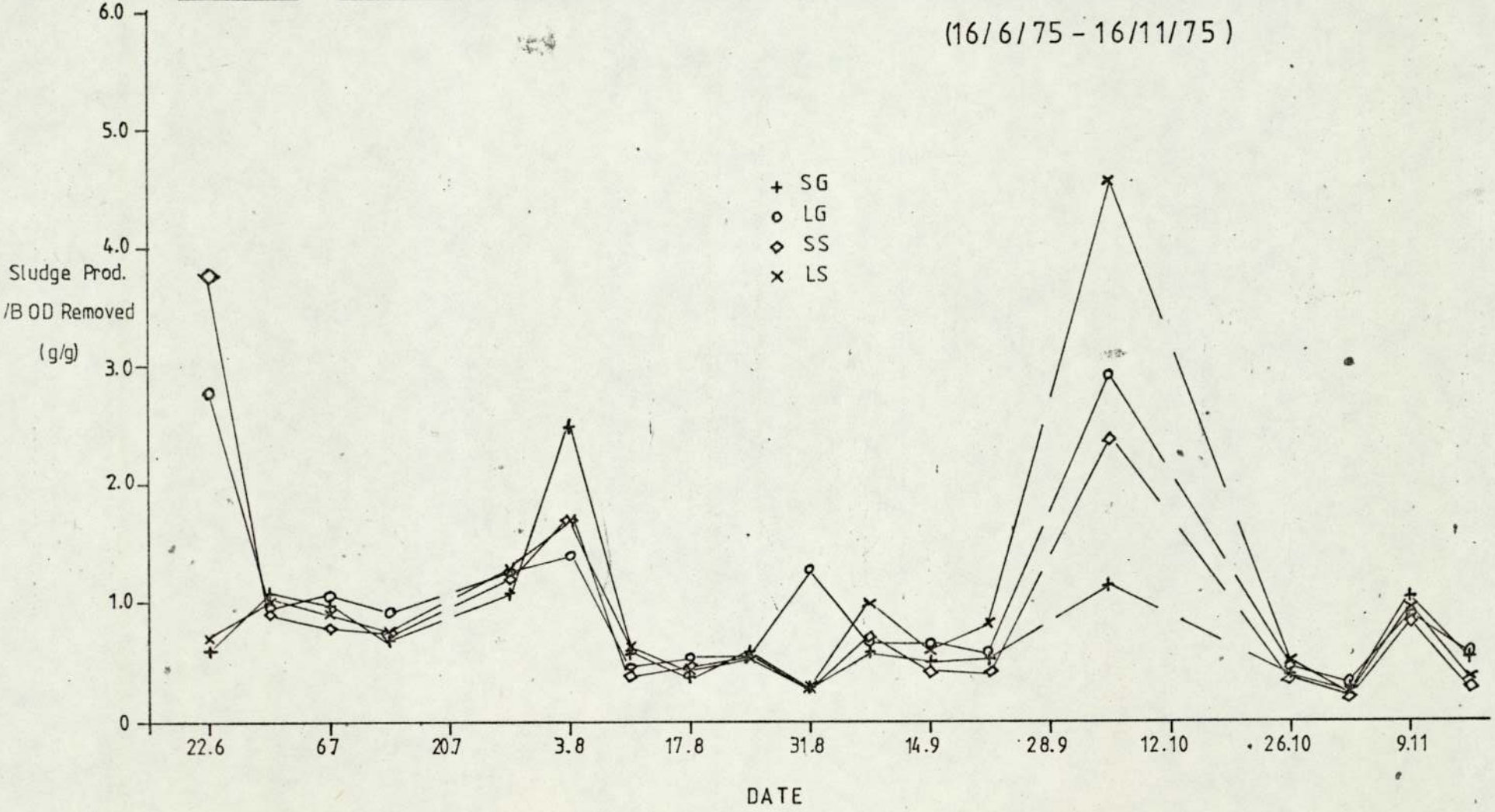


Figure 7.7 Sludge Production/BOD Removal Ratio for Plastic Filters.

(16/6/75 – 16/11/75)

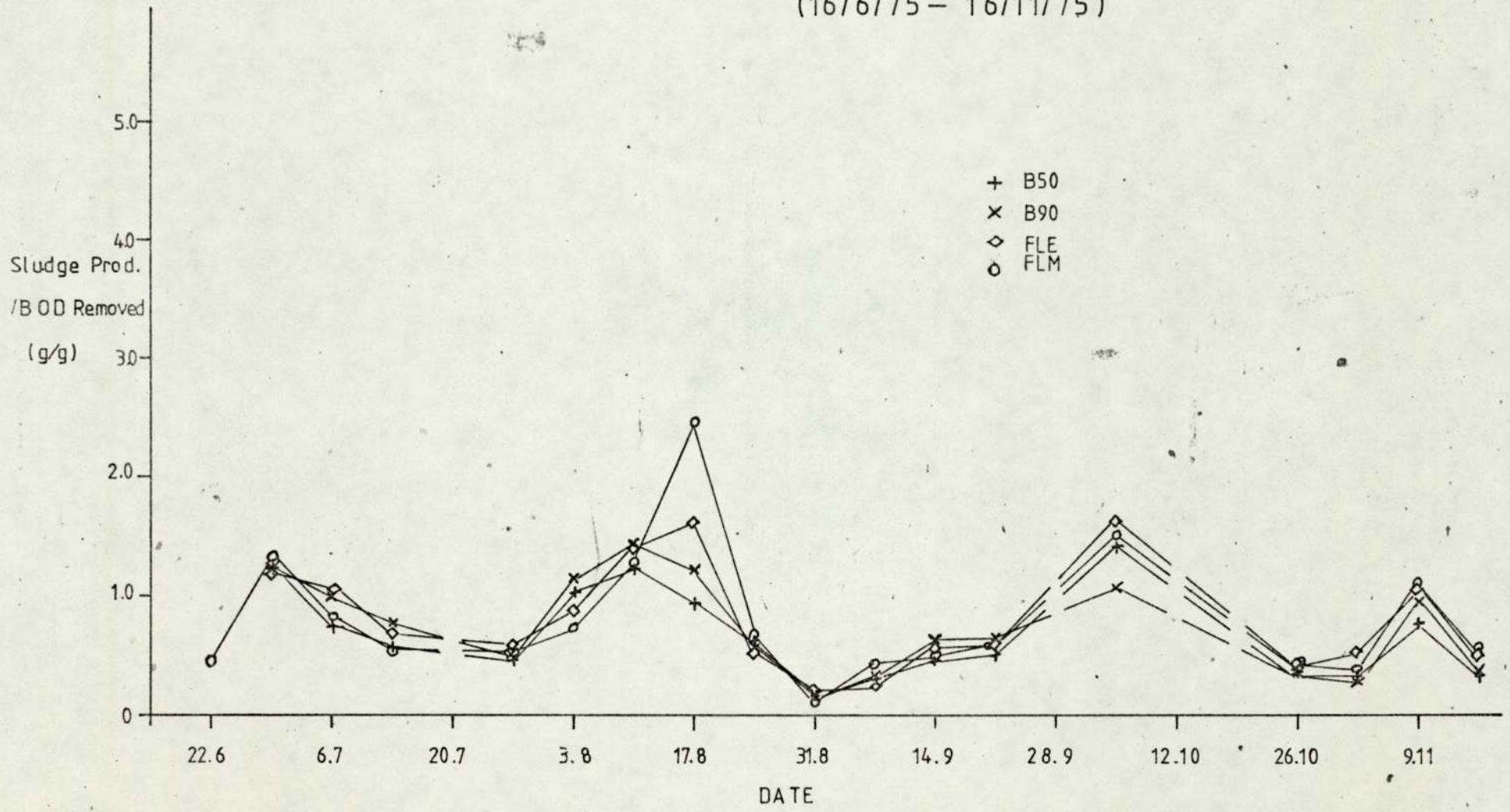


Figure 7.8 Duplicate Mineral Filter Suspended Solids. (Settled Effluents)

(16/6/75 – 16/11/75)

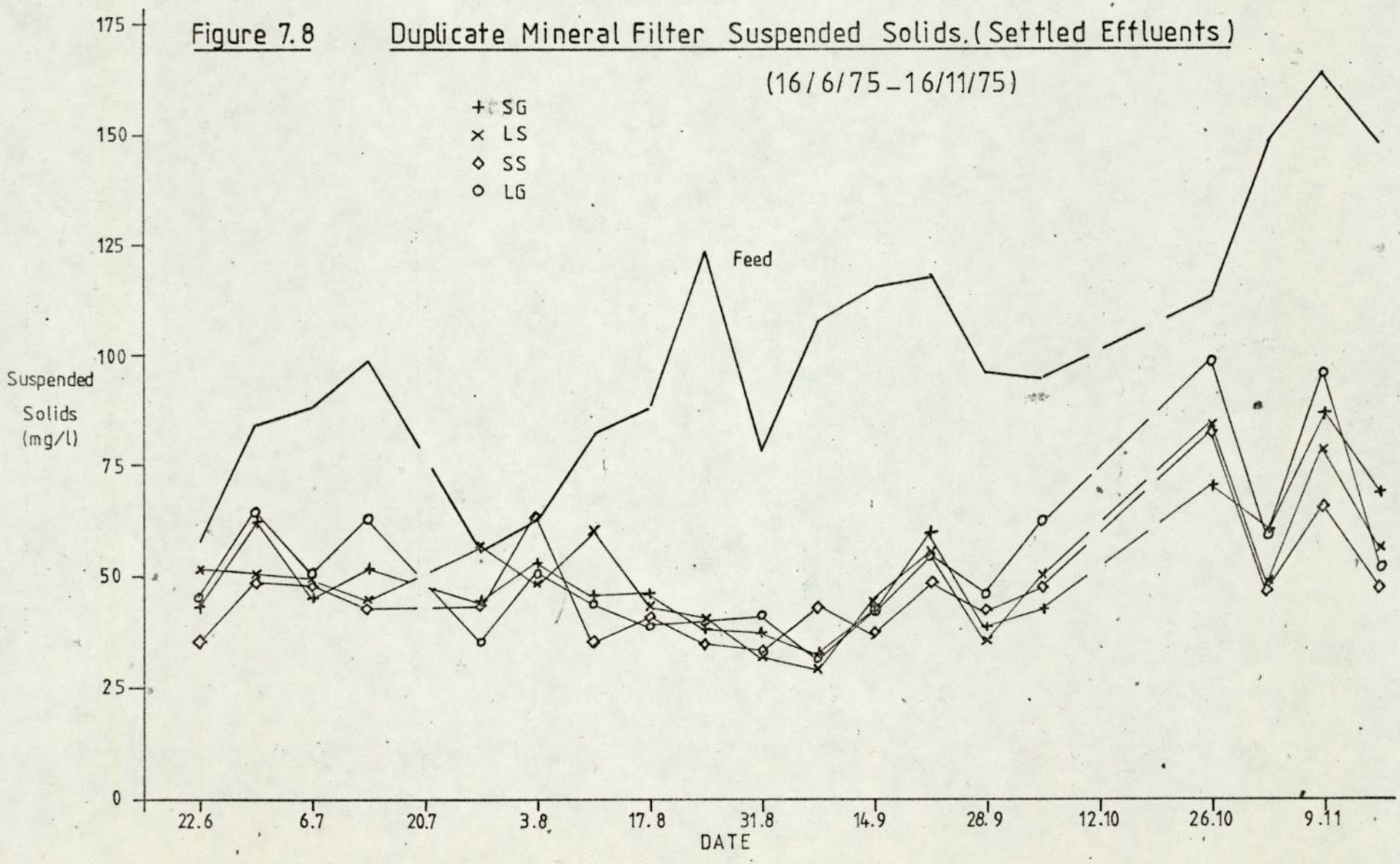


Figure 7.9 Duplicate Plastic Filters Suspended Solids (Settled Effluents)

(16/6/75 – 16/11/75)

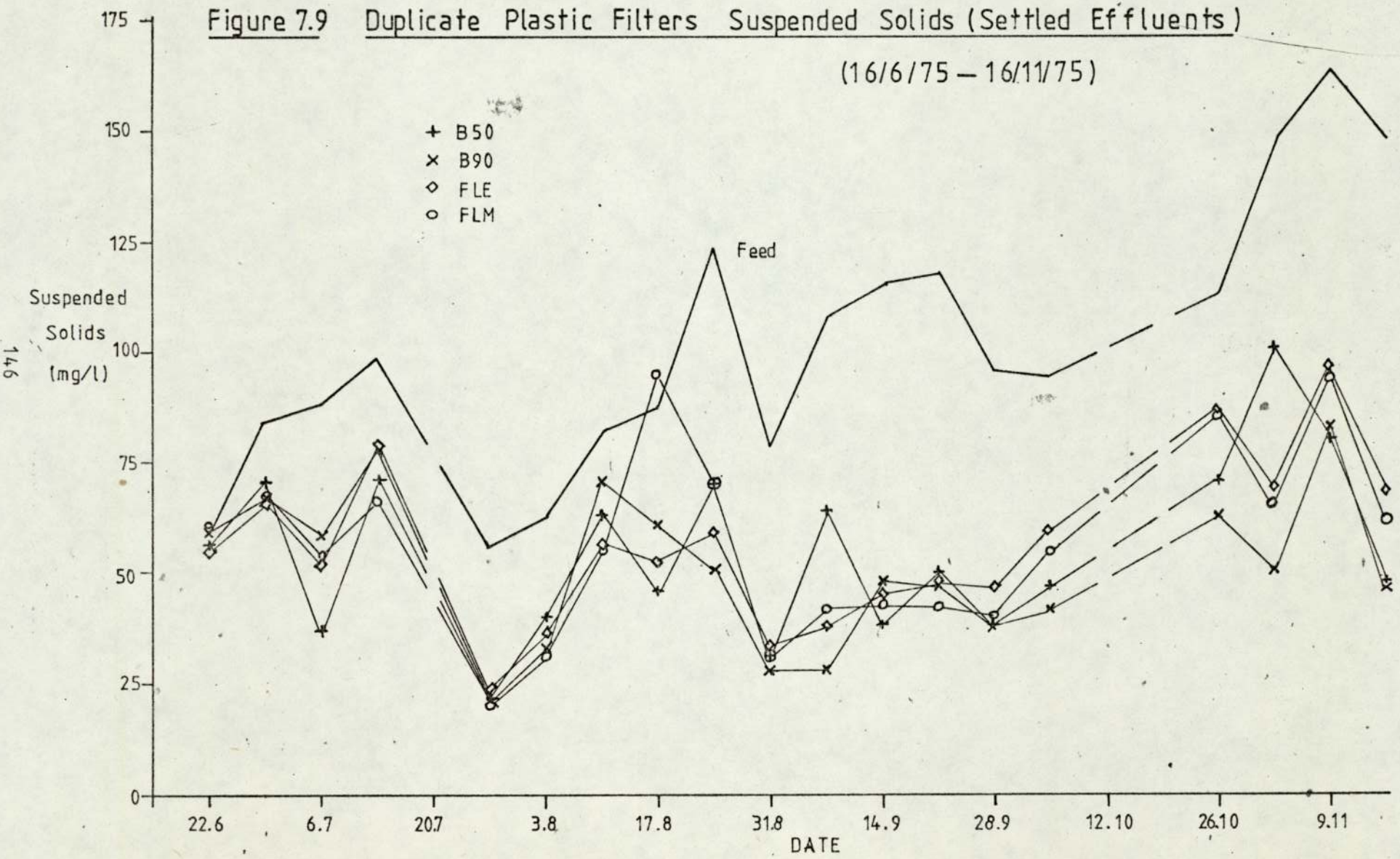


Figure 7.10 Duplicate Filters Effluent CODs (16/6/75-16/11/75)

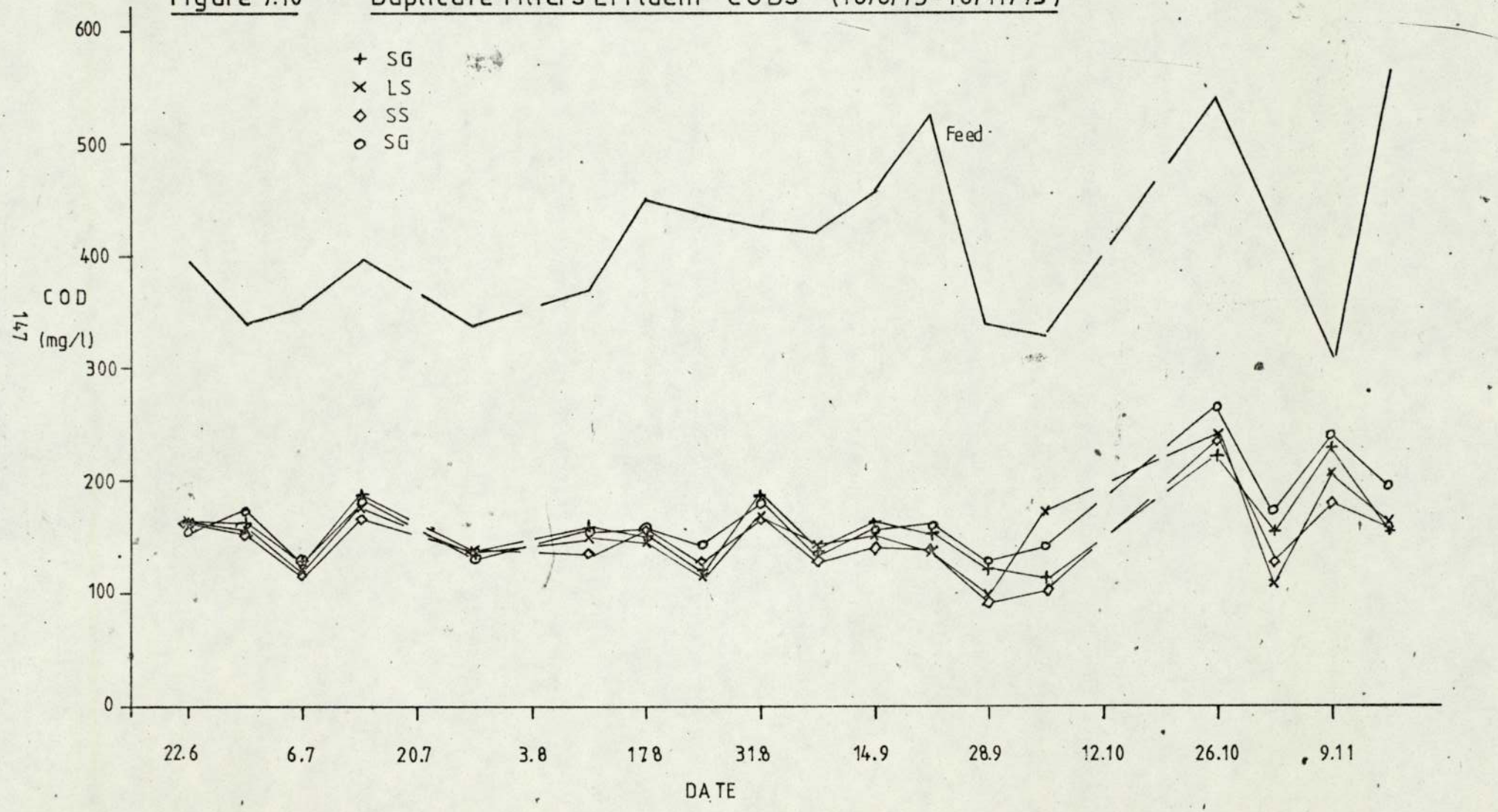
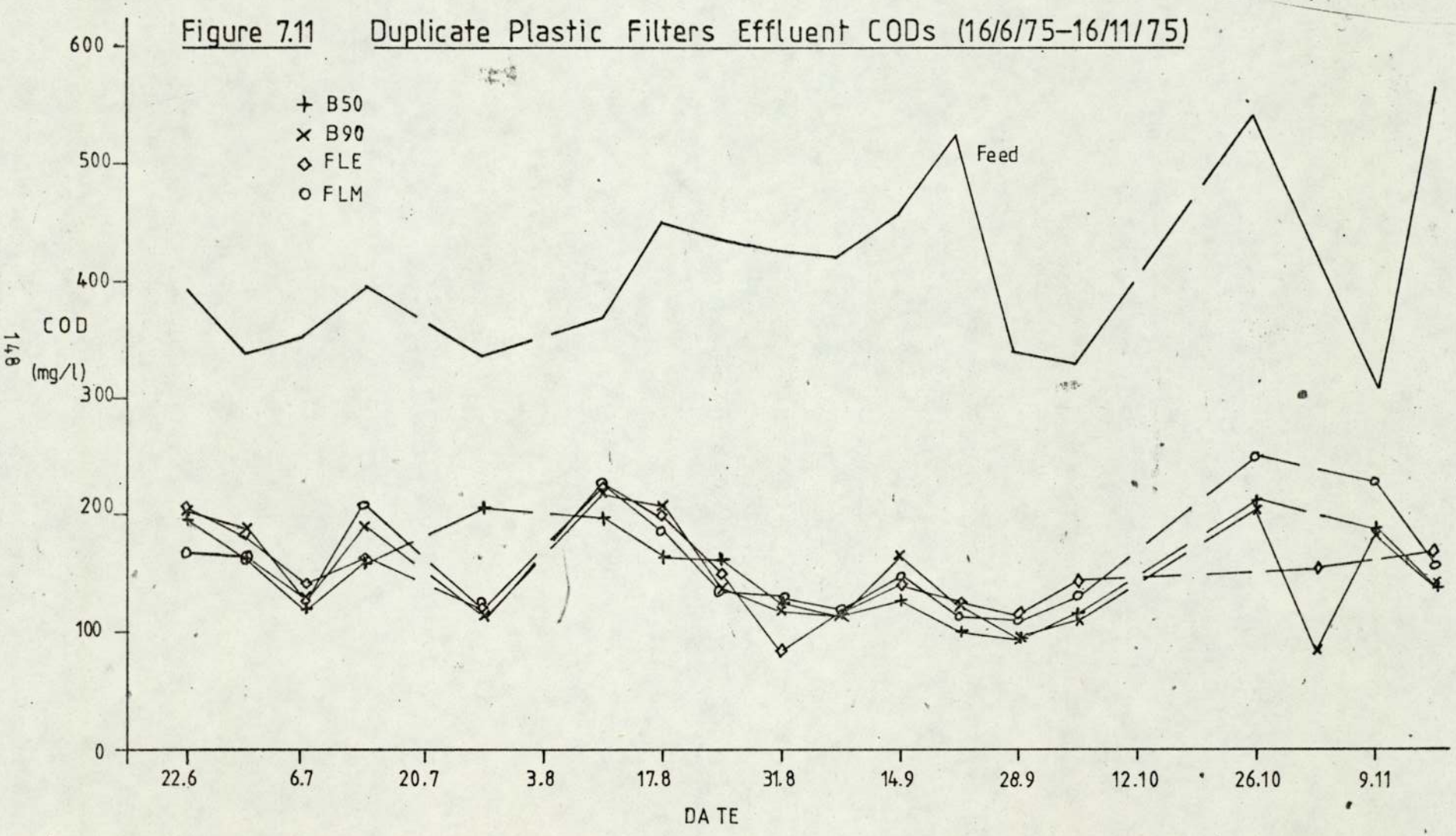


Figure 7.11 Duplicate Plastic Filters Effluent CODs (16/6/75–16/11/75)



C. Period 2: 19 November 1975 to 27 January 1976

I. Results

i) Flows:-

After 13/11/75, no settled sewage was available on the Eign part of the sewage treatment works. In order to prevent the biomass which had developed on the pilot scale filters being lost, a limited supply of degritted comminuted crude sewage was obtained by gravity feed through a 75 mm uPVC pipeline from the top of the crude sewage screw pumps. Unfortunately, the head was limited, hence the much reduced flow. During this period two rectangular tanks used for cold digestion of sludge were converted into horizontal flow settlement tanks for the experimental plant.

From appendix 7.C.1, it can be seen that the flows were markedly reduced. This supply of sewage led to two particular operational problems. Because of the limited supply, the constant head tank supplying the distributor arms was never full, which caused difficulties in regulating the amount of sewage geing supplied to each tank of filters such that twice the volume should have been applied to the plastic media filters compared to that supplied to the mineral media filters. The second operational problem, which further exacerbated the regulation of the flows, was due to the nature of the supply. Although degritted, the crude sewage contained a high concentration of grease and gross solids. Due to this and the reduced flow through the distributor arms, large accummulations of grease developed in the arms, which when detached caused blockage of the distributor jets causing maldistribution over the surface of the filters. This occurred most frequently in the distributor arms supplying the mineral media filters. In view of the reduced level

of sewage in the header tank, any restriction in flow through one distribution system raised the sewage level in the header tank thus increasing the flow to the other octagonal tank of filters.

It can also be seen from appendix 7.C.1 that difficulties were also encountered with the flow recorders. The damp situation of the recorders and the autumn weather caused rapid discharge of the dry cell batteries. Another frequent difficulty during the period was damage to the micro switches attached to the tipping troughs. Replacement of the switches was a major problem at the time due to their unavailability.

ii) Temperature Data:-

During this period, two major difficulties were encountered in obtaining continuous and accurate temperature recordings.

As previously mentioned, the low flow of the crude sewage into the header tank meant that the tank was not completely filled. On occasions, the temperature probe was not immersed in sewage due to the difficulties in regulating the flow. However, the air temperature during this period was generally much lower than that of the sewage, therefore periods when the probe was recording air temperature were easily discernible and were disregarded.

The other difficulty encountered was one of instability within the chart recorder, leading to incorrect readings. Due to this problem, temperatures recorded for five weeks of the period were disregarded. After a thorough overhaul of the chart recorder in December by the equipment suppliers, it functioned correctly and reliable recordings achieved.

iii) Routine Analytical Data:-

During this short study period of nine weeks, much of the routine

analytical work was not conducted for various reasons. From appendices 7.C.4 to 7.C.9, it may be seen that no analytical results are presented for the week ending 23/11/75. This was the first week of the period during which numerous teething problems precluded the opportunity to carry out a full sampling programme. No samples were taken during the weeks ending 28/12/75 and 4/1/76 for analysis although the pilot plant was visited during this period to ensure correct operation. From appendix 7.C.5 it may be seen that two COD results for the week ending 14/12/75 are missing. This was due to the problem of limited facilities described in the results section for period 1.

From appendix 7.C.4, it may be seen that, apart from the missing BOD data already accounted for, data is also missing for the weeks ending 21/12/75 and 11/1/76. No BOD samples were set up during the week ending 21/12/75 due to staff vacations the following week preventing titration of the 5 day incubated dilutions. No BOD results are presented for the week 11/1/76 due to staff illness which prevented titration of the incubated dilutions.

II. Discussion of Physico Chemical Data for Period 2

In view of the very limited extent of this period and the lack of analytical data which has been explained in the results section, none of the analytical data recorded has been presented graphically.

Considering the flows shown in appendix 7.C.1, it may be seen that these were severely curtailed compared to the flows received by the filters in the first period of study; however the ratio of flow to the plastic media filters to that applied to the mineral media filters was quite similar at 1.64. In view of the nature of the sewage (i.e. unsettled) the BOD concentration was approximately double

that applied to the filters during the first period, with the result that the organic loading applied to the mineral media filters at 0.793 kg BOD/m^3/d was only 11.2% lower than during the first period (0.893 kg BOD/m^3/d). In the case of the plastic media filters, the reduction in organic loading was greater at 17.9% (1.303 kg BOD/m^3/d) compared to the loading of 1.588 kg BOD/m^3/d during the first period. However, caution must be exercised when comparing the performance figures to those attained during the first period in view of the different nature of the sewage applied to the filters and the hydraulic loadings employed.

During this period, two major difficulties were encountered in obtaining continuous and accurate temperature recordings. As previously mentioned, the low flow of the crude sewage into the header tank meant that the tank was not completely full. On occasions the temperature probe was not immersed in sewage due to the difficulties in regulating the flow. However, the air temperature during this period was much lower than that of the sewage, therefore periods when the probe was recording air temperature were easily discernible and were disregarded.

The other difficulty encountered was one of instability within the chart recorder, leading to incorrect readings. Due to this problem, temperatures recorded for five weeks were disregarded. Appendix 7.C.3 showing the weekly meaned temperatures of all sixteen filters at 12.00 hours indicates that certain filters tended to be consistently cooler than other filters within the same tank. This pattern had also been observed during the first period of the study. As previously noted, the differences appear to relate to the amount of incident solar radiation upon the surface of the filters. The

duplicate filters positioned diagonally opposite within the same tank do not appear to bear any significant similarities in temperature. Only the two filters containing the two Flocor media were similar; this being due to the fact that the two probes were within the same filter.

Appendix 7.C.2 shows that the maximum and minimum temperatures of the sewage feed were higher during late December and early January 1976 than observed in November during the previous phase, although the difference between the maximum and minimum temperatures tended to be greater. Apart from the week ending the 23/11/75, the maximum and minimum temperatures recorded for the plastic and mineral media showed similar tendencies to those recorded during the first period of the study; namely that the plastic media maximum and minimum temperatures most closely followed the sewage temperature variations although the range of temperature was greater and the overall temperature lower. The mineral media had the lowest maximum and minimum temperatures, although the range recorded was slightly more restricted than for the plastic media, presumably because of less ventilation due to the lower void capacities and the large heat mass present. The low temperatures recorded during the week ending 23/11/75 were due to highly fluctuating sewage flows and low air temperatures. Examination of table 7.4 showing the mean of the analytical data for the duplicate filters during this period shows that the effluent qualities varied significantly with respect to time. This variation was due to the fluctuations in flow rates and the quality of the applied sewage. Also, from table 7.4, it can be seen that the percentage removals of all filters for BOD and COD were high compared to period 1 and the effluent qualities comparable. However, there appears to be a vast

Table 7.4 Analysis Of Variance of Physico Chemical Data for Hereford High Rate Filters (Period 2,19/11/75-27/1/76)

	LG	SG	LS	SS	B50	B90	FLE	FLM	L.S.D.
Midday Temp. (^{o}C)	10.240	10.350	10.400	10.600	10.600	10.338	10.250	11.113	-
Actual Flows ($m^3/m^3/d$)	1.12	1.12	1.12	1.12	1.84	1.84	1.84	2.04	-
BOD Applied (mg/l)	708.0	780.0	780.0	780.0	780.0	780.0	780.0	780.0	-
BOD Removed (mg/l)	630.81	622.06	634.38	631.88	554.30	578.69	473.38	539.31	(M) 111.33 (T) 78.72
Effluent BOD (mg/l)	77.19	85.94	73.63	76.13	153.75	129.31	234.63	168.81	(M) 110.12. (T) 77.86
Percent BOD Removed	89.1	87.9	89.6	89.2	78.3	81.7	66.9	76.2	-
Sludge Production (g/g BOD removed)	0.61	1.31	1.20	0.60	2.14	1.49	5.70	1.35	(M) 4.30

Table 7.4 (cont.) A of V of Physico Chemical Data for Hereford High Rate Filters (Period 2, 19/11/75 - 27/1/76)

	LG	SG	LS	SS	B50	B90	FLE	FLM	L.S.D.
Unsettled Effluent SS (mg/l)	294.50	536.42	493.83	264.17	757.25	715.83	1030.8	587.92	(T) 612.68
Settled Effluent SS (mg/l)	57.70	53.75	55.08	45.83	103.75	94.50	141.50	101.17	(M) 53.96 (T) 46.73
COD Applied (mg/l)	1382.8	1382.8	1382.8	1382.8	1382.8	1382.8	1382.8	1382.8	-
COD Effluent (mg/l)	142.0	129.4	133.6	120.8	145.2	151.8	172.2	174.2	(M) 232.5
COD Removed (mg/l)	1240.8	1253.4	1249.2	1262.0	1237.6	1231.0	1210.6	1208.6	(M) 21.01 (T) 16.61
Percent COD Removed	89.7	90.6	90.3	91.3	89.5	89.0	87.5	87.4	-

difference in the mechanism of the organic matter removal during the two periods. Again, from table 7.4 it can be seen that the solids contents of the effluents from all the filters was very high compared to period 1. Examination of the sludge production/BOD removal figures for the period indicate an exceedingly high rate of sludge production in most cases. It should be recalled that the sewage applied to the filters was unsettled, containing high concentrations of gross solids. Therefore the appar ent efficiency of the filters in removal of organic matter should be viewed with caution, since primary settlement alone would remove much of the load. However, as mentioned above, the quality of the effluents was comparable in terms of BOD and COD concentrations to that achieved during the first period, therefore the filters must have played a role in the removal of a certain amount of the organic matter. Part of the organic matter will have been removed by oxidation, whilst another fraction will be transferred to the solid phase and hence settled out in the effluents; however, returning to the table, it can be seen that the sludge production figures for the 89/50 mm slag and the 125/75 mm granite were lower than during the first period, therefore oxidation of the material must account for quite a proportion of the organic matter removal.

In view of the limited period, lack of analytical data and instability of the sewage supply for this period, few conclusions should be drawn with regard to the comparative filter performances.

D. Period 3: 29 January 1976 to 29 July 1976

As of 29/1/1976, comminuted sewage was diverted from the top of the crude sewage screw pumps on the main works to two converted cold digestion tanks, to provide primary settlement for the sewage. The tanks were modified such that the crude sewage entered the deep end towards the base of the tank. The inflow was directed against the end wall to minimize the turbulence which might prevent settlement of sludge. The shallow end of the tank was modified by the addition of a concrete weir across its length. In order to regulate the gravity inflow to the settlement tanks from the top of the screw pumps, two valves were installed in the pipework immediately before the settlement tanks. Each settlement tank (approximately 400 m^3) was modified to provide between 2 and 8 hours settlement dependent upon the flow through the tank. Two tanks were modified in order that a supply of settled effluent could be guaranteed to the pilot plant during necessary desludging and maintenance operations on any one tank.

In order to supply the pilot header tank with settled sewage, it was necessary to use the previously mentioned Mono pump. The pump was mounted adjacent to the two settlement tanks; with its inlet strainer submerged in settled sewage in the outlet channel.

Excess settled effluent from the modified tanks was returned to the main works inlet by making use of the existing dewatering pipework for the sludge tanks; however, it was found that careful regulation of the tank inflow was required, since the dewatering line was of small diameter. The settlement tanks could be desludged using the existing desludging facilities.

In practice, it was found that minimizing the frequency of

desludging the settlement tanks improved the quality of the effluent; in order to achieve this objective both tanks were kept in use, thus increasing the retention time of each tank by minimizing the flow and also keeping the accu mulation of sludge to a minimum. Unfortunately, it was found that rising sludge became a problem in the settlement tanks. By only desludging at fortnightly intervals, anaerobic digestion of the accu mulating sludge occurred. This caused the sludge to rise to the surface of the tank and to be lost over the outlet weir, to the detriment of the settled effluent quality and often blocking the Mono pump inlet strainer; in order to prevent this, scum boards were added to the outlet weirs.

Even permitting extended periods between desludging operations, it was found that only a small volume of sludge could be removed from the tanks. The construction of the tanks was such that the sludge did not collect at the deep end but remained distributed throughout the floor of the tanks. Therefore, in order to remove the sludge, it was necessary to drain a tank and wash out the accu mulated sludge using a high pressure hose.

I. Results

i) Flows:-

From appendix 7.D.1, it can be seen that at the beginning of this period only one flow recorder was operative in each tank; two of the tipping troughs having been returned to the Water Research Centre for servicing.

Over the period 18 - 21/4/76, no sewage was supplied to the filters due to an electrical fault on the Rotherwas site which caused the supply pump to be switched off. Over this period serious damage

was caused to the biological film. Unfortunately the break in the sewage supply coincided with a period of strong winds and bright sunlight which serious drying effects upon the filters.

During the first month of operation in this period, difficulty was encountered in achieving the desired nominal flows. These difficulties were gradually overcome as the operators gained experience of the system. Precise regulation of the flow through the settlement tanks was necessary. Excessive flows caused the outlet weirs to be flooded due to the inability of the surplus settled effluent pipework to handle the flows; however, if the flow through the settlement tanks was too restricted, insufficient settled sewage was available for the Mono pump to supply the pilot plant header tank, thus limiting the flow to the filters.

It can be seen from appendix 7.D.4 that there were occasional weeks when no flow records are present for a particular tipping trough. These omissions are due to errors in the integrator readings as a result of faulty switches and/or loss of the power supply.

ii) Temperature:-

From appendix 7.D.2 and 7.D.3 showing the weekly meaned comparative mid-day bed temperatures and the maximum and minimum temperatures, it can be seen that there are four sections of missing data. During the week ending 8/2/76 insufficient sewage was present in the header tank to cover the temperature probe hence the missing data in appendix 7.D.2. Considering appendix 7.D.3 showing the comparative filter temperatures at mid-day, there are three weeks of omission; these were due to staff vacations and also excessive workloads during a period of biological sampling which prevented the mid-day temperatures being taken.

iii) Routine Analytical Results:-

Observing appendices 7.D5 to 7.D.7, it can be seen that in the cases of the suspended solids and COD results there was a fortnight (2/5/76 and 9/5/76) where no results are presented. This was due to sampling of the filters' films for biological activity, during which, apart from the daily analysis of the sewage fed to the filters, all sampling and analysis was suspended. In the case of the BOD data shown in appendix 7.D.4, there was a further week, namely the week ending 18/4/76, when no results were obtained. This was due to a suspension of BOD analysis over the Easter vacation.

From appendix 7.D.8, showing the ammoniacal N results, it can be seen that there were four weeks for which no analysis was carried out. These four weeks were weeks during which biological examinations of the filter films were being carried out. Appendix 7.D.9, listing the oxidised nitrogen concentrations, shows that only occasional analyses of effluent samples were conducted, due to the infrequent and limited presence of oxidised nitrogen.

II. Discussion of Physico Chemical Data for Period 3

At the end of January 1976 a source of settled sewage was available for the pilot plant in sufficient quantity to permit application to the filters at the originally intended nominal flow rates of 2.8 $m^3/m^3/d$ to the natural media filters and at 5.6 $m^3/m^3/d$ to the plastic media filters. However, from table 7 it may be seen that in practice these rates were not achieved. It may be further noticed that there was greater stability in the flow rates during the period than previously attained, and that the ratio of the flow to the plastic media filters to that to the natural media filters at 1.85 was closer to the desired ratio of 2.00. Apart from initial teething

problems with the settlement tanks and the disruption to the supply during the week ending 25/4/76, the flow variations in time were quite limited. Overall, it can be seen that the flow applied to tank A was close to the nominal flow of 2.8 $m^3/m^3/d$ (being 10% less), and that the flow received by tank B filters was 13% lower than the nominal flow. The major difficulty in achieving the desired flow to tank B was the dimensions of the distribution system and the head of effluent available.

Considering the temperature data for this period, it can be seen from figure 7.12 showing the mean maximum and minimum temperatures that there is a gradual increase in the temperatures from approximately 11°C to 22°C in the six month period; i.e. a doubling in the average temperature. It should be recalled that the data refers to 1976 when high ambient temperatures and little rainfall were recorded. From statistical analysis of the data in appendices 7.D.2 and 7.D.3, the following tables were prepared:-

Table 7.5: Mean Max. & Min. Temperatures and L.S.D.s for the period 29/1/76 to 29/7/76

	Feed	FLM 2cw	SS biol	L.S.D.
Max. Temperature	18.277	17.577	17.431	0.210
Min. Temperature	17.235	16.358	16.342	0.180

(Temperature in °C)

Table 7.6: Weekly Averaged Daily Max. & Min. Temperatures (29/1/76 - 29/7/76)

	Max.	S.D.	Min.	S.D.	Fluct^n.	S.D.
Feed	18.28	3.35	17.23	3.58	1.048	0.620
FLM 2cw	17.58	3.83	16.36	3.85	1.219	0.435
SS biol	17.43	3.74	16.34	3.51	1.088	0.380

(Temperature in °C)

From these tables it can be seen that both the maximum and minimum temperatures of the applied sewage were significantly higher than the respective temperatures of the two filters. No significant difference was evident between either the maximum or the minimum of the two filter temperatures. It may also be noticed from the above tables that the daily fluctuations in temperature of both filters was greater than that observed for the applied sewage although only by 0.17°C in the case of FLM 2cw and only 0.04°C in the case of SS biol. This increased variation being due to the ventilation of the filters.

Comparing the temperature data collected for this period to that collected for the first period of study, apart from the absolute temperature differences several other points become evident. During period 1 the daily fluctuation of the sewage temperature was greater at 1.32°C compared to 1.03°C, the fluctuation in the two filter temperatures was also greater at 1.72°C and 1.75°C. The main explanation for this difference was the prevailing weather conditions. During the first period of study in the autumn of 1975, there was a greater temperature difference between the air and the sewage, leading to greater ventilation of the filters and also greater cooling of the sewage, particularly overnight. Whilst considering the effect of ambient weather conditions, it is interesting to note from figure 7.12 that during the third period (29/1/76 - 29/7/76) there were occasions when the temperature of one or other filter exceeded that of the applied sewage. This situation could be brought about by two factors; the air temperature may be greater than that of the sewage thus supplying heat to the filters, and also the situation can occur when the atmospheric temperature is comparable to that of the applied sewage. In this case the higher temperature of the filters can be brought about by the metabolic heat of the biomass. When the sewage

and air temperature are similar, little or no ventilation may occur (Petru 1958) and therefore this metabolic heat permits an increase in the filter temperatures.

Turning to consider the comparative temperature data presented in appendix 7.D.3, it can be seen that,as previously, the highest and lowest weekly meaned temperatures in each tank are indicated. Statistical analysis of the data reveals that the duplicate filters did not vary significantly and that the variations which did occur between the different types of media were barely significant at the 10% level of probability (see table 7.7).

Table 7.7: Mean Mid-day Temperatures of the Duplicate Filters (29/1/76 - 29/7/76)

SG	LS	SS	LG
16.9813	16.8083	17.1083	16.7063
B50	**B90**	**FLE**	**FLM**
17.0167	16.6250	16.6542	16.8854

L.S.D. = 0.2691°C

During the first period there was a significant difference between the temperatures of the duplicate filters, which did not occur in the third period. This difference in temperature results may be explained by the ambient air temperatures and hours of sunlight available. During period 1 there was a limited number of sunlight hours and also the air temperature was less than the sewage temperature; however in the third period the air and sewage temperatures are comparable therefore direct solar radiation had an insignificant effect on the surface of the filters, the degree of ventilation now being of greater importance. The extent of the ventilation of filters

has been discussed in chapter 2, when it was explained that the nature of the media had an effect on ventilation. Since the prevailing conditions for most of period three were similar for all 16 filters, the media of the individual filters is of great comparative importance. Considering the mineral media filters, the two large grades of media had the largest voids which were less easily obscured by filter film hence permitting greater ventilation; this is reflected in the temperatures which are slightly lower than for the smaller media (table 7.7). The pattern is however not so easily discernible in the plastic media filters apart from the higher temperature of the Biopac 50 filters compared to the other filters. The Biopac 50 media has much smaller pore sizes than the other three media, and also the distribution of the pores is random compared to the highly regular large pore structure of the two Flocor media. From visual observations of the surfaces of the filters during the period, the Biopac 50 filters tended to support the greatest growth of film which frequently obscured many of the pores, thus reducing the ventilation and any possible heat loss.

Considering the analytical data shown in table 7.8, it may be seen that time had a significant effect upon all of the parameters studied; this effect however was in the most part due to the random variation in the quality of the settled sewage applied to the filters and the variation in the flow rates. Figures 7.13, 7.14, 7.19 and 7.20 show how the BOD and suspended solids concentrations of the settled sewage varied in time. This variation can be seen to have an impact upon the quality of the filter effluents.

Apart from the random variations in the quality of the settled sewage applied to the filters, two other effects can be seen in

Table 7.8 Analysis of Variance of Physico Chemical Data from Hereford High Rate Filters.(Period 3.29/1/76 - 29/7/76)

	LG	SG	LS	SS	B50	B90	FLE	FLM	L.S.D.
Midday Temp. (°C)	16.706	16.981	16.808	17.108	17.017	16.625	16.654	16.885	(M) 0.269 (T) 0.466
Nominal Flow ($m^3/m^3/d$)	2.8	2.8	2.8	2.8	5.6	5.6	5.6	6.2	-
Actual Flows ($m^3/m^3/d$)	2.66	2.66	2.66	2.66	4.94	4.94	4.94	5.49	-
BOD Applied. (mg/l)	365.2	365.2	365.2	365.2	365.2	365.2	365.2	365.2	-
BOD Removed (mg/l)	258.408	268.859	264.489	270.957	302.620	286.326	271.712	267.543	(M) 8.328 (T) 14.121
Effluent BOD (mg/l)	106.788	96.337	100.707	94.239	62.576	78.870	93.484	99.239	(M) 8.259 (T) 14.004
Percent BOD Removed.	70.8	73.6	72.4	74.2	82.9	78.4	74.4	73.3	-
Sludge Production (g/g BOD removed)	0.737	0.717	0.707	0.689	0.578	0.637	0.748	0.734	(M) 0.092 (T) 0.156

Table 7.8 (cont.) A of V of Physico Chemical Data From Hereford High Rate Filters,(Period 3,29/1/76 - 29/7/76).

	LG	SG	LS	SS	B50	B90	FLE	FLM	L.S.D.
Unsettled Effluent SS (mg/l)	170.958	175.448	171.990	173.052	164.625	170.094	190.906	188.521	(M) 18.513 (T) 32.066
Settled Effluent SS (mg/l)	74.219	70.375	74.125	70.115	55.188	62.313	66.469	66.240	(R) 3.184 (M) 6.368 (T) 11.030
COD Applied (mg/l)	763.1	763.1	763.1	763.1	763.1	763.1	763.1	763.1	-
COD Effluent (mg/l)	230.167	215.792	226.146	212.458	158.771	182.042	193.354	194.500	(R) 5.199 (M) 10.398 (T) 18.009
COD Removed (mg/l)	532.958	547.333	536.979	550.667	604.354	581.292	569.771	568.833	(M) 13.182 (T) 22.831
Percent COD Removed	69.8	71.7	70.4	72.2	79.2	76.2	74.7	74.5	-

figures 7.13 to 7.24, to occur at different times during this period of study. Between 18/4/76 and 21/4/76 no sewage was applied to the filters. Unfortunately this lack of sewage coincided with a period of high temperature, strong winds and long hours of strong sunlight, with the result that the filters were severely dried out. At the surface of the filters, the film became so dessicated that thick sheets of it separated from the filter media, and were washed through the filters on resumption of pumping.

The effect of this can be seen in figures 7.19 and 7.20 where the suspended solids concentrations of the settled filter effluents doubled between the week ending 18/4/76 and the week ending 25/4/76. This increase in solids loss gave rise to a marked increase in the sludge produced per unit weight of BOD removed during the week ending 25/4/76. Rather surprisingly the loss of filter film did not cause a vast increase in the effluents' BOD or COD concentrations, indicating the resilience of the filters to shock treatment.

Between 20/6/76 and 11/7/76, it can be seen that all four types of mineral media lost a high concentration of solids in their effluents (figures 7.19 and 7.20). The loss of the solids appeared to have a significant effect on the filter performances. Whilst the settled sewage applied to the filters declined considerably in strength at the same time, which in itself could account for a fall in the percentage BOD removal efficiency of the filters, the CODs of the settled effluents increased, and the sludge production per unit weight of BOD removed increased dramatically. The intensity of this effect was restricted to the mineral media filters, although a minor inflection occurred in the plastic media filter effluents a week before the mineral media. In view of the BOD strength of the applied sewage at this time, and

the behaviour of the plastic media filters, it would appear reasonable to assume that the nature of the sewage did not cause the loss of solids from tank A filters. Reviewing the daily log for this period showed that during the weeks ending 27/6/76 and 4/7/76, the distribution arm motor for tank A frequently cut out during the daytime due to thermal overload. Although these breaks were only of short duration they obviously had a significant effect upon the filters' performances.

Examination of figures 7.13, 7.14, 7.15 and 7.16 shows that, whilst the BOD concentration of the settled sewage applied to the filters varied greatly, the mineral media filters generally gave a BOD removal of approximately 70% with no discernible trend during this period. However, when examining figure 7.16, it can be seen that the plastic media filters all tended to increase in their BOD removal efficiencies from approximately 70% at the beginning of the period to nearly 90% by the end of the period. This trend did not appear to have any significant effect upon the relative sludge productions.

The initial decline in the sludge production/BOD removal data shown in figures 7.17 and 7.18 must in part reflect the reduced solids concentration being applied to the filters. It should be recalled that not only did the solids content fall with a change in the sewage supplied, but also the nature of the solids would change, with less inert or highly stable organic solids being applied to the filters. These solids would be gradually both flushed out of the filters and also to an extent digested by the filter film. The change in the nature of the sewage also in this case seemed to have resulted in a change of filter film. This point will be discussed in further detail later in the chapter and also in chapter 8.

Considering the ammoniacal nitrogen contents of the filters' effluents, it can be seen that wide variations in the concentrations occurred. It should be remembered that the weekly result for each filter is based on the analysis of only one composite sample, and hence a wide scatter of results may be expected.

There are perhaps two features of particular interest in figures 7.23 and 7.24. It may be seen that initially the filter effluents all contained less ammoniacal nitrogen than the settled sewage feed, but that during March and for the most of the period thereafter the effluents' ammoniacal nitrogen concentrations were greater than that of the applied sewage. This initial loss of ammoniacal nitrogen through the filters was most probably due to a net increase in the filter biomass; the ammoniacal nitrogen being required for the synthesis of cellular tissues. This period of ammoniacal nitrogen consumption within the filters also coincided with the decline in the sludge production per gram of BOD removed, which again is likely to be due to cellular construction within the filters. Both these phases end in March 1976, after which the ammoniacal nitrogen in the filter effluents exceeded that being applied to the filters. This situation may be normally expected in filters executing carbonaceous oxidation; deamination occurs as a result of organic matter destruction.

The other noticeable feature concerning the ammoniacal nitrogen concentrations was their low values. In domestic sewage it would be reasonable to expect the concentration to be in the range 25 to 40 mg/l as nitrogen. This low concentration of ammoniacal nitrogen present in the sewage was probably due to the high proportion of carbonaceous trade waste in the crude sewage, which had a very limited

ammoniacal concentration.

Close examination of the means and values of the least significant differences in table 7.8 show that the Biopac 50 filters had the lowest concentrations of suspended solids in their unsettled effluents. The value was significantly lower than the means for the two types of Flocor media. All the mineral media filters tended to fall midway between these extremes with no significant differences between their means. A similar trend can be seen for the suspended solids concentrations of the settled effluents, where again the Biopac 50 media had significantly the lowest solids content. An interesting feature of these results was the poor quality of the natural media effluents which in several cases were significantly worse than all the plastic media effluents. Also, whilst not statistically significant, it can be seen that the smaller grades of the mineral media tended to have better quality effluents than the larger grades. The significance of the differences in the suspended solids of the settled effluents data was unfortunately marred by the significant variation of the duplicate filters.

The pattern shown by the mean suspended solids of the settled effluents was similarly reflected in the COD and the BOD data for the period. Considering the COD data, the variation between the duplicates was just significant hence slightly detracting from the value of the differences between the various media. However, the pattern shown by the suspended solids of the settled effluents was amplified in the case of the effluent CODs. The Biopac 50 filters had significantly the lowest COD concentration in their effluents, being 23.3 mg/l lower than the concentration in the Biopac 90 effluents. The Biopac 90 effluents were themselves significantly weaker than any

other of the six remaining types of media effluents. The two types of Flocor effluents were remarkably similar (as also occurred with the suspended solids contents) and were significantly weaker than the mineral media effluents. Considering the COD concentrations of the mineral media effluents it can be seen that these fell into two significantly different groups. The small 89/50 mm media (both granite and slag) had significantly weaker effluents than the large 125/75 mm grades, although they were significantly worse than any of the pastic media effluents. Overall, therefore, the worst mineral media effluent (125/75 mm granite) was 45% stronger in terms of the COD concentration.

Turning to the BOD results for this period, a similar pattern was shown in table 7.8; the Biopac 50 effluent being significantly lower than the remaining six types of effluent. However, the differences between the remaining six types of media were not so significant as was the case for the COD concentrations. There was slightly greater difference between the two types of Flocor media, but it is not statistically significant. The four types of mineral media showed limited differences which in some cases were just statistically significant. It can be seen that the overall trend for the BOD concentrations of the effluents was similar to that observed for the COD concentrations.

Turning to the sludge production data in table 7.8, it can be seen that the pattern exhibited by the suspended solids concentrations of the unsettled filter effluents had been slightly altered. The BOD removals of each media type also had a significant effect upon the order of performances. The result was a compression of the overall variations exhibited. Biopac 50 produced significantly less sludge

per gram of BOD removed than any of the other media types (apart from Biopac 90). Biopac 90 produced the second least amount of sludge, being significantly less than four other types of media. The two Flocor media produced slightly more sludge than the mineral media filters per gram of BOD removed, but the differences were not significant.

Overall, it may be said that under the temperatures and loading conditions prevailing during this period, the Biopac 50 produced the least solids in the effluent and gave the greatest COD and BOD removals. The four mineral media gave the worst quality effluents; the larger grades of slag and granite giving particularly poor BOD and COD removals.

Comparing the performances of the filters during this period to those achieved during period 1, it should be noted that the BOD strength of the sewage was approximately 15% stronger but that the flows to the filters were slightly lower during the third period, with the overall result that the gravimetric loadings were greater (see table 7.9). Comparing tables 7.3 and 7.8, it can be seen that the average temperature of the filters was approximately 3°C higher, the percentage COD and BOD removals greater, the solids concentrations of the effluents higher and that the sludge production rates were lower during the third period. At first sight, it may appear strange that the sludge production rates were lower during the third period when the concentrations of solids in the effluents were greater. However, the weight of BOD removed and the nature of the solids in the effluents should be considered.

Table 7.9: Comparison of Gravimetric Loadings to the Filters during Periods 1 and 3

	Period 1	Period 3
Tank A	0.893	0.971
*Tank B	1.588	1.804

Loading in kg BOD/m^3/d

*Loading to Flocor M filters 11% higher.

The performances of the various filters in the two periods suggest that the filters were more mature during the third period of study. In the initial period, the BOD removal was lower due to the immature state of the filters. The filter effluents contained less solids than during the third period as a result of this immaturity. In the first period, the filters were developing a biological film and few macrograzers were present. During the first period, the filter film would be fairly thin and in a young healthy state. In the third period a more stable macrograzing population was established leading to removal of portions of the filter films. Also in the third period, regions of the filter films may have been in poor condition due to the lysis of the film, leading to greater solids concentrations in the effluents.

Considering the performances of the individual filters, from tables 7.3 and 7.8, it can be seen that in the initial period the relative performances of the various media were not clearly defined. Overall, Biopac 50 filters tended to produce the least solids in the unsettled effluents and provided a good COD removal; however, considering the settled effluents, the 89/50 mm slag tended to have a lower suspended solids concentration than the Biopac 50 filters and the BOD removal was greatest in the 89/50 mm slag filters. Considering the sludge production rate during the first period, the

Biopac 50 filters produced the least, with the 125/75 mm granite filters producing the most.

By period three, the overall pattern of filter performances tended to be more clearly defined with the Biopac 50 filters giving the lowest solids production, best BOD and COD removals and the lowest sludge production rate. Of the mineral media filters, the gradings seemed to be of significance; the larger grades of slag and granite producing worse effluents and removal performances than the small grades. The two Flocor media, whilst not performing as well as the Biopac media, tended to give slightly better COD and BOD removals than the natural media. Although the relative performances of the different media during period three were more clearly defined than during the first period, it should be noted that the variation in the performances of the duplicate filters was of greater significance.

Figure 7.12 Weekly Averaged Daily Temperature Maxima and Minima.

(29/1/76 - 29/7/76)

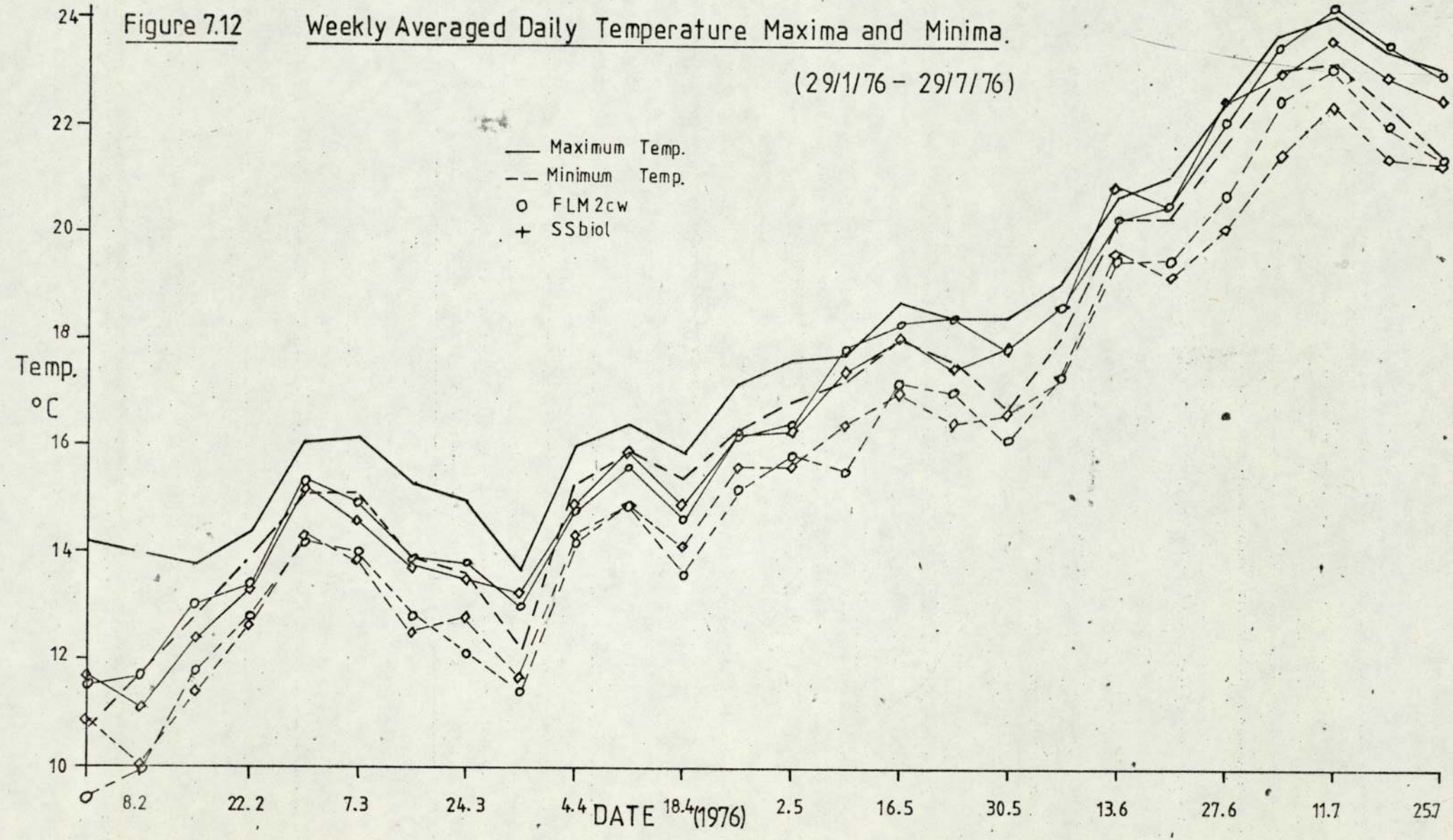


Figure 7.13 Settled Sewage and Mean Filter Effluent BOD Concentration.

(mineral media) (29/1/76 - 29/7/76)

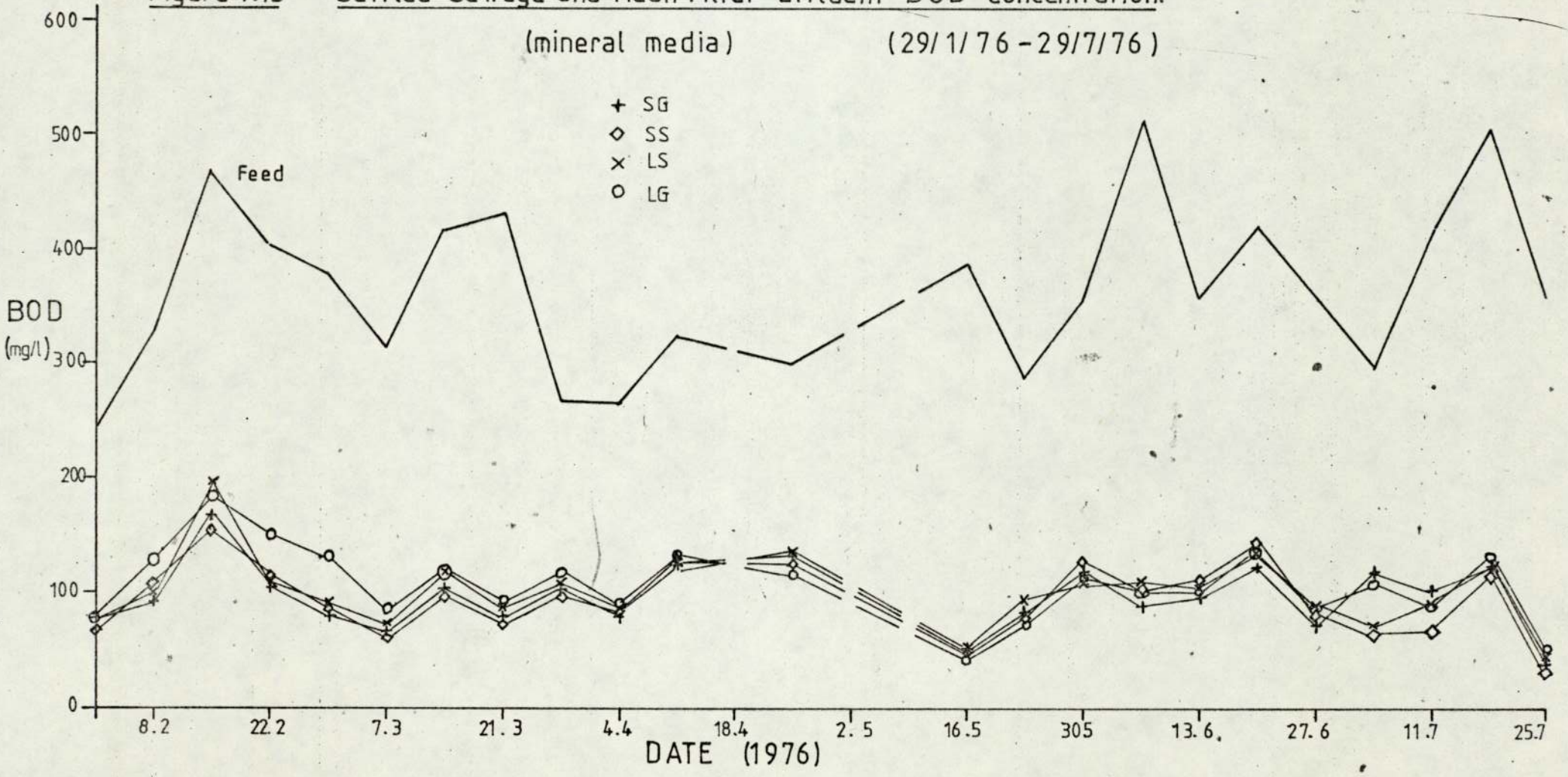


Figure 7.14 Settled Sewage and Mean Filter Effluent BOD Concentration.

(plastic media) (29/1/76 – 29/7/76)

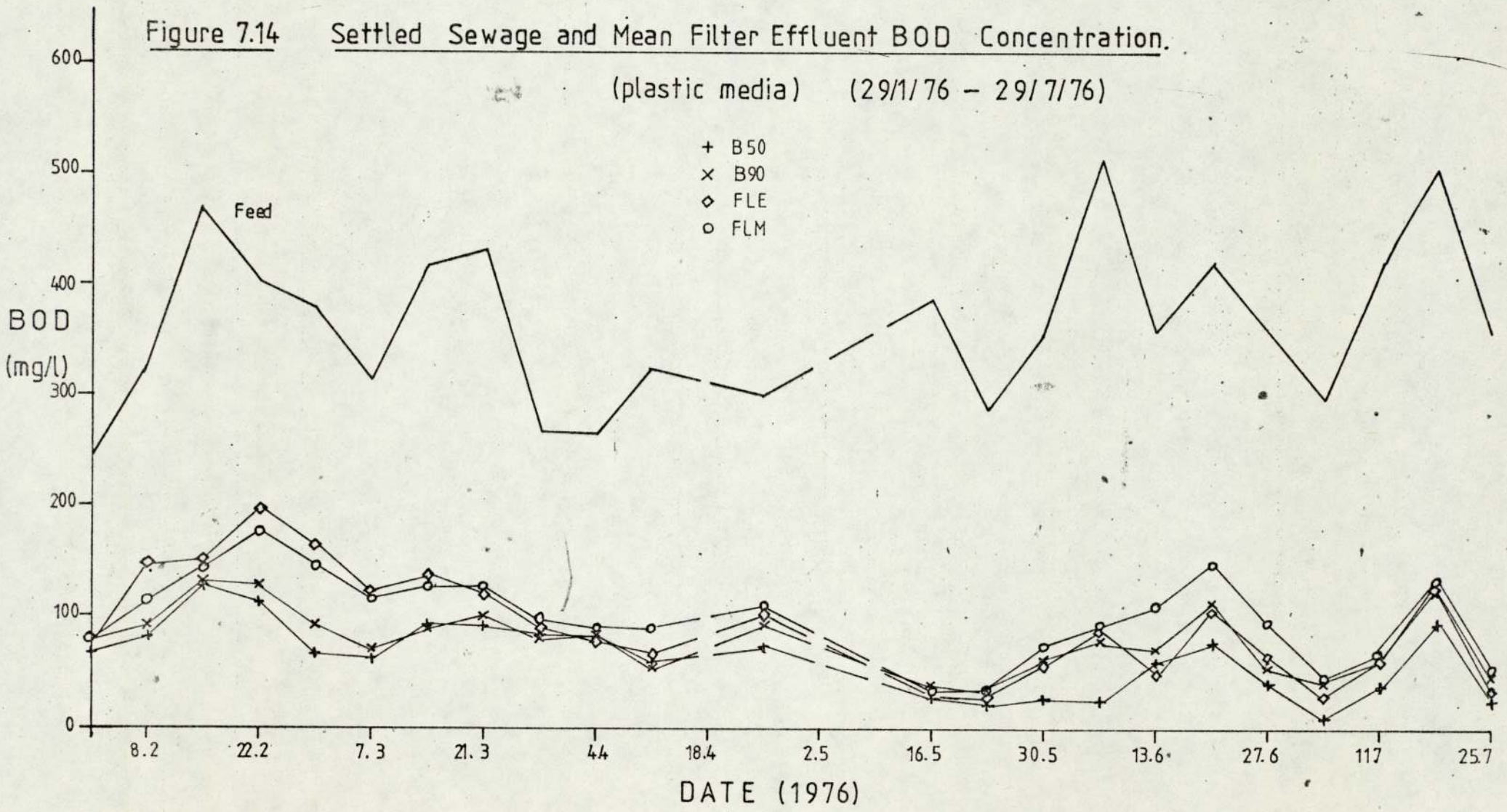


Figure 7.15 Percentage BOD Removal of the Duplicate Mineral Filters.

(29/1/76 – 29/7/76)

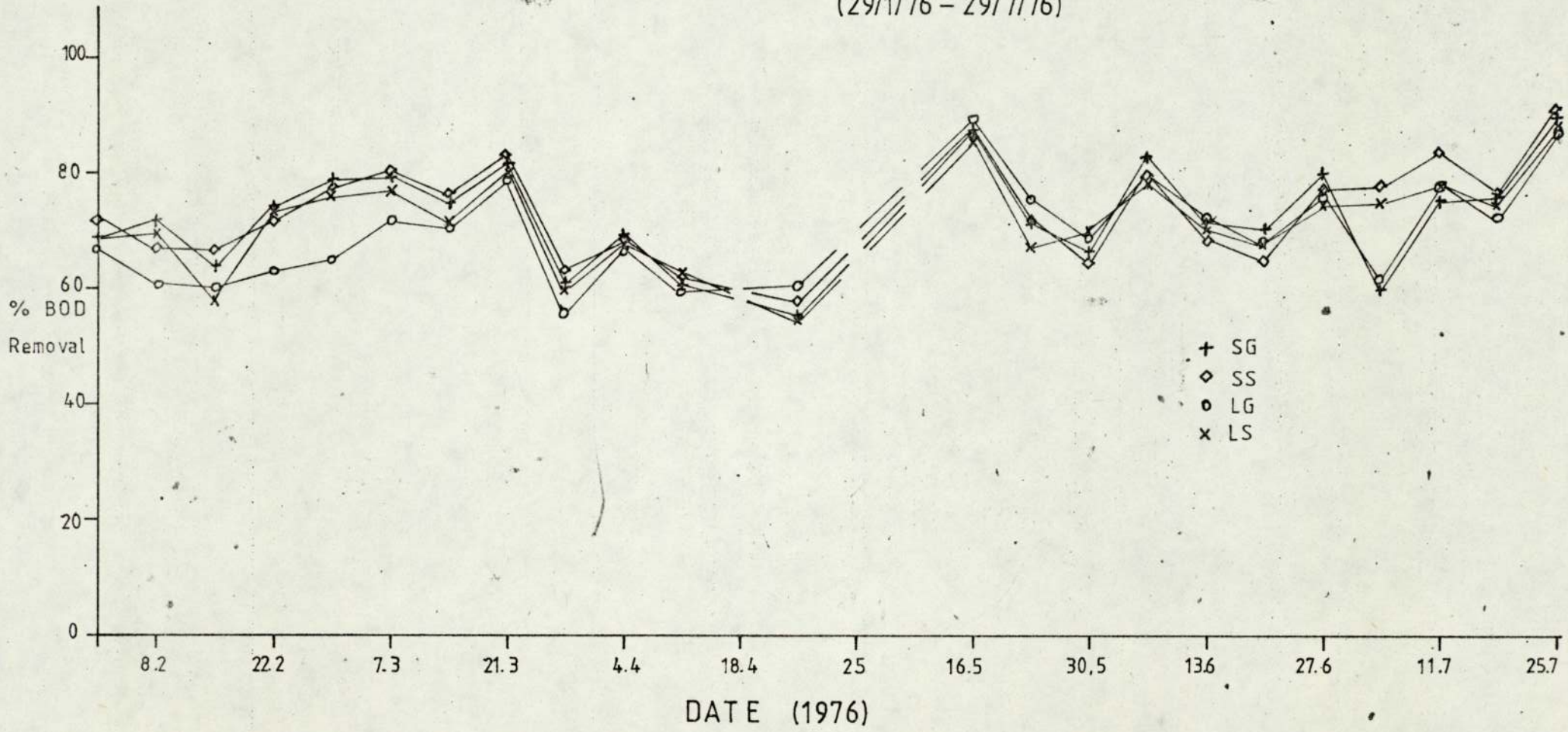


Figure 7.16 Percentage BOD Removal of the Duplicate Plastic Filters.

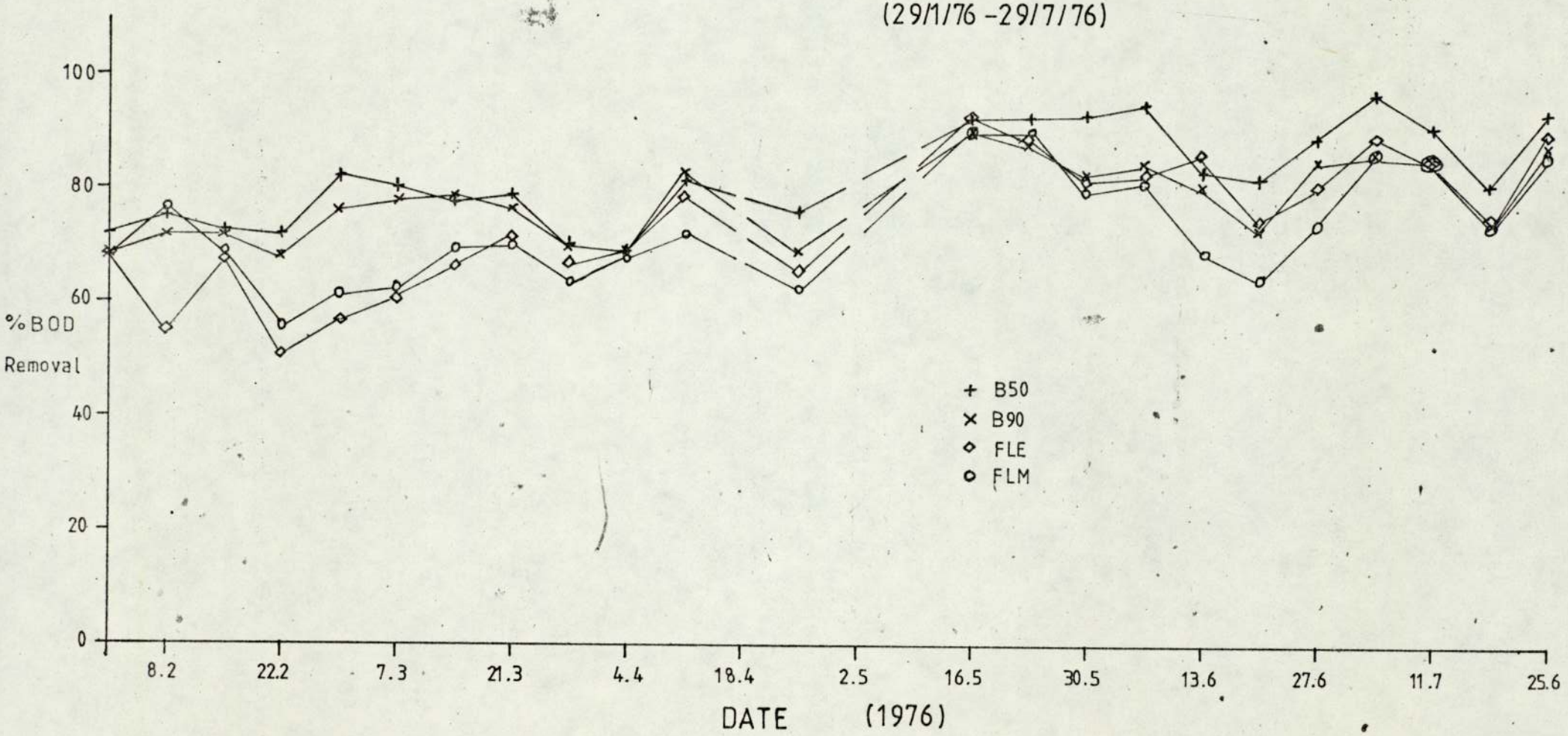


Figure 7.17 Sludge Production/BOD Removal Ratio for mineral Filters.

(29/1/76 – 29/7/76).

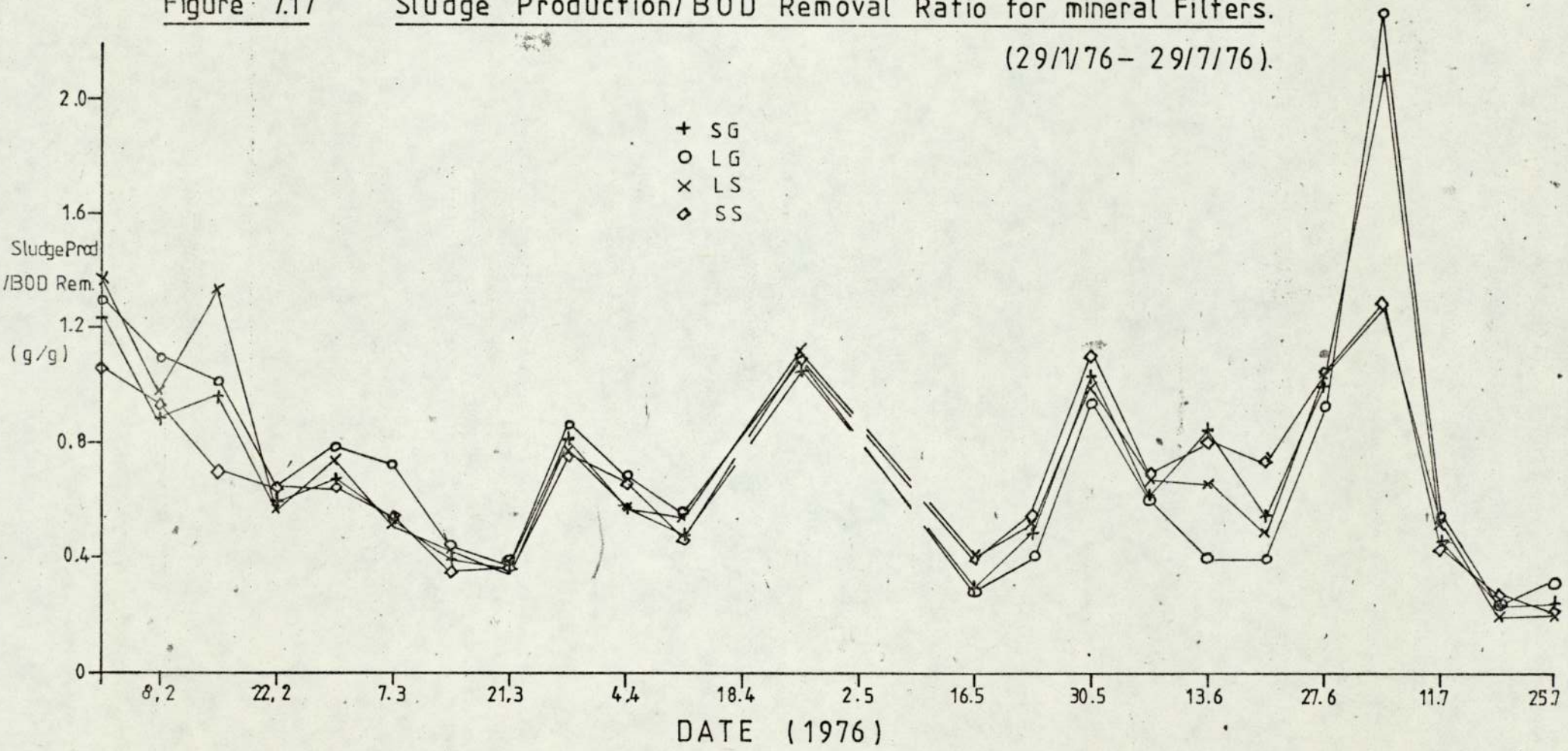


Figure 7.18 Sludge Production/BOD Removal Ratio for Plastic Filters.

(29/1/76 – 29/7/76)

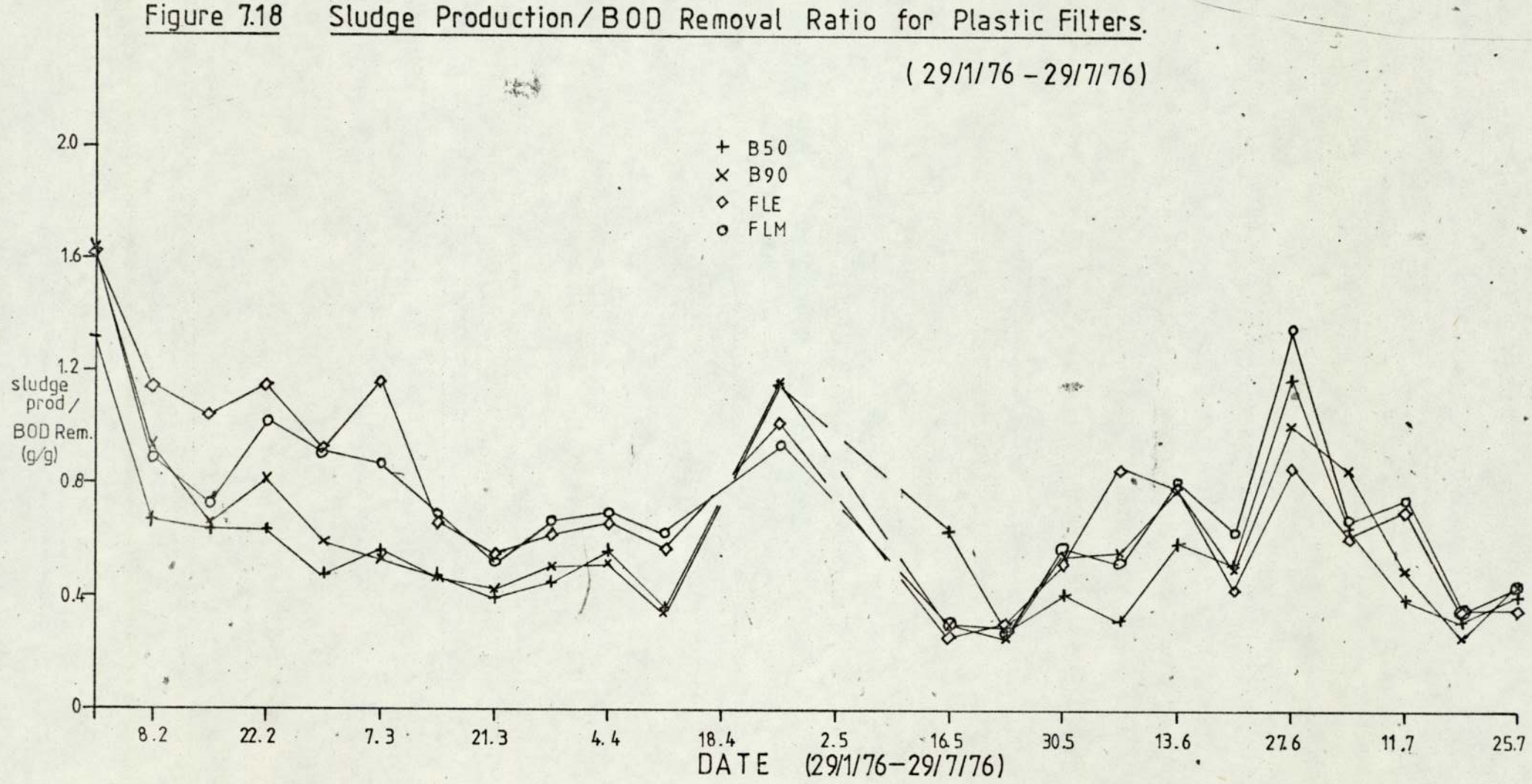


Figure 7.19 Duplicate Mineral Filter Suspended Solids. (Settled Effluents.)

(29/1/76 – 29/7/76)

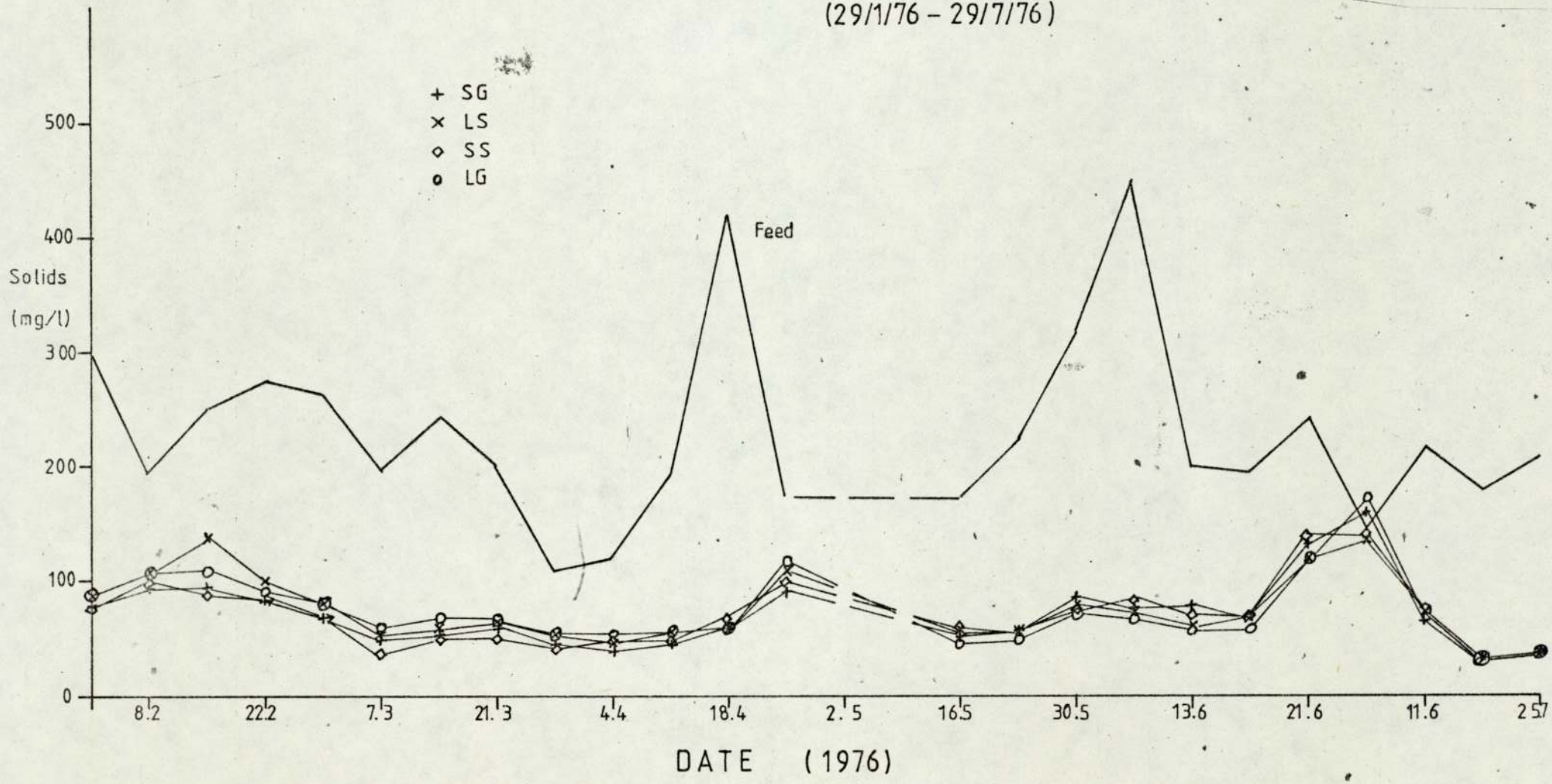


Figure 7.20 Duplicate Plastic Filters Suspended Solids (Settled Effluents)

(29/1/76 – 29/7/76)

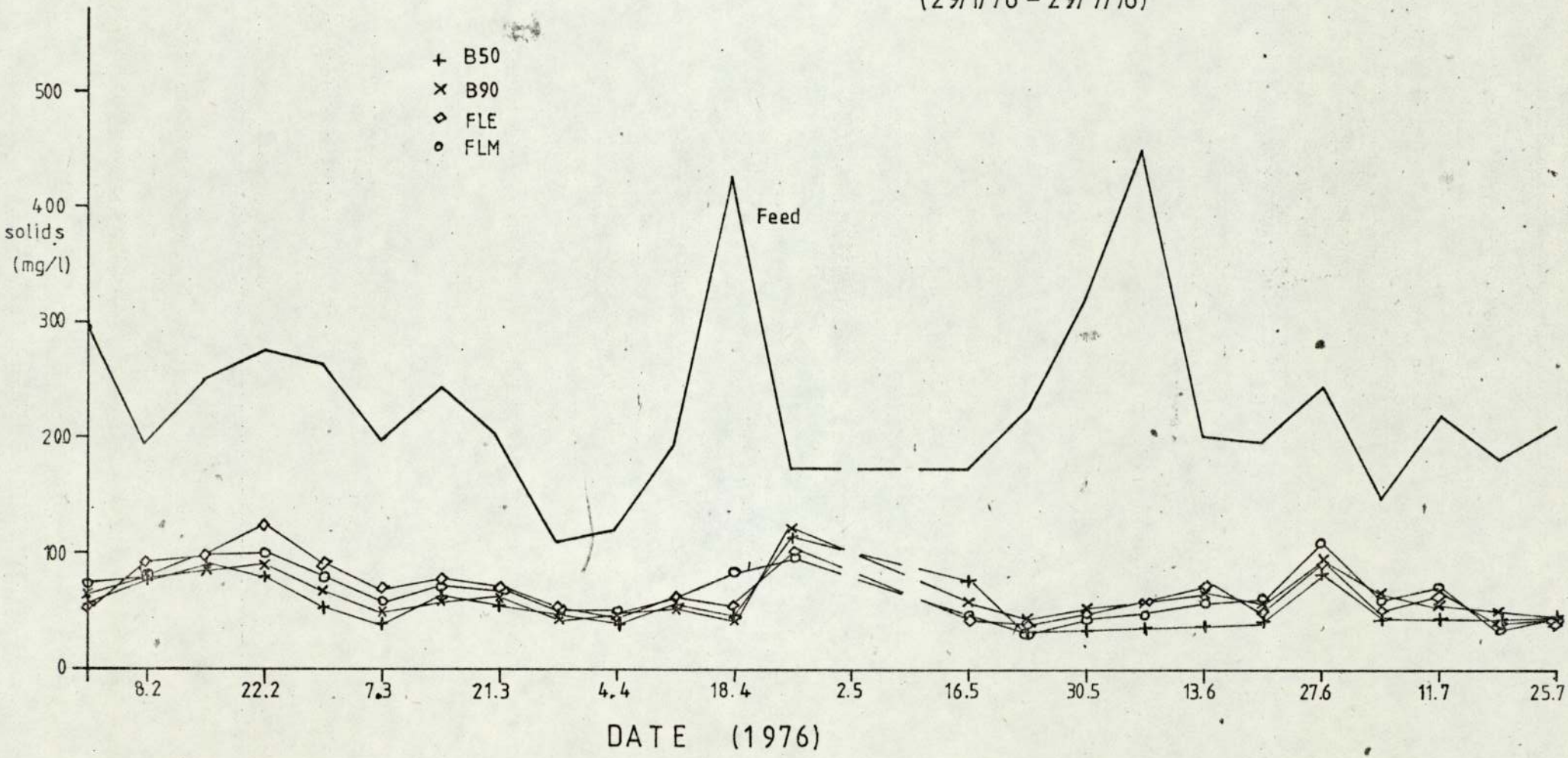


Figure 7.21 Duplicate Mineral Filter Effluent CODs (29/1/76 – 29/7/76)

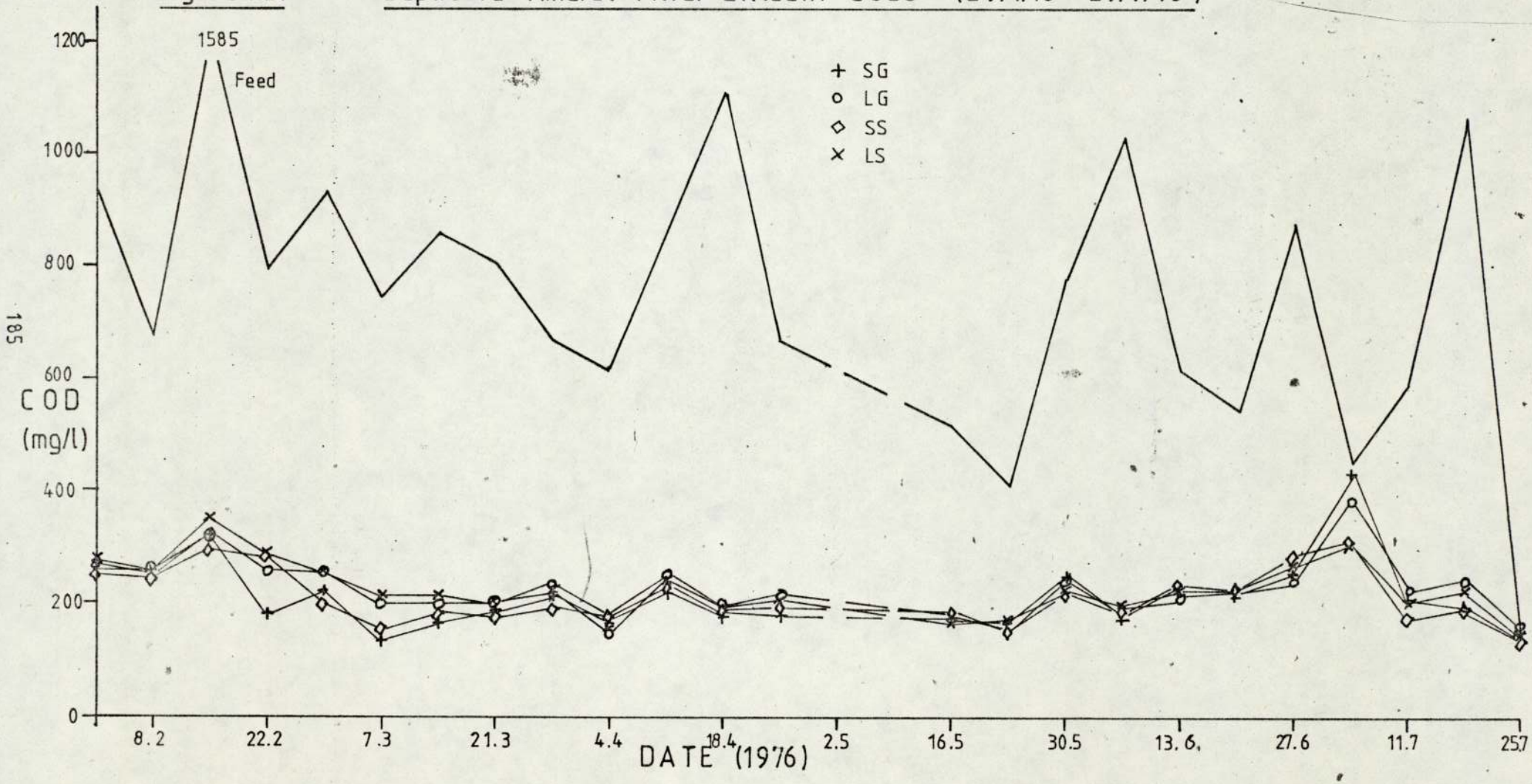


Figure 7.22 Duplicate Plastic Filter Effluent CODs (29/1/76- 29/7/76).

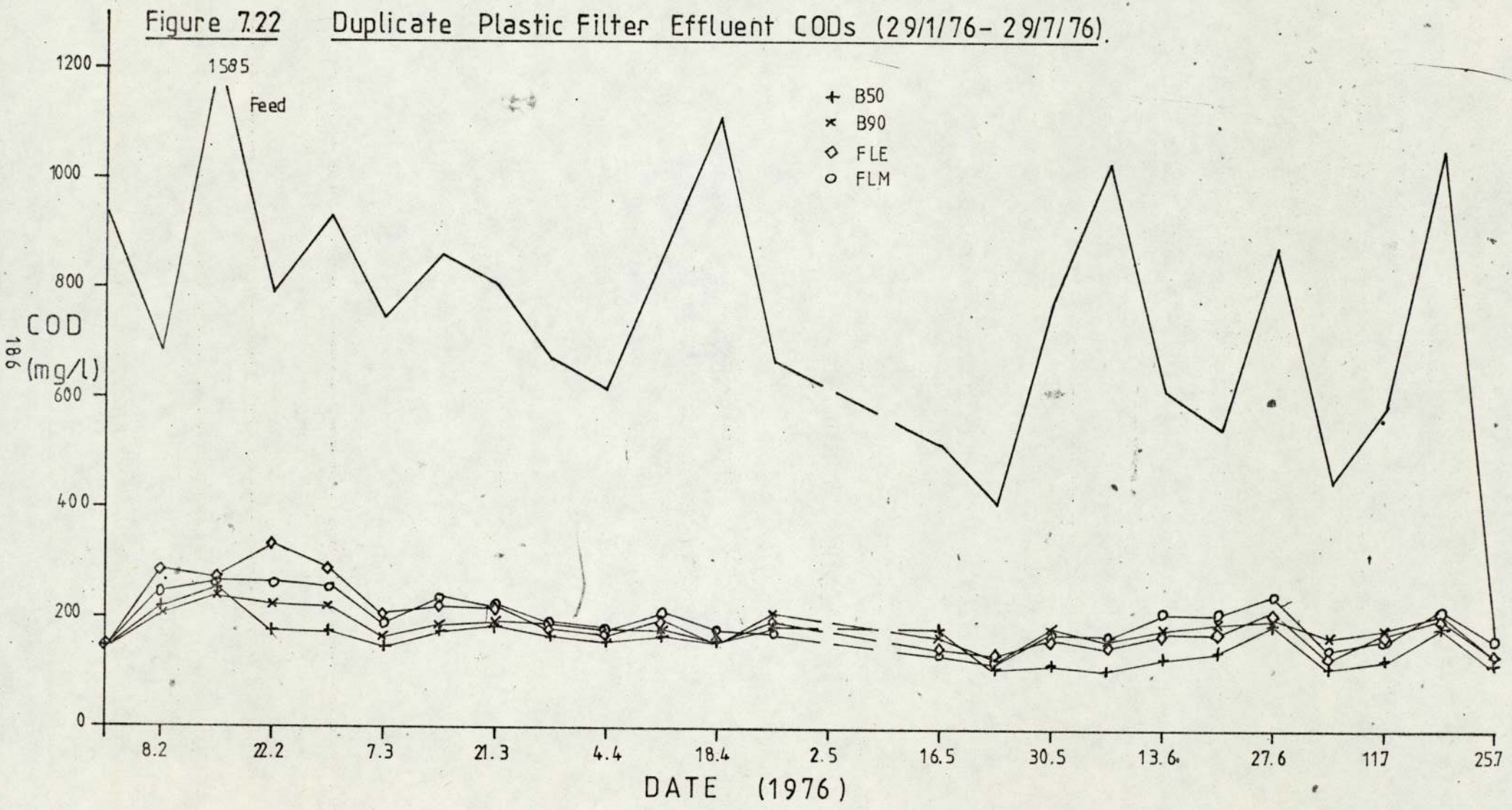


Figure 7.23 Duplicate Mineral Filter Effluent Ammonia Contents.

(29/1/76 - 29/7/76)

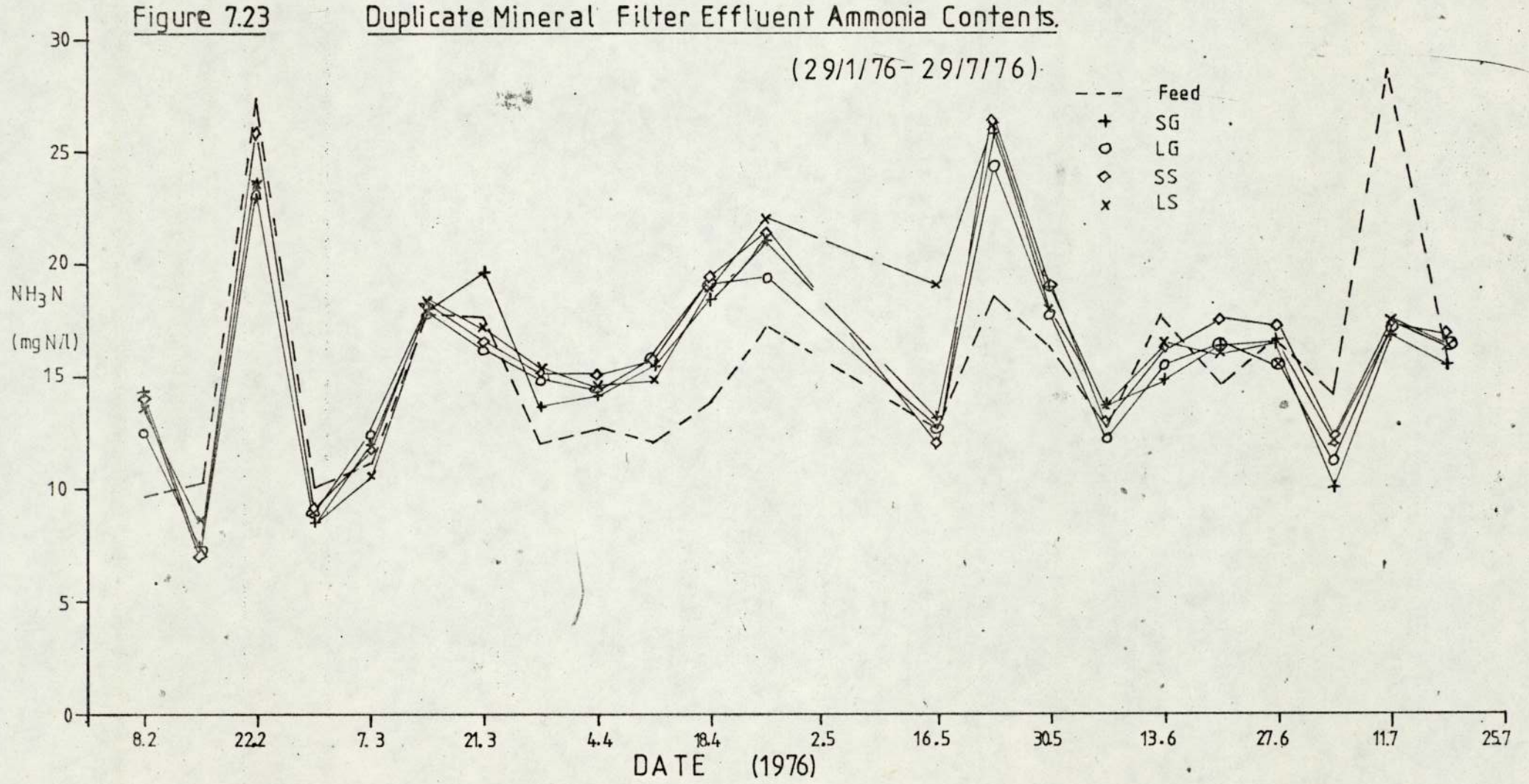
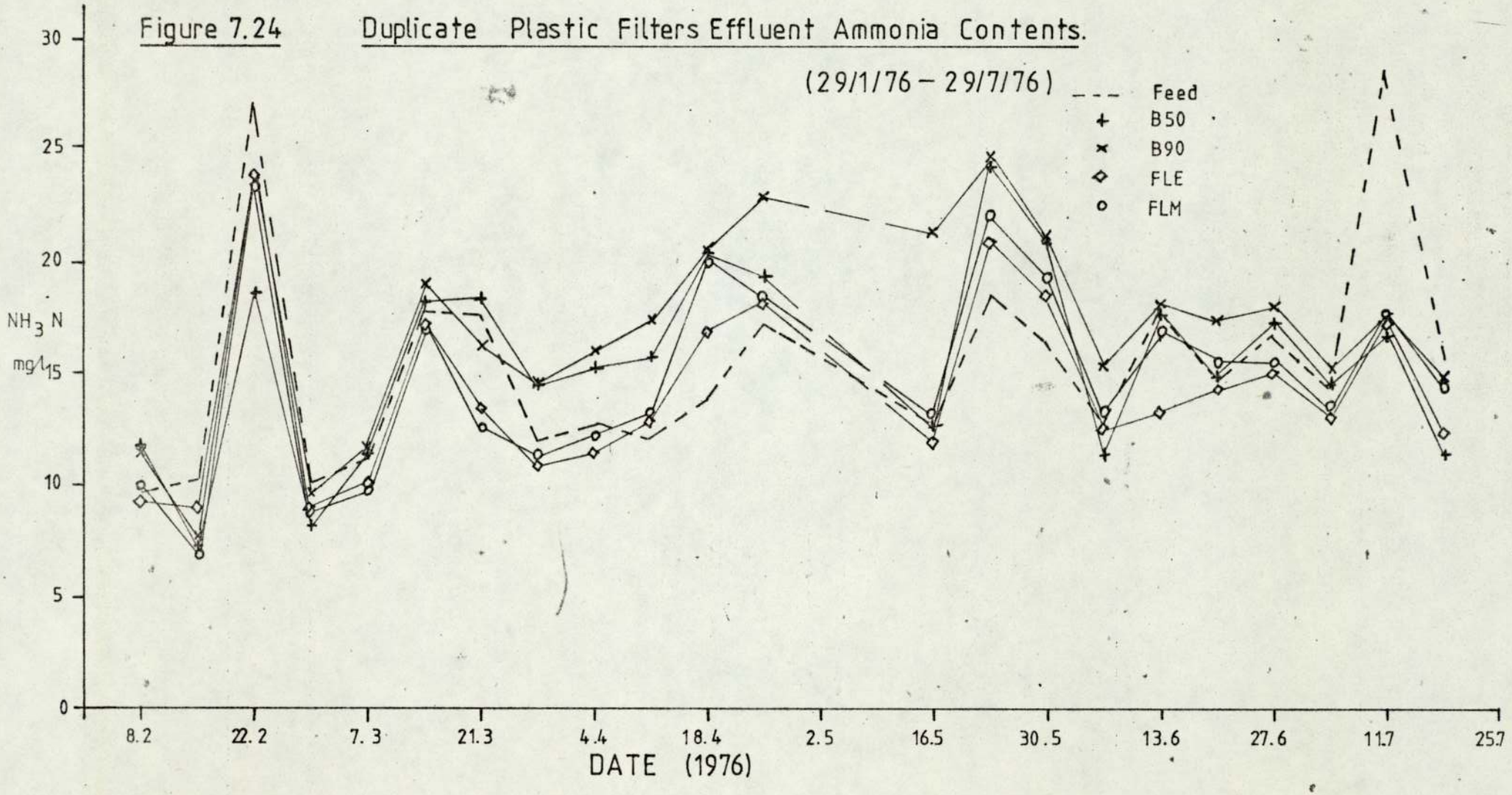


Figure 7.24 Duplicate Plastic Filters Effluent Ammonia Contents.



E. Period 4: 29 July 1976 to 17 July 1977

On 29/7/76, a new source of settled sewage for the pilot plant was obtained from the main works. The new primary settlement tanks on the Eign site had recently been commissioned; the Mono pump which until now had been pumping settled effluent from the two converted cold digestion tanks to the pilot plant header tank was moved to a position from which it could draw primary settled effluent from an outlet chamber from one of the new primary tanks.

I. Results

i) Flow Results:-

From appendix 7.E.1, it can be seen that this source of settled sewage permitted a fairly constant flow on to the filter beds; blockages due to gross solids not being experienced during this period. The presence of only one tipping trough flow record per tank of filters between 14/11/76 and 17/4/77 was due to the removal of two troughs from the site for servicing.

During late February and March 1977, there were several breaks in the sewage supply to the pilot plant for two related reasons. On the fourth of March overnight for fifteen hours, the pump had to be stopped to permit repair to the delivery pipework. Between 19/3/77 and 21/3/77 the electricity supply was cut off for approximately 48 hours. There were further short cuts in the power supply during March which reduced the average flow to the filter beds. In April 1977, between the ninth and the eighteenth, the sewage flow was halted due to damage to the Mono pump sustained as a result of ineffective mounting brackets. The flow was also cut between the fifth and the ninth of June, 1977 due to defective pipework in the main works primary settlement tank from which the pilot plant was supplied.

ii) Temperature Results:-

From Appendix 7.E.2, it can be seen that the maximum and minimum feed temperatures during the seven weeks in February, March and April 1977 were not recorded. The reason for the absence of this data was that the sewage feed temperature probe during this period was frequently exposed to the atmosphere as a result of power cuts, pump breakdowns and pipework problems mentioned in the section detailing the flow results.

From appendix 7.E.3, it can be seen that the weekly meaned filter temperatures at mid-day were not available for five weeks early in 1977. No comparative temperatures were taken during the week ending 2/1/77 due to staff vacations. Other weeks of missing data were as a result of additional analytical workload due to biological sampling of the filters' films. This analysis was protracted as a result of staff illness and difficulties with maintaining the supply of settled sewage.

iii) Routine Analytical Results:-

From appendices 7.E.4 to 7.E.9, it can be seen that there were many occasions where averaged analytical data were not available. Considering the BOD data, no results were available for the 8/8/76 due to staffing difficulties; no results were available for 24/10/76 due to biological sampling; no results were available for the fortnight 26/12/76 to 2/1/77 due to staff vacations; no data was available for February due to protracted biological sampling, no samples were collected for the week ending 10/4/77 due to Easter vacations, and also none the following week because of a pump breakdown mentioned in the flow section. Finally, no data was collected for the two weeks ending 15/5/77 and 22/5/77 due to the additional workload imposed as a result of biological sampling.

No comparative data was available for the CODs or suspended solids of the effluents for the weeks previously mentioned for the reasons explained above.

COD and suspended solids data was not available for the week ending 12/6/77 as a result of inadequate and irregular sewage supplies and the additional time lost in trying to maintain a flow to the filter beds.

From appendix 7.E.8, it can be seen that the ammoniacal nitrogen data not presented was due to the omission of sampling for the reasons previously mentioned. It can be seen that in the case of the total oxidised nitrogen results (appendix 7.E.9) analysis was frequently omitted. These omissions were in the most part deliberate, since the value of frequent total oxidised nitrogen results was limited.

II. Period 4: Discussion of the Physico Chemical Data for Period 4

At the end of July 1976, settled sewage was withdrawn from the outlet chamber of the main works primary settlement tank for the pilot plant using the existing Mono pump, now resited. Observation of appendix 7.E.1 shows that the mean flow rate of 2.74 $m^3/m^3/d$ to the mineral media filters was very close to the nominal rate of 2.8 $m^3/m^3/d$. However, the desired flow value for the plastic media filters of 5.6 $m^3/m^3/d$ was not achieved; there was an average shortfall of 12%. As previously mentioned, under the existing pilot plant conditions, it was only just possible to attain the nominal rate. Any minor blockage of the distributor arms or reduction in the level of the sewage in the header tank resulted in a marked decrease in the volume of sewage applied to the filters.

Apart from late February, March and early April 1977, the flows to the filters were quite stable (the flow variations occurring in early 1977 being explained in the results section). The ratio of sewage applied to the plastic filters to that applied to the mineral media filters at 1.8 was close to the desired ratio of 2.0, although not quite so close as the 1.85 value achieved during period three.

Considering the temperature data, from figure 7.25, it can be seen that during this 51 week period the sewage temperatures ranged from approximately 22°C in the summer of 1976 down to about 12°C in January and February 1977 and then rose to approximately 18°C again in the summer of 1977. From figure 7.25, it can be seen that the daily maximum and minimum temperatures recorded for the sewage differed by just greater than 1.0°C quite consistently throughout the period, with an indication that the daily fluctuation was reduced in the summer months. The maximum temperature of the plastic media filter (FLM 2cw) was for most of the period fractionally higher than that of the mineral media; however during May 1977 the mineral media filter temperature (SS biol) tended to increase more rapidly than that of the Flocor M filter and became frequently the warmer filter during June and July 1977.

Turning to consider the statistical analysis of the maximum and minimum temperatures, from the following two tables 7.10 and 7.11, it can be seen that all the temperatures differed significantly; the feed maximum and minimum temperatures being greatest.

Table 7.10: Mean, Max. & Min. Temperatures and L.S.D.s for the Period 29/7/76 - 17/7/77

	Feed	FLM 2cw	SS biol	L.S.D.
Maximum	16.977	16.309	16.116	0.125
Minimum	15.835	14.791	14.577	0.171

(Temperatures in ^{o}C)

Table 7.11: Standard Deviations & Fluctuations of the Max. & Min. Temperatures (29/7/76 - 17/7/77)

	Max.	S.D.	Min.	S.D.	Fluct.^{n}	S.D.
Feed	16.977	3.405	15.835	3.412	1.140	0.299
FLM 2cw	16.309	3.674	14.791	3.596	1.519	0.516
SS biol	16.116	3.735	14.577	3.605	1.516	0.502

(Temperatures in ^{o}C)

The difference between the feed temperature and either filter temperature was greater than that between the two filters. The plastic media (FLM 2cw) was significantly warmer than SS biol in terms of both the maximum and minimum temperatures. Considering table 7.11, the mean fluctuations recorded for the sewage temperatures were less than those for the two filters and also had the smallest deviation; the standard deviations of the sewage maximum and minimum temperatures were also less than for either filter. It is interesting to note that there was remarkably little difference between the standard deviations of the two filters, yet the differences in the mean, maximum and minimum temperatures are significant.

During the summer of period 3, the maximum temperatures of the two filters frequently exceeded that of the applied sewage (the possible reasons being explained in the discussion of that period). Apart

Table 7.12 Analysis of Variance of Physico Chemical Data from the Hereford High Rate Filters(Period 4,29/7/76-17/7/77)

	LG	SG	LS	SS	B50	B90	FLE	FLM	L.S.D.
Midday Temp. (°C)	14.938	15.139	15.093	15.281	15.389	14.970	14.687	15.342	(R) 0.077 (M) 0.219 (T) 0.367
Nominal Flow ($m^3/m^3/d$)	2.8	2.8	2.8	2.8	5.6	5.6	5.6	6.2	-
Actual Flows ($m^3/m^3/d$)	2.74	2.74	2.74	2.74	4.92	4.92	4.92	5.48	-
BOD Applied (mg/l)	352.3	352.3	352.3	352.3	352.3	352.3	352.3	352.3	-
BOD Removed (mg/l)	272.929	290.143	288.129	294.671	309.557	299.229	288.686	284.100	(M) 5.313 (T) 11.112
Effluent BOD (mg/l)	84.833	67.069	69.639	64.194	48.667	59.069	69.986	74.653	(M) 5.334 (T) 11.314
Percent BOD Removed.	75.9	81.0	80.2	81.8	86.2	83.2	80.1	78.8	-
Sludge Production (g/g BOD removed)	0.606	0.575	0.612	0.564	0.530	0.541	0.607	0.625	(R) 0.097 (M) 0.046

Table 7.12(cont) A of V of Physico Chemical Data from Hereford High Rate Filters (period 4, 29/7/76 - 17/7/77).

	LG	SG	LS	SS	B50	B90	FLE	FLM	L.S.D.
Unsettled Effluent SS (mg/l)	164.78	158.92	170.32	162.08	153.64	153.13	173.97	171.83	(M) 11.22 (T) 24.78
Settled Effluent SS (mg/l)	65.92	60.17	62.67	58.67	50.49	57.40	59.27	59.35	(R) 1.88 (M) 3.76 (T) 8.30
COD Applied (mg/l)	436.02	436.02	436.02	436.02	436.02	436.02	436.02	436.02	-
COD Effluent (mg/l)	171.59	152.18	155.03	145.71	127.99	140.79	143.47	144.13	(R) 2.61 (M) 5.21 (T) 11.51
COD Removed (mg/l)	264.44	283.85	281.00	290.32	308.04	295.18	292.55	291.90	(R) 2.12 (M) 6.01 (T) 13.27
Percent COD Removed.	60.6	65.1	64.4	66.6	70.6	67.7	67.1	66.9	-

from the first month's data (August 1976), the sewage temperature was greater than that of either filter. In September 1976, the ambient air temperature dropped dramatically and there was an end to the period of drought. Both these changes in weather would affect the temperature of the sewage and the rate of heat loss from the filters to the atmosphere. From the analysis of variance table 7.12, it can be seen that the comparative temperatures varied significantly in time, between the duplicate filters, and due to the nature of the media. The statistical analysis shows that the FLE 2cw filter was significantly cooler than any other filter and that the B90 biol filter was significantly cooler than any other filter in tank B apart from FLE 2cw. In the case of tank A filters, the SS filter was significantly warmer than the other filters; however, it was not significantly warmer than three of the plastic media filters.

Considering replication, it can be seen that in all cases there was a significant variation in the temperature means, which indicated that something other than the type of media had an important effect upon the filter temperature. As previously mentioned, the degree of solar radiation received appeared to have some effect. However, it is curious to note that the sector exhibiting the lowest temperature in each bed was adjacent to the sector exhibiting the highest temperature. This is particularly noteworthy in the case of the FLE 1 cw and FLE 2cw sectors which were constructed of the same media and were in fact two halves of the same filter. Observation of table 7.12 shows that when the media temperatures are considered, FLE 1cw and FLE 2cw showed the lowest mean temperature, being significantly lower than any other temperature mean calculated. The Flocor E media has highly regular large voids which were less

frequently blocked than the voids of any other media. However, it should be recalled than when observing the effects of replication, FLE 1cw and FLE 2cw were not only significantly different, but FLE 1cw also exhibited the highest mean temperature in tank B; therefore the nature of the media may only partially explain the low temperature shown in the table.

Comparing the temperatures recorded during this period to those collected during periods 1 and 3, it can be seen that the variations between the maximum and minimum daily temperatures were greater than those during the third period but less than those of the first period. The standard deviations of the maximum and minimum temperatures and the temperature fluctuations were similar in periods three and four, but in contrast to period 3, the maximum and minimum temperatures of the 89/50 slag were significantly lower.

From the comparative mid-day filter temperatures for the three periods, a confused picture emerges. In the first period the location of the filters and the effects of solar radiation appeared to be highly significant. In the third period the effects of solar radiation were minimized, and also the rate of heat loss to the surrounding structures and atmosphere due to the high ambient temperatures were minimal with the result that the temperature differences were not outstanding. However, in the fourth period, for the bulk of which the ambient temperature was lower than that of the sewage temperature, the comparative temperature results were confusing; in both tanks of filters, the filter exhibiting the highest temperature was adjacent to the filter exhibiting the lowest temperature. In the case of the plastic media filters, the filters with the highest and lowest temperatures were halves of the same filter of Flocor E.

In the fourth period, which covered almost twelve months of operation, the apparently conflicting results could be due to different factors affecting the relative filter temperatures at different times of the year. The compilation of all the data into one block could then give rise to this curious artefact.

Considering the analytical data for the fourth period, from table 7.12, it can be seen that the variation in the quality of the settled sewage applied to the filters caused significant variations in the filter effluents. Observations of figures 7.26 to 7.37 show that these time variations were in the most part random, with one or two individual short term trends. Examining the suspended solids concentrations of the sewage and the settled effluents shown in figures 7.32 and 7.33, the wide variation in the sewage suspended solids can be seen to be largely reflected in the quality of the effluents, although the variations were diminished in intensity. There were two pronounced peaks in the suspended solids concentrations in the sewage, on 12/9/76 and 24/4/77. There was no obvious reason for the high value for the week ending 12/9/76; it was not accompanied by any increase in the COD or BOD concentrations of the settled sewage. From figures 7.26, 7.32 and 7.34, it can be seen that in late August and September 1976 the quality of the settled sewage was unstable, with uncorrelated peaks in the suspended solids, BOD and COD.

Considering the suspended solids contents of the settled filter effluents shown in figures 7.32 and 7.33, it can be seen that two high peaks of concentration occurred in late February, early March 1977 and also in late March. These peaks were of similar intensity to the supply quality variations. There are three possible explanations for the high effluent concentrations, of which only one

could account for the high settled sewage solids. Between March and May 1977, the rainfall was particularly low so that an absence of infiltration and/or surface water might reduce the normal dilution obtained, increasing the solids content. Although, in periods of low flow, the retention time of the primary tanks can be increased, resulting in a better quality of settled sewage. The second possible explanation for the high suspended solids concentration of the settled filter effluents is the effects of supply cuts to the filters. The settled sewage flow was disconnected between 19 - 21/3/77 and also between 9 - 18/4/77 due to the damage to pipework and the Mono pump; after each break in the supply, on resumption of normal operation, the filter effluents' solids concentrations rose, probably due to removal of lysed material from the filters and the inability of the filters to convert the colloidal solids in the sewage to larger more readily settleable solids. The third possible reason for the high concentration of effluent solids is the biological condition of the filter film. After an accummulation of film during the winter, as a result of reduced grazing activity, as the temperature increases in the spring so do the populations of the macrograzers leading to a heavy unloading of the filter film. In this particular case it was certainly noticeable that the thickness of the film on the surface of the various filters declined at this time.

Whilst the solids content of the settled effluent certainly did peak at these two occasions, comparing the values of the solids concentrations with those occurring at other times, it can be seen that the peaks were not highly abnormal, therefore it is possibly coincidence that the settled sewage contained high suspended solids concentrations at a time when the effluents were so poor. This then begs the question of whether the disturbed flows caused the solids

losses or whether the filters were naturally unloading.

Turning to the BOD concentrations of the settled sewage and the filter effluents shown in figures 7.26 and 7.27, it can be seen that there was a wide variation in the settled sewage BOD concentration which tended to be reflected in the effluents. Comparing figures 7.26 and 7.27 to figures 7.28 and 7.29, it can be seen that the percentage BOD removal was inversely proportional to the load applied to the filters. This trend was particularly noticeable in September 1976, when the BOD concentration of the applied sewage markedly declined paralleled by a steady increase in the percentage removal by all the filters. Over the whole period, the average BOD concentration of the settled sewage was 352.3 mg/l (compared to 365.2 mg/l in period 3) and a mean removal of 81% was achieved by the filters providing an effluent BOD concentration of 67.3 mg/l.

The increase in the solids content of the settled sewage in March 1977 was correlated to an increase in the BOD concentration.

From figures 7.30 and 7.31, it can be seen that the weight of sludge produced per gram of BOD removed by each filter varied considerably, oscillating about an overall average of 0.58 g/g of BOD removed. In late February - March 1977 and April 1977 the rate of sludge production increased dramatically (increasing almost sixfold in one particular case).

Examination of figures 7.34 and 7.35 show that the COD concentration of the settled sewage behaved in a similar manner to the suspended solids and the BOD concentrations, with a noticeable peak in concentration in February - March 1977 but oddly not in April 1977; however turning to figure 7.26 it can be seen that the BOD concentration in April 1977 did not peak so dramatically as in February - March 1977.

Overall, for the entire period and all the filters, the COD concentration of the settled sewage was 436 mg/l and a mean effluent concentration of 147.6 mg/l giving a mean percentage removal of 66%. An interesting feature of the settled sewage was the low COD/BOD ratio of 1.25, probably as a consequence of the high proportion of readily biologically oxidizable matter present in the crude sewage due to the nature of the trade effluent discharges to the sewage works.

Figures 7.36 and 7.37, showing the ammoniacal nitrogen concentrations of the settled sewage and filter effluents, indicate that throughout this period deamination of proteinaceous material was occurring. It can also be seen that the variations in the strength of the settled sewage followed the BOD concentrations; most noticeable is the slight increase in the settled sewage ammoniacal nitrogen concentration in February - March 1977, and particularly the strength of the effluents. Overall, the settled sewage contained an average of 9.8 mg/l of ammoniacal nitrogen and the effluents a mean of 13.35 mg/l as ammoniacal nitrogen, therefore resulting in a net deamination of 3.55 mg/l N.

From table 7.12, it can be seen that the suspended solids contents of the different media settled effluents varied considerably and also that there was a significant variation between the duplicate filters. The Biopac 50 filter effluents were significantly lowest in suspended solids, with the three other plastic media having settled effluents of similar suspended solids content. Although not by a significant margin, the 125/75 mm granite filters had the worst effluents. Examining the suspended solids contents of the unsettled effluents, it can be seen that the two types of Biopac clearly had significantly better quality effluents than those of the two Flocor media, whilst

all the mineral media tend to lie some way between these two extremes. Of the mineral media, the two smaller grades tended to have better quality effluents.

Considering the CODs of the effluents, it can be seen from table 7.12 that the Biopac 50 filters had significantly the best quality effluents, with little difference between the three other plastic media. All the mineral media had worse effluents than any of the plastic media filters, with the 125/75 mm granite being significantly the worst. The 89/50 mm slag had significantly the lowest COD concentration of the mineral media. However, for the COD data, there was a significant difference between the duplicate filters which reduced the significance of the media removal performances. The percentage removal of COD ranged from 70.6% for the Biopac 50 filters to as low as 60.6% for the 125/75 mm granite filters.

Comparing the BOD removal performances of the filters as depicted in table 7.12, it can be seen that yet again the Biopac 50 filters removed significantly the greatest BOD concentration whilst the Biopac 90 filters removed more than any other filters. The 125/75 mm granite had significantly the worst BOD removal ability.

Turning to the sludge production rate, it can be seen that a similar pattern emerged to that developed for the other analytical parameters; namely that the small grades of mineral media produced less sludge per gram of BOD removed than the 125/75 mm grades of media, Biopac 50 just produced less sludge than any other media followed by the larger Biopac 90 media. The two types of Flocor media produced similar quantities of sludge per gram of BOD removed to the 125/75 mm grades of mineral media.

Overall, therefore, the Biopac 50 media gave the best quality

effluent during period four (and hence the greatest removal). The small grades of mineral media tended to give better performances than the larger media, which in turn performed to a comparable extent to the two Flocor media.

Comparing the filters' performances in period 4 to the performances in periods 1 and 3, the hydraulic and gravimetric loadings should first be considered. The settled sewage BOD during the fourth period was of a similar strength to the other two periods and also the flows were comparable, to give the gravimetric loadings shown in the table:-

Table 7.13: Comparative Gravimetric Loadings of Filters in Periods 1, 3 and 4

	P1.	P3.	P4.
Tank A Mean	0.870 (0.893)	1.107 (0.971)	1.223 (0.965)
S.D.	0.341	0.226	0.810
*Tank B Mean	1.491 (1.588)	2.030 (1.804)	2.423 (1.733)
S.D.	0.500	0.564	2.518

Loadings in kg. BOD/m^3/d

*Loadings to Flocor M filters 11% higher

Figures in brackets refer to loadings applied during effluent sampling periods only.

From table 7.13, it can be seen that using the loadings calculated from the effluent sampling periods flows and BOD concentrations, a different loading pattern emerged to that indicated from determinations of the flows and strength of the applied sewage at times other than just during effluent sampling.

Considering the BOD removal efficiencies, during period 4 the filters had a slightly higher average of 81% compared to 75% in the third period and 70% during the first period. A similar trend was shown by the COD results. Turning to relative sludge production data, in period 4 the mean production was 0.58 g/g of BOD removed in period 1. Overall, these trends suggest that the filters were still immature, indicated by their increasing removal efficiencies and decreasing rates of sludge production. However, this trend may only be an artefact of the manner in which the removal efficiencies have been expressed. Considering the gravimetric loadings calculated from the effluent sampling period only (data in brackets in table 7.13), then it would appear that the loadings applied to tank A filters in periods 3 and 4 were similar and that the loadings applied to tank B filters declined between periods 3 and 4; however, the loadings calculated using the entire analytical results for the settled sewage and the flows during each sampling period indicate that both the tank A and tank B filters received higher loadings during period 4 than during period 3. Therefore, since the loadings applied to the filters during effluent sampling in the fourth period were considerably lower than the overall load applied, the effluent quality sampled may be expected to be better than that attained overall throughout the period, and also sludge production per gram of BOD removed would be less. Caution should also be exercised when comparing the relative removal efficiencies of the plastic and the mineral media filters, since the variations in applied gravimetric loads differed for both tanks of filters. Of the plastic media, Biopac 50 had the greatest BOD and COD removal, producing the least sludge per weight of BOD removed. Biopac 90 had the next best removal efficiency whilst the two types of Flocor media trailed, having comparable removal efficiencies and

sludge production figures. It should be recalled that Flocor M had an 11% greater hydraulic loading (and consequently gravimetric loading) than Flocor E. In terms of their relative specific surface areas, the removal efficiency per surface area of the media may produce a different order. Considering the mineral media, their removal performances and sludge production appeared to fall between that of the two groups of plastic media. A distinct pattern had also emerged within the mineral media; the small grades giving the greatest removal efficiencies and least sludge production. There were indications that of the two small grades, the 89/50 mm slag produced the best performance; of the larger grade, the 125/75 mm granite tended to give the poorer removal efficiency and the greatest weight of sludge produced per weight of BOD removed.

Appendices 7.F.1, 7.F.2 and 7.F.3 show the BOD loading and removal of the eight media types during periods 1,3 and 4 respectively. The loadings and removals have been expressed in terms of the weight of BOD applied to the available specific surface area of the filters per day (g BOD/m^2/d). From these tables it may be seen that the loadings to the plastic and mineral media filters were comparable, although due to the high specific surface areas of the Biopac 50 and Flocor M media in particular, their loadings were the lowest of all the eight media types. In spite of approximately twice the volumetric load being applied to the plastic media filters during all three periods, the two large grades of mineral media had the highest organic loadings in terms of the weight of BOD applied per unit of specific surface area. The data from appendices 7.F.1, 7.F.2 and 7.F.3 have been plotted in figures 7.38, 7.39 and 7.40. From the three figures, the most obvious feature was that all eight filters removed a similar

fraction of the applied BOD per given area of specific surface, which implies that the nature of the various media did not have a significant effect upon the film developed or its ability to oxidise the settled sewage. This result also implies that over the range of gravimetric loadings considered, the weight of BOD removed was constant at approximately 75% of the applied load. The correlation coefficients of the BOD removal to the applied BOD/m^2 of specific surface/day for the three periods were 0.99, 0.98 and 0.99 respectively, showing a very high degree of correlation between the loading applied and the BOD removed.

Figures 7.38, 7.39 and 7.40 therefore imply that in order to improve the quality of the effluent from the filters, the gravimetric load must be reduced or the specific surface area of the media increased; that is, the greater the specific surface area of the media, the greater the quantity of BOD that may be removed and the better the quality of the effluent, given a constant hydraulic and gravimetric loading per given volume of media. In practice, the amount of organic matter oxidised in a filter therefore would be limited by the nature of the void capacity and its ability to remain unponded.

Comparing the Hereford data to previously published results, particularly Bruce et al. (1975) and Banks et al. (1976), the BOD removal performances of the Hereford filters appear to lie between those achieved in the two studies cited. Bruce et al. (1975) used very similar hydraulic loadings and similar strength Stevenage settled sewage to that used in the present study, yet only a 50% BOD removal was achieved resulting in a settled secondary effluent of 150 mg/l BOD. Banks et al. (1976) using BOD loadings of 3.5 kg/m^3/d achieved settled

secondary effluents with BOD strengths of 70 - 80 mg/l; that is a BOD removal of approximately 80%, slightly better than that achieved at Hereford. The COD/BOD ratios of the settled sewages were Stevenage 1.8:1, Ipswich 1.4:1 and Hereford 1.2:1, which probably indicates different treatabilities of the sewages; the lower the COD/BOD ratio indicating a more readily biologically oxidizable sewage.

From figures 7.38, 7.39 and 7.40, it can be seen that the BOD removal performances of the various media at Herefore were in direct proportion to their specific surface areas. Similar trends in media performances were shown by Bruce and Boon (1971), except in the case of Cloisonyle, a plastic media in which all the surfaces are vertical. Truesdale et al. (1961) also found that BOD removal was well correlated to specific surface area; curiously Banks et al. (1976) found that there was no significant correlation between BOD removal performance and specific surface area of the media.

Sludge production figures at Hereford showed marked variations which were not correlated to the nature of the media or specific surface environmental conditions; generally greater than 0.5 g/g of BOD removed.

Bruce and Boon (1971) also found that sludge production did not appear to be related to the media or its specific surface area. The amount of sludge produced in that study was highly variable in the range 0.63 - 1.00 g/g BOD removed.

In common with Banks et al. (1976) the temperatures experienced by the filters in this study did not appear to have any significant effect upon the performances. The differences in temperature between the sewage and filter beds at Hereford were similar to those reported by Bruce (1970).

Figure 7.25 Weekly Averaged Daily Temperature Maxima and Minima.

(29/7/76 - 17/7/77)

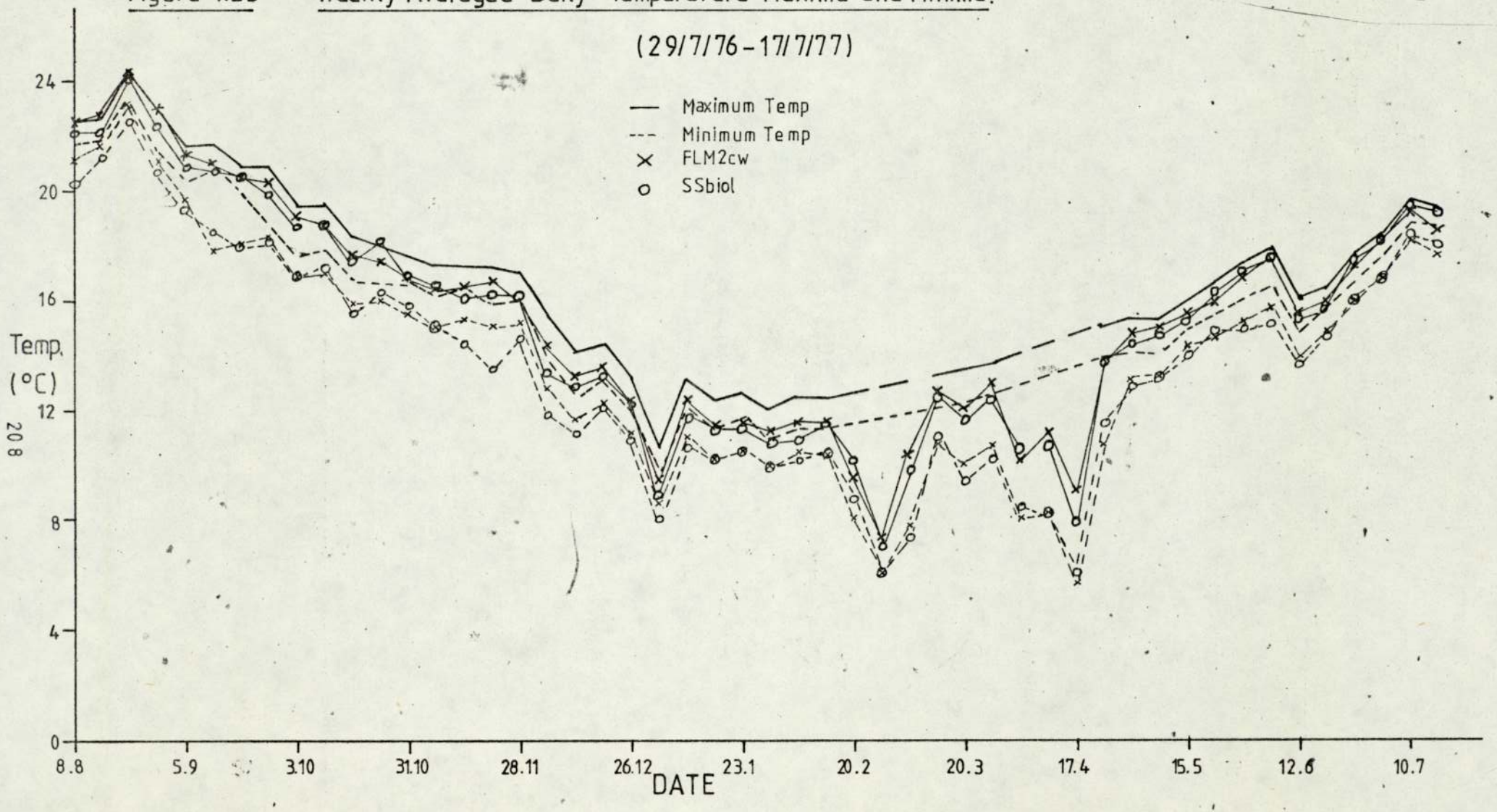


Figure 7.26 Settled Sewage and Mean Filter Effluent BOD Concentration. (29/7/76-17/7/77.)

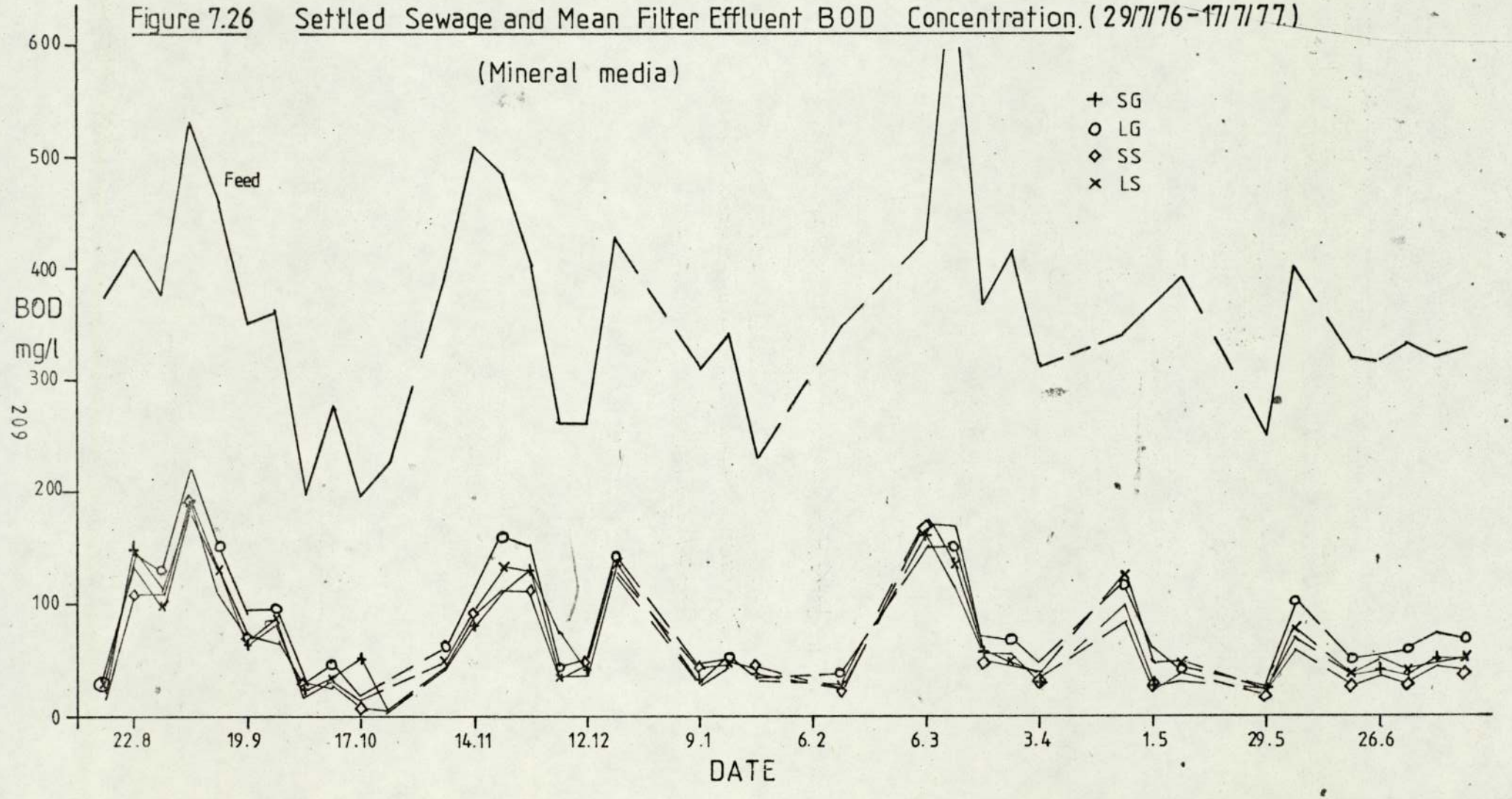


Figure 7.27 Settled Sewage and Mean Filter Effluent BOD Concentration (29/7/76-17/7/77)

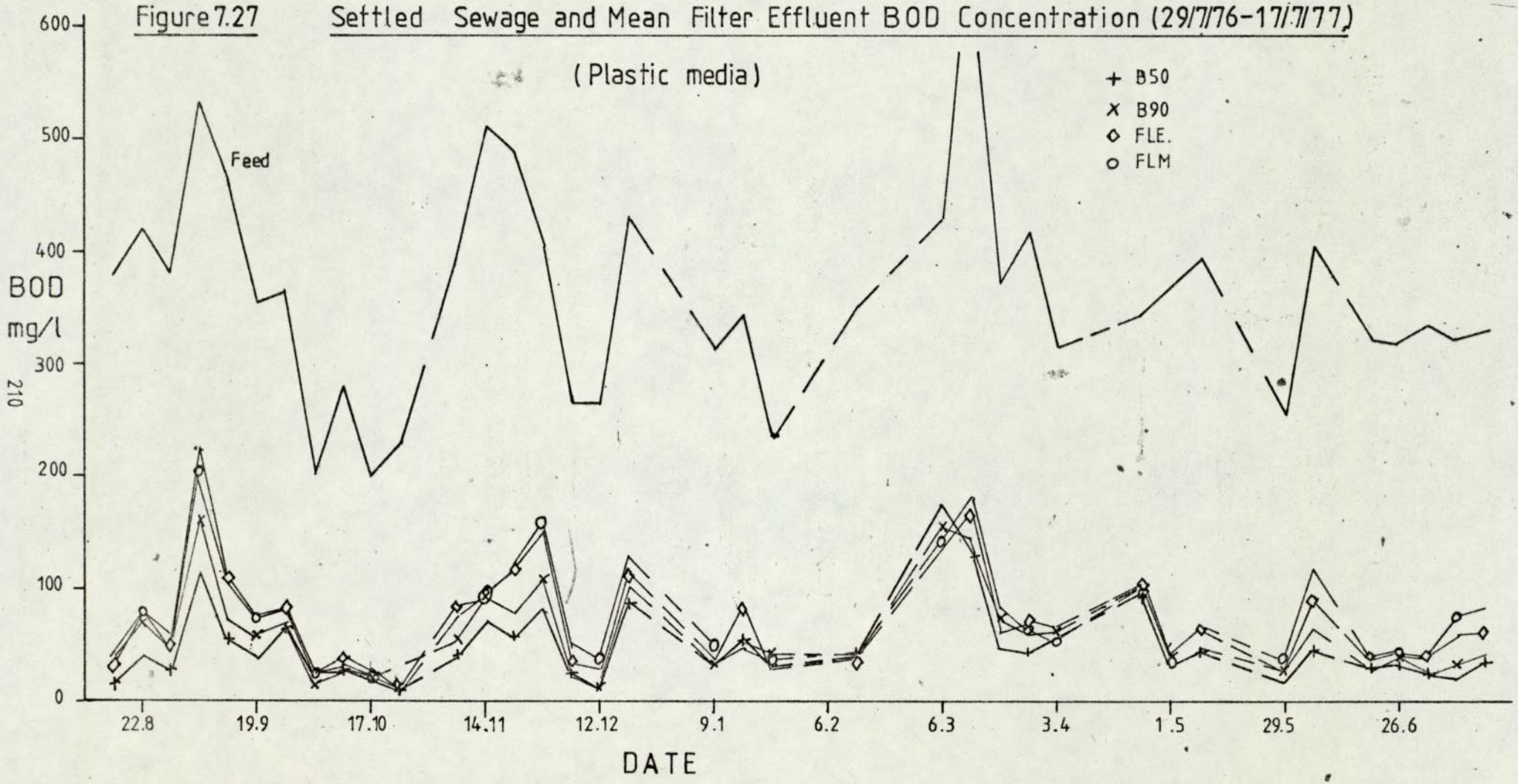


Figure 7.28 Percentage BOD Removals of the Mineral Media Filters. (29/7/76 - 12/7/77)

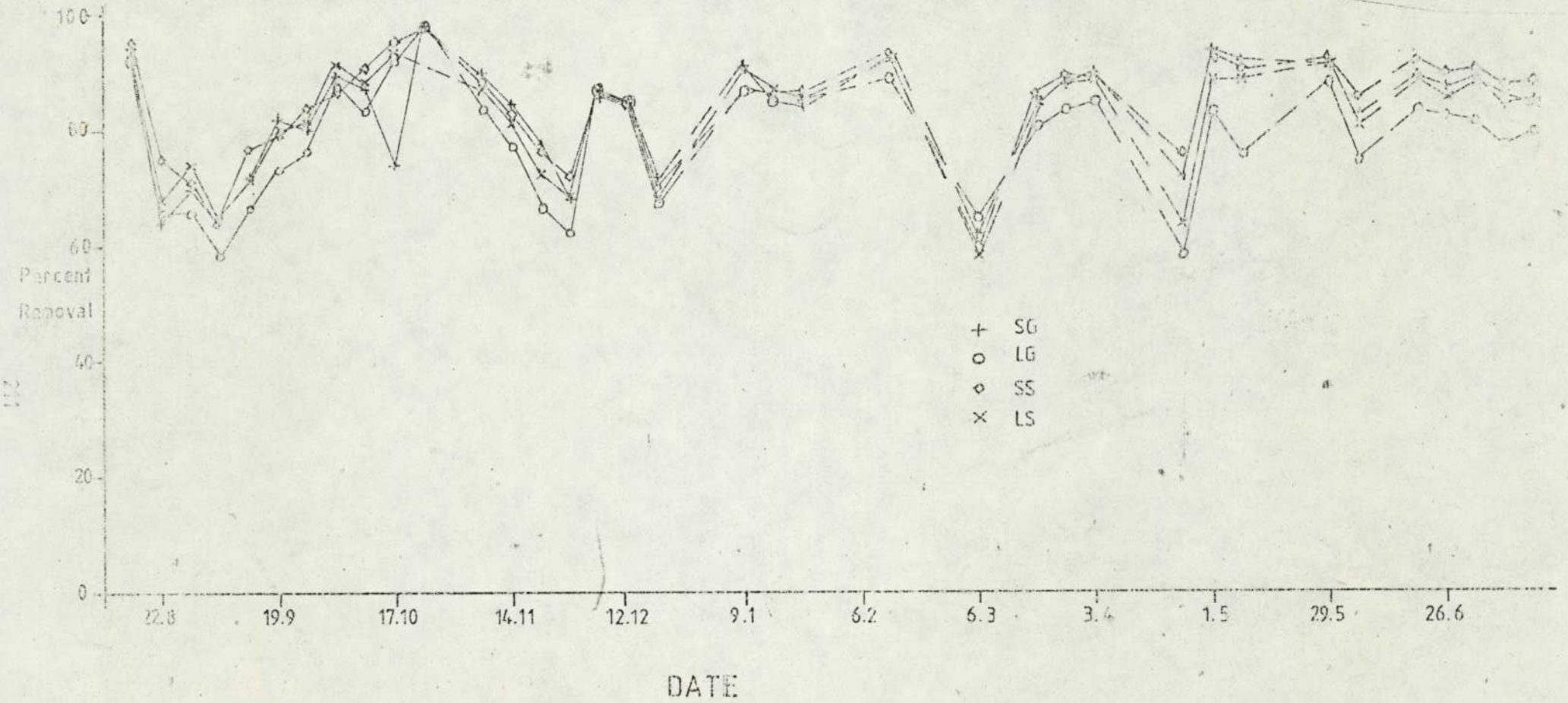


Figure 7.29 Percentage BOD Removals of the Plastic Media Filters (29/7/76 - 17/7/77)

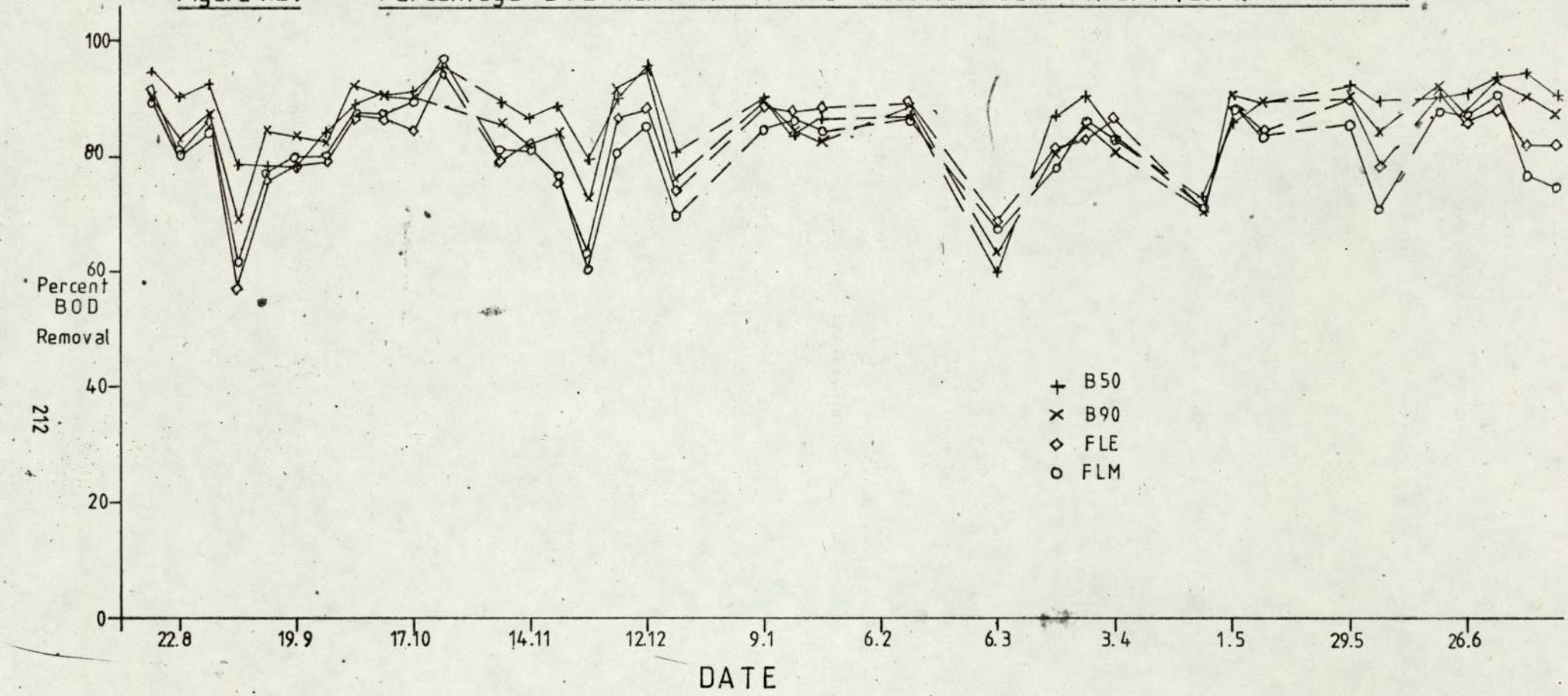


Figure 7.30 Sludge Production/ BOD Removal Ratio for Mineral Media Filters (29/7/76-17/1/77)

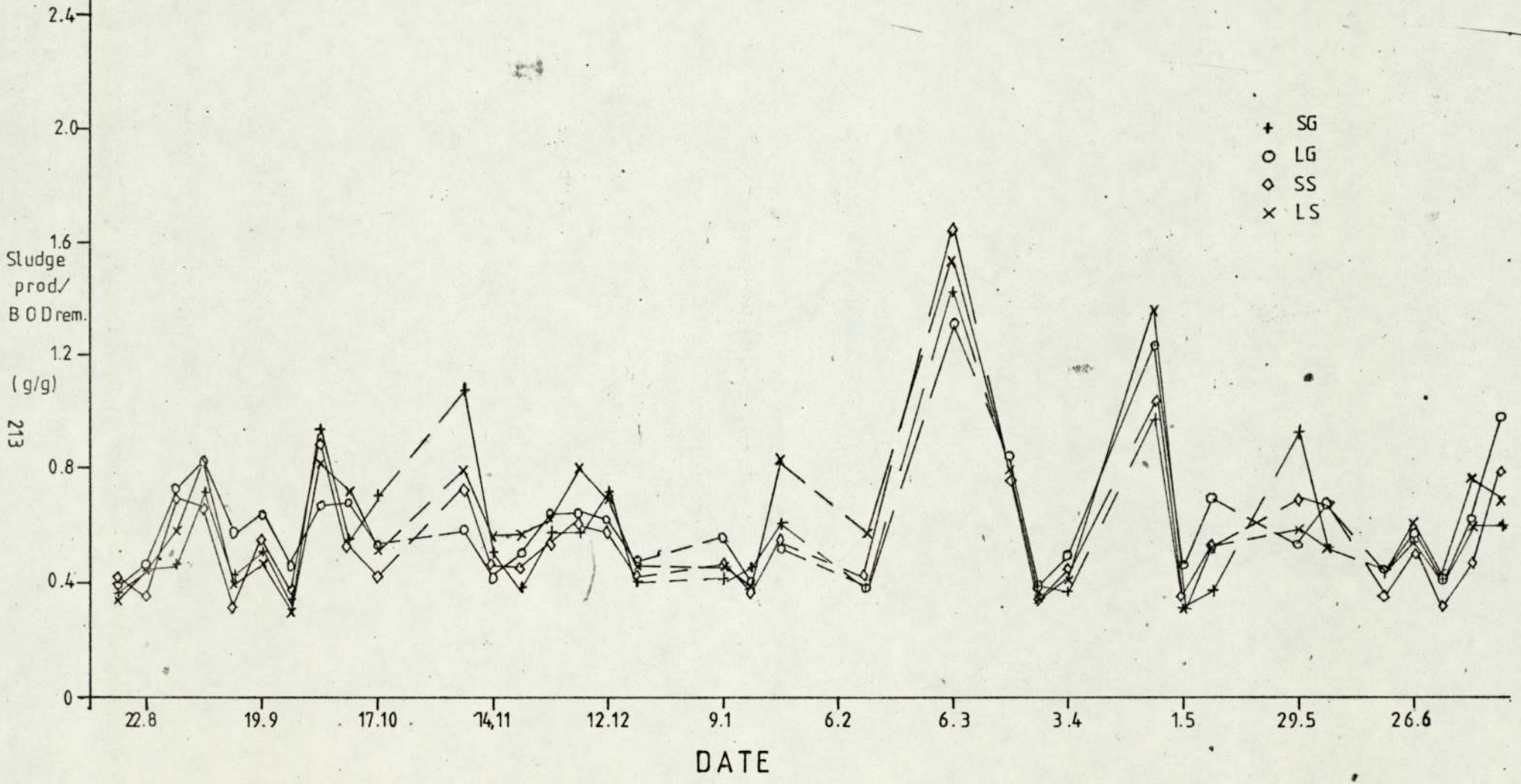


Figure 7.31 Sludge Production/BOD Removal Ratio for Plastic Media Filters.

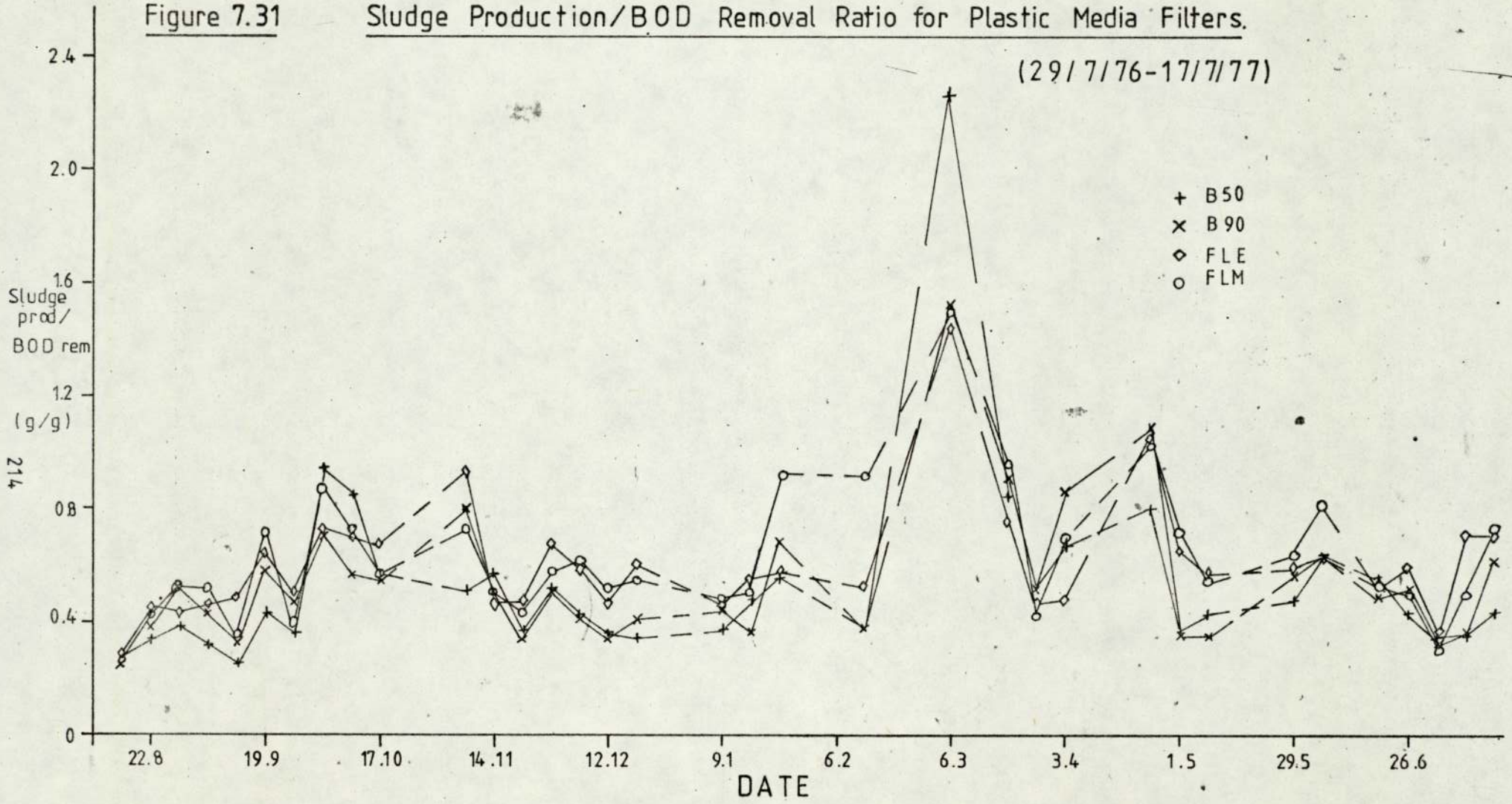


Figure 7.32 Duplicate Mineral Filter Suspended Solids.(Settled Effluent) (29/7/76-17/7/77)

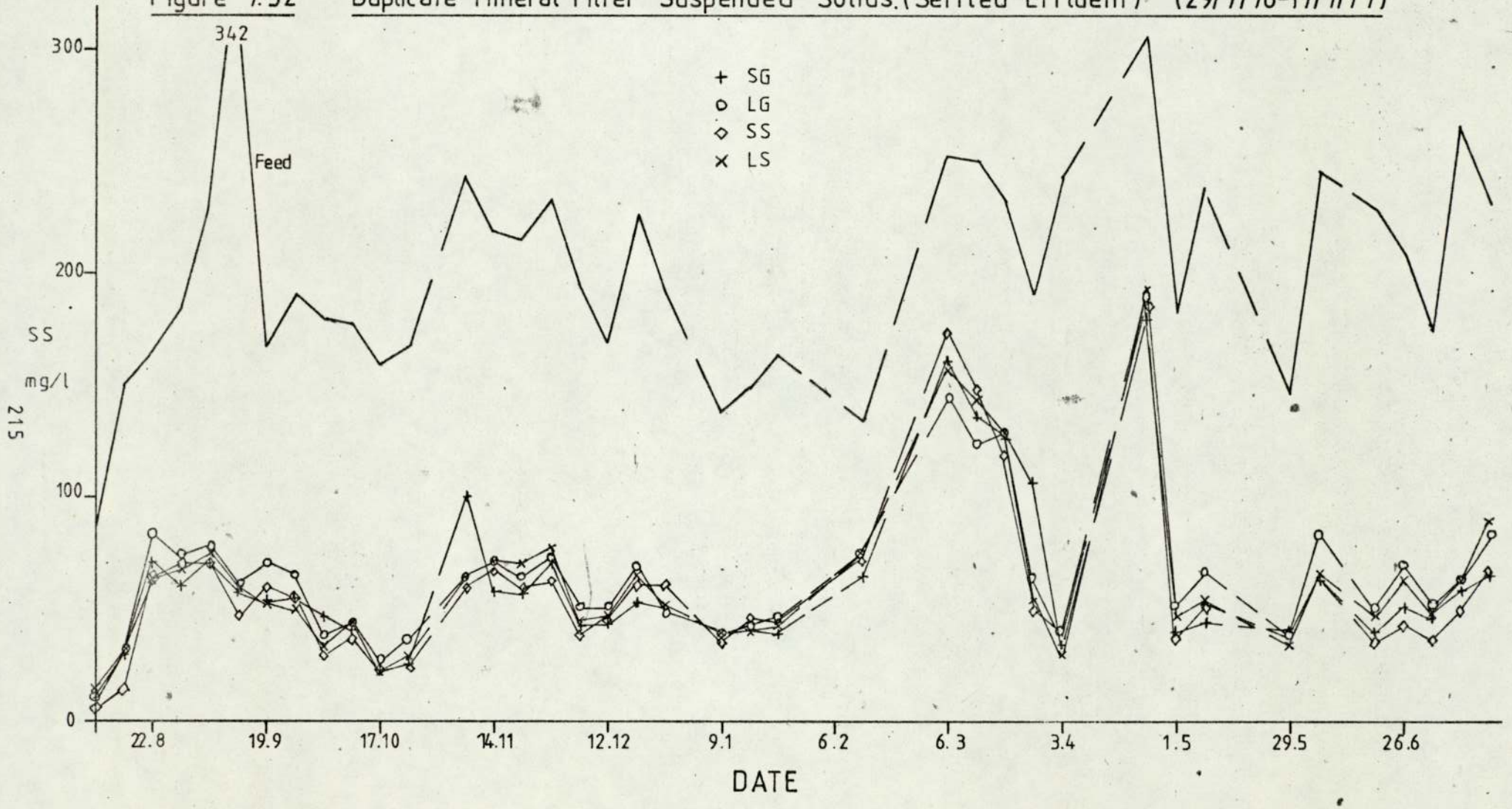


Figure 7.33 Duplicate Plastic Media Filters Suspended Solids (Settled Effluents 29/7/76-17/7/77)

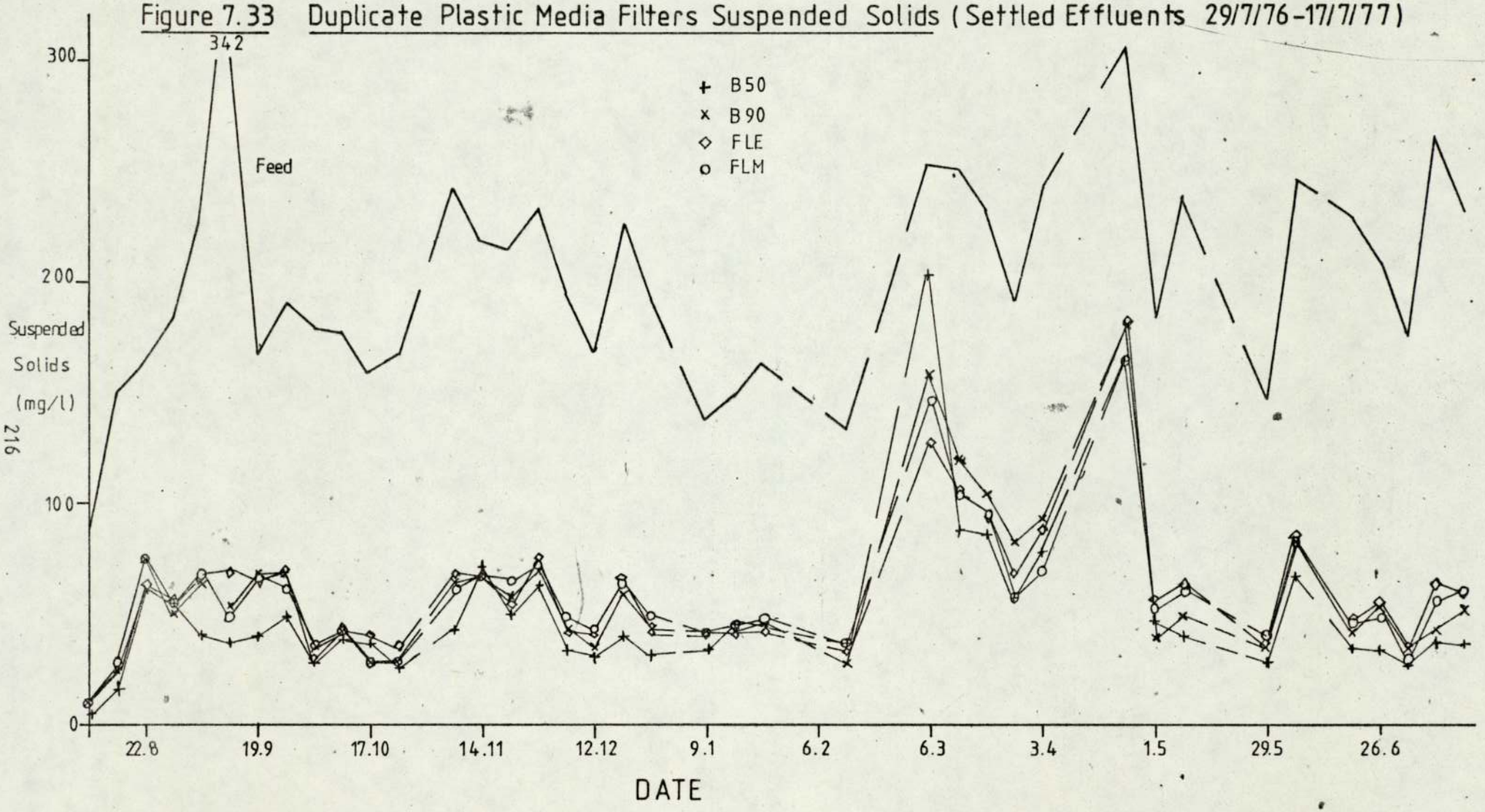


Figure 7.34 Duplicate Mineral Filters Effluent CODs (29/7/76 - 17/7/77)

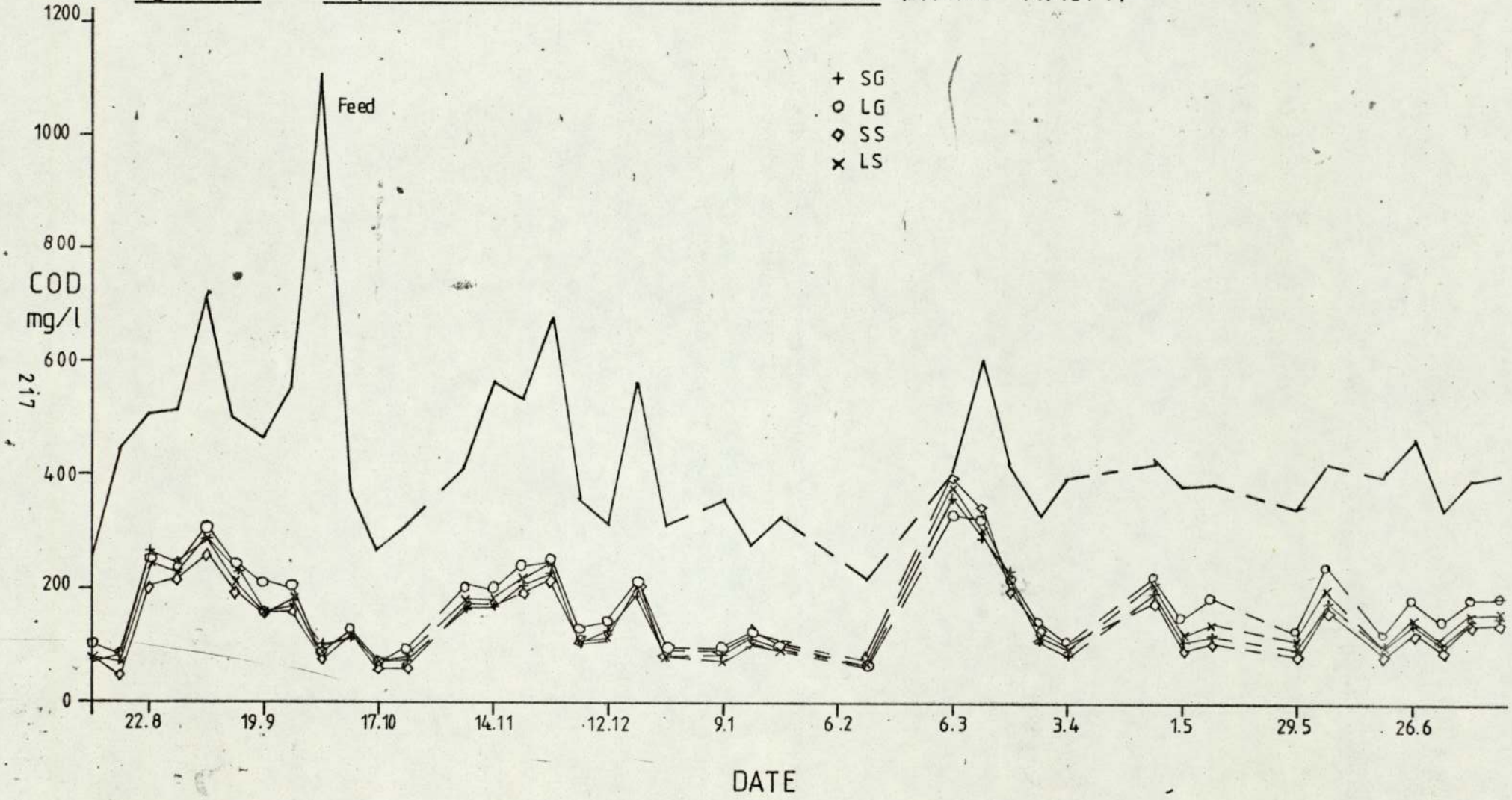


Figure 7.35 Duplicate Plastic Filter Effluent CODs (29/7/76 -17/7/77).

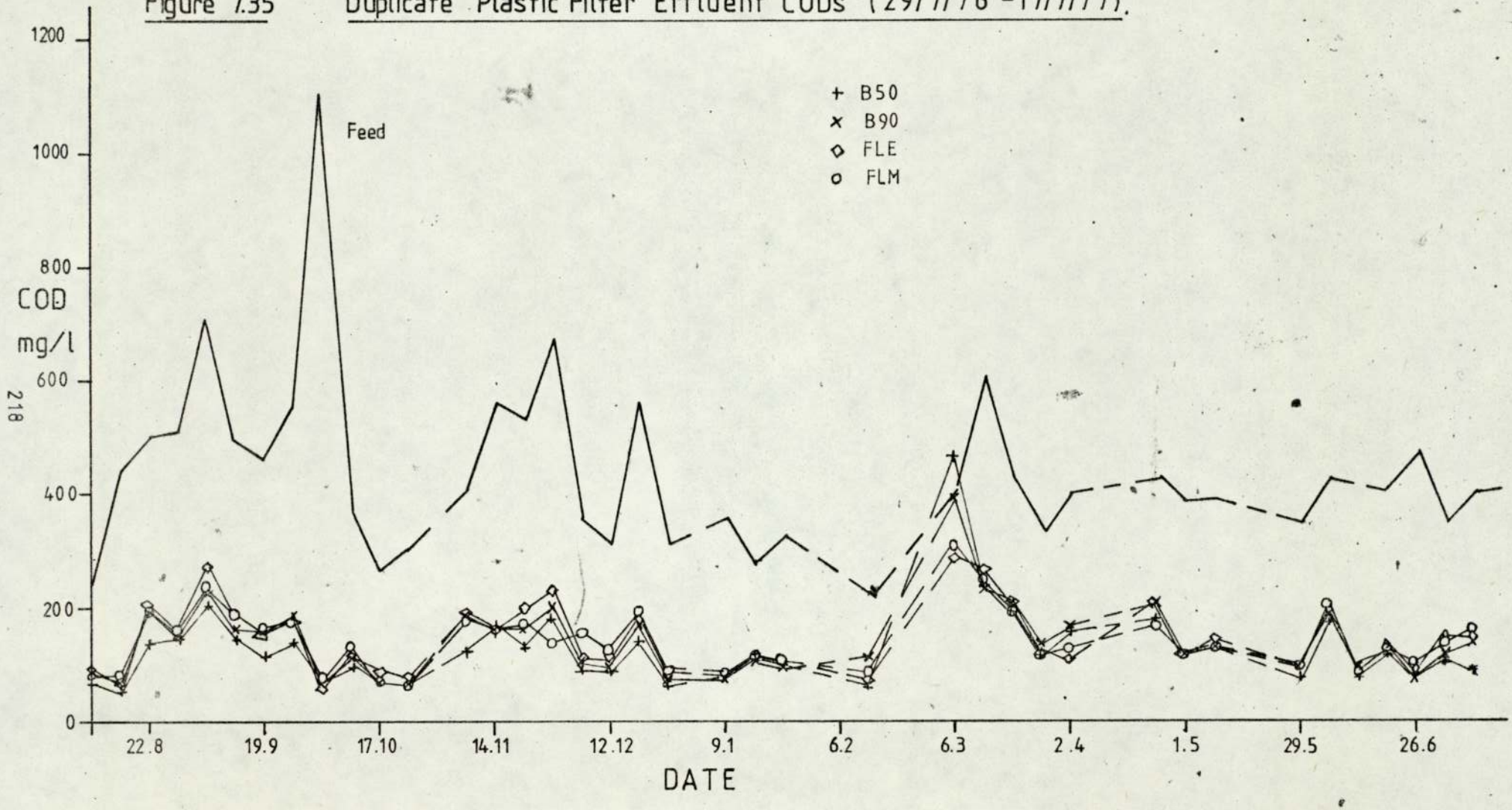


Figure 7.36 Duplicate Mineral Media Filter Effluents, Ammonia Concentrations. (29/7/76 – 17/7/77)

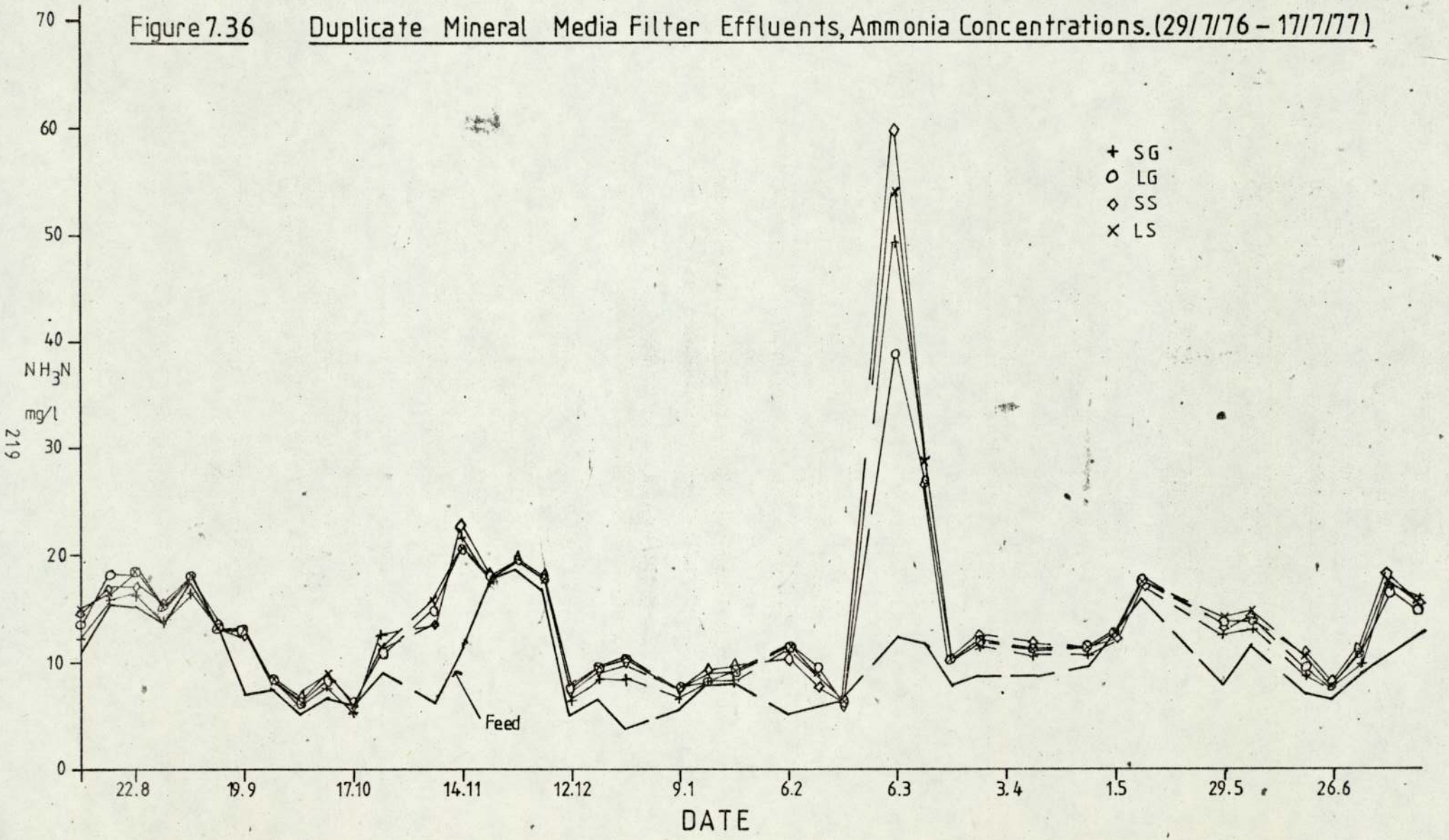


Figure 7.37 Duplicate Plastic Media Filter Effluents Ammonia Concentrations (29/7/76-17/7/77)

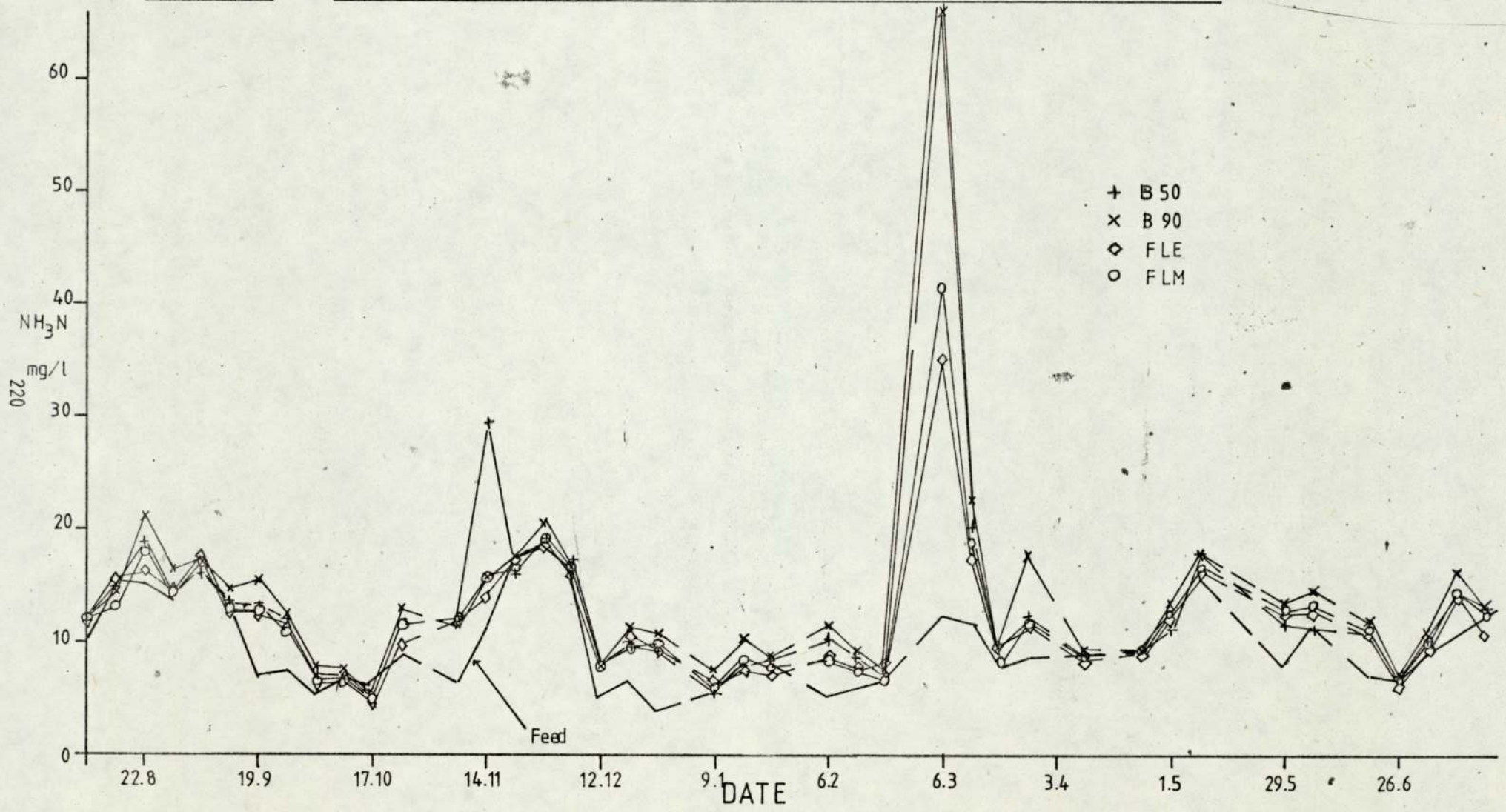


Figure 7.38 Plot of BOD Removed against BOD Applied to the Eight Media.

(16/6/75 - 16/11/75)

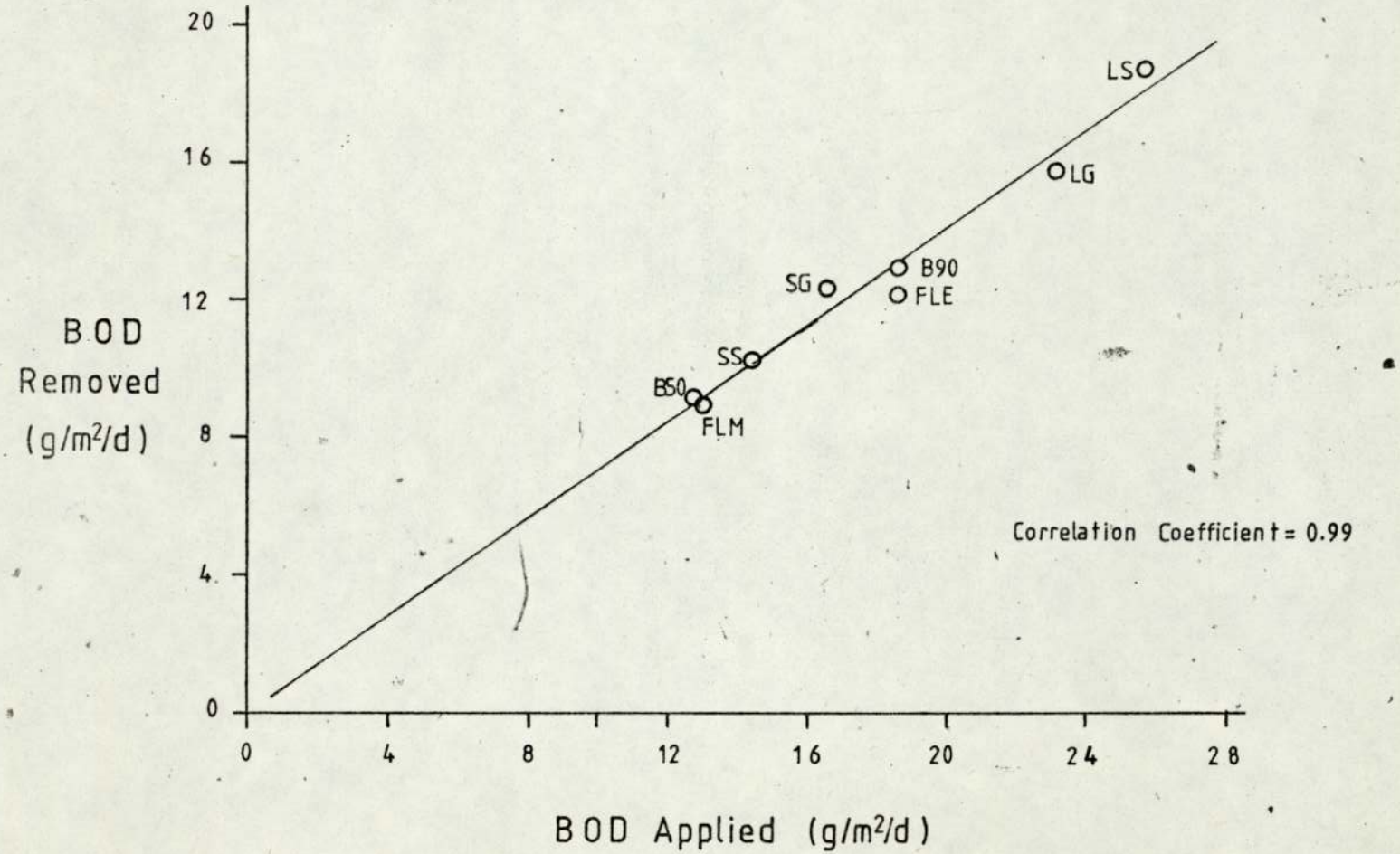


Figure 7.39 Plot of BOD Removed against BOD Applied to the Eight Media.

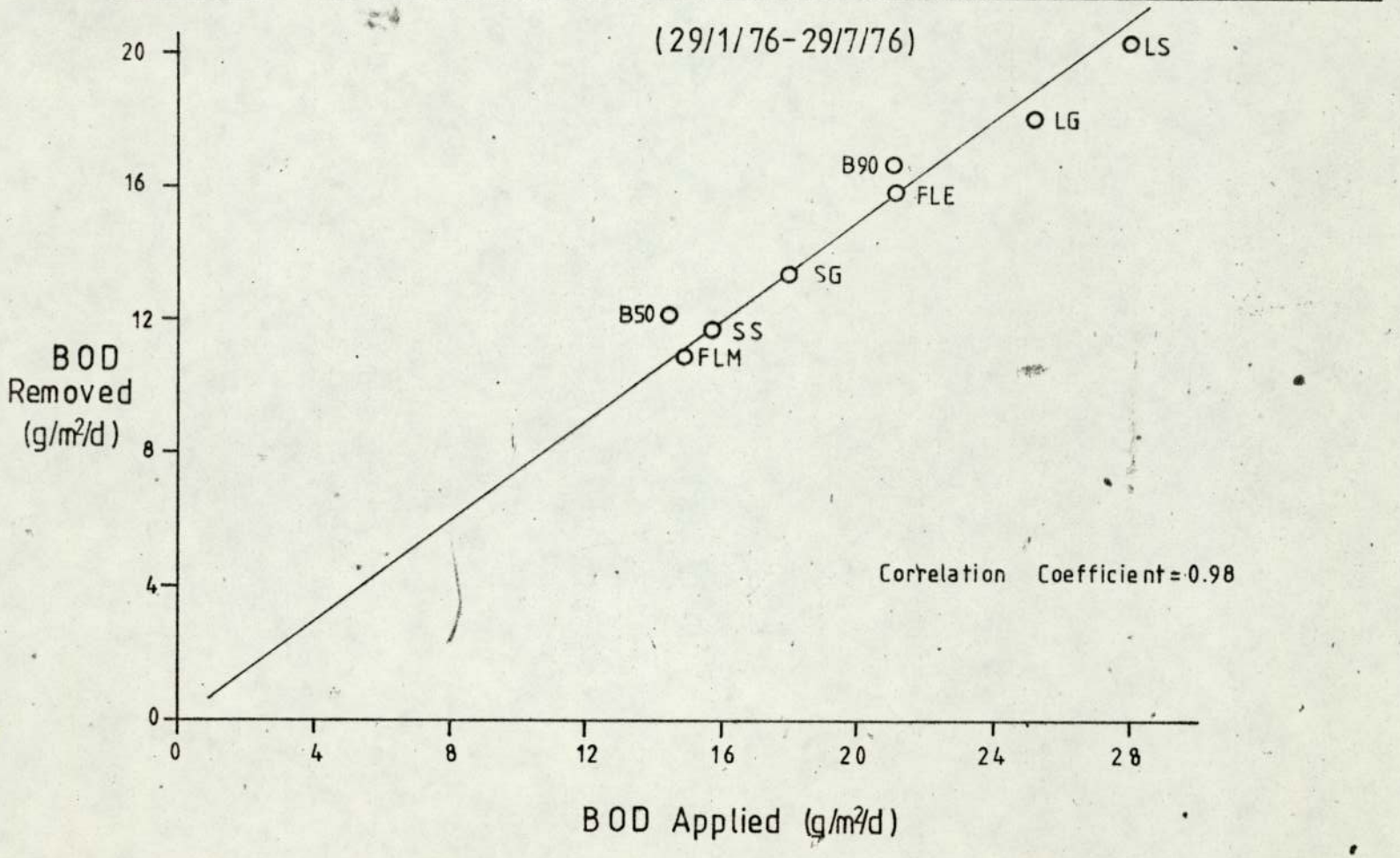


Figure 7.40 Plot of BOD Removed against BOD Applied to the Eight Media (29/7/76-17/7/77)

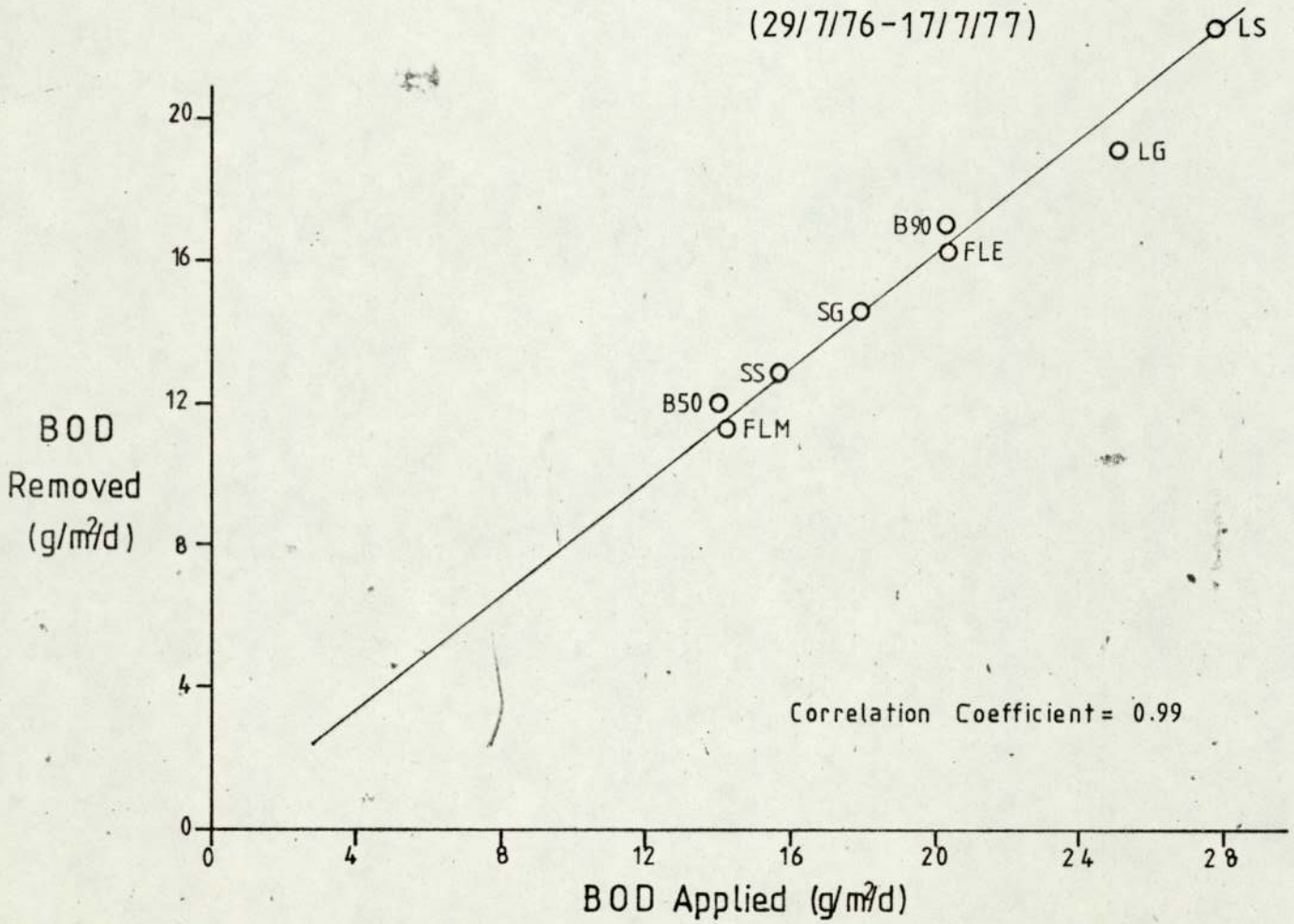


Figure 7.41 Sludge Production vs. BOD Applied to the Eight Filter Media

(16/6/75-16/11/75)

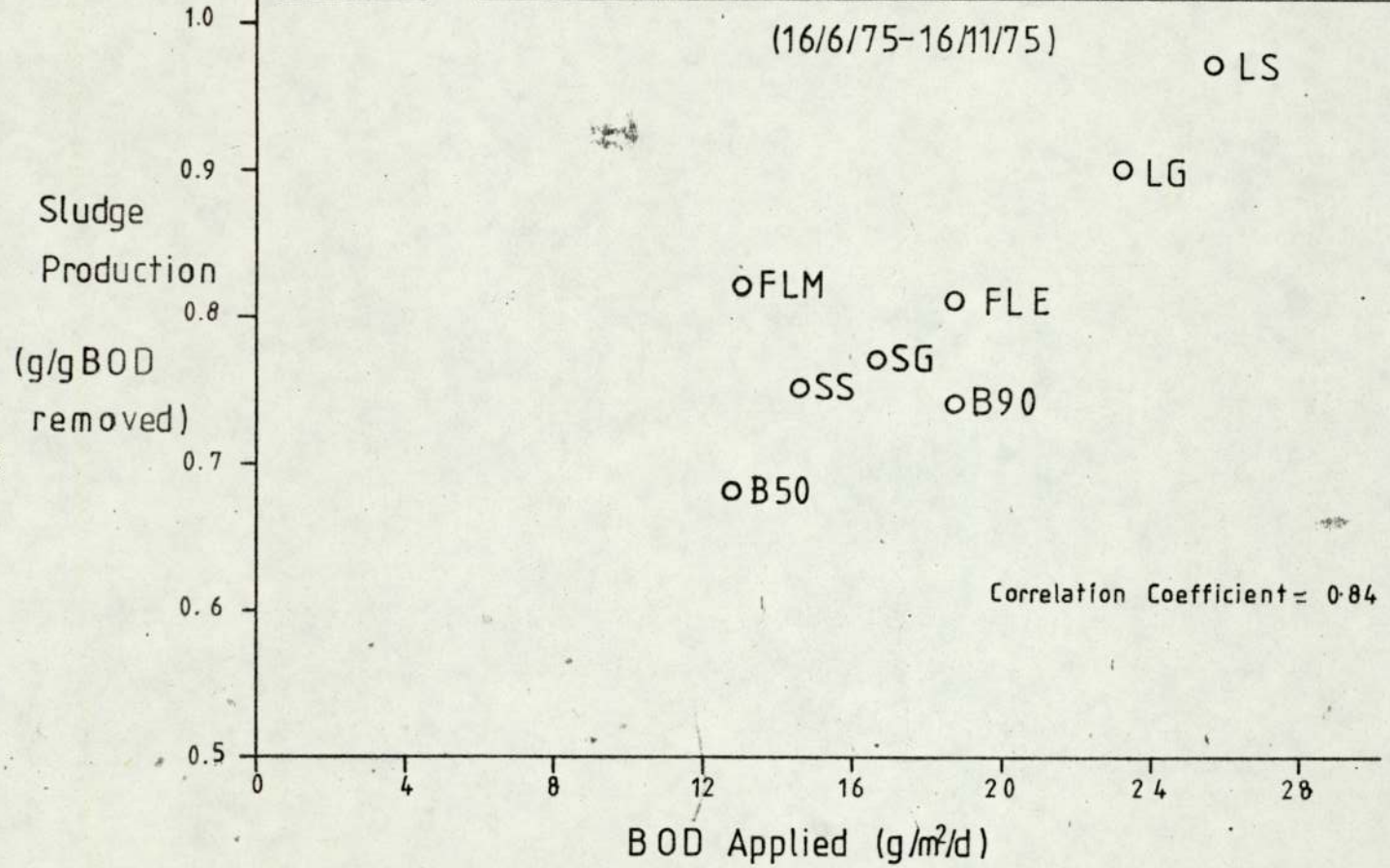


Figure 7.42 Sludge Production vs. BOD Applied to the Eight Filter Media.

(29/1/76 - 29/7/76)

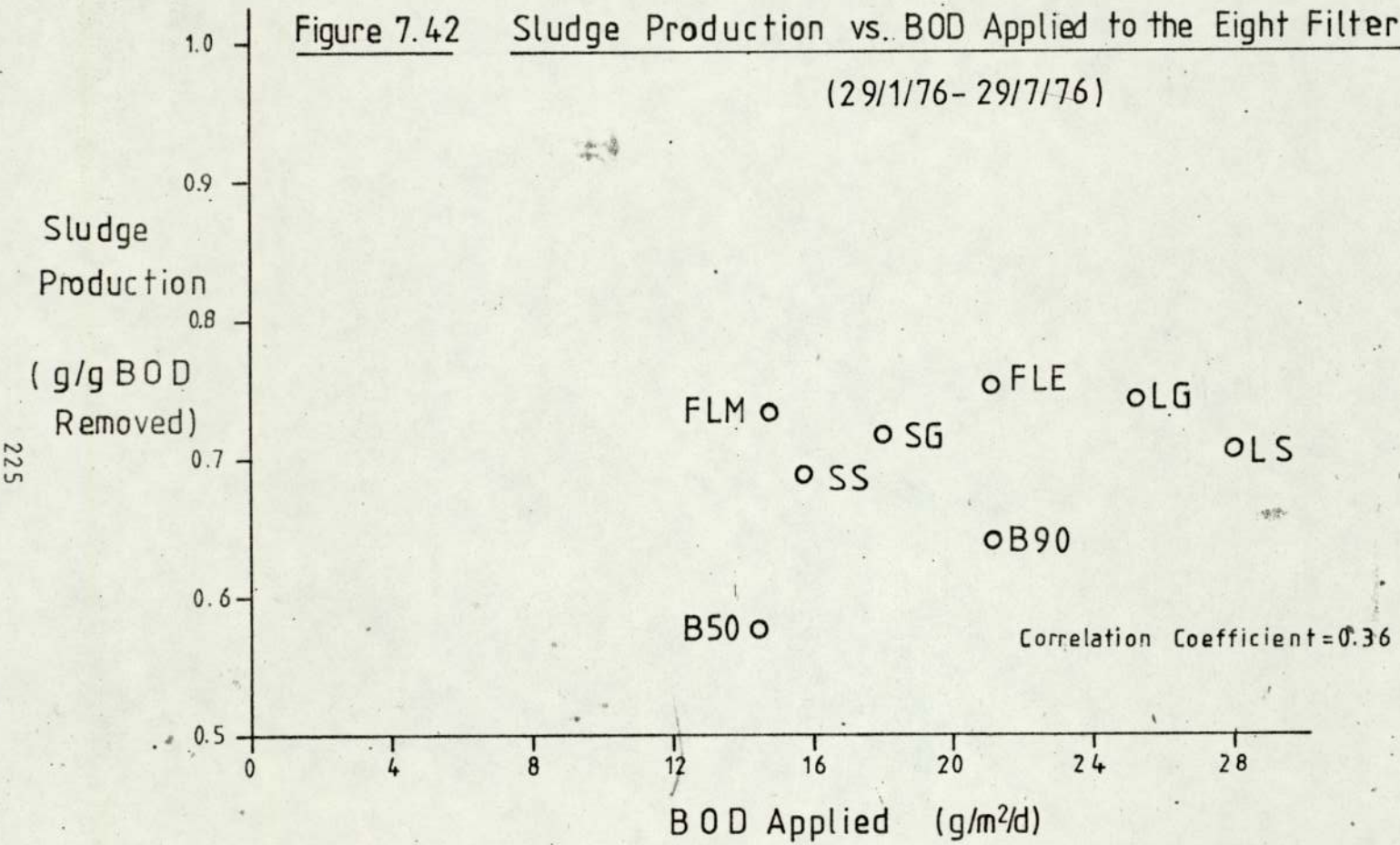
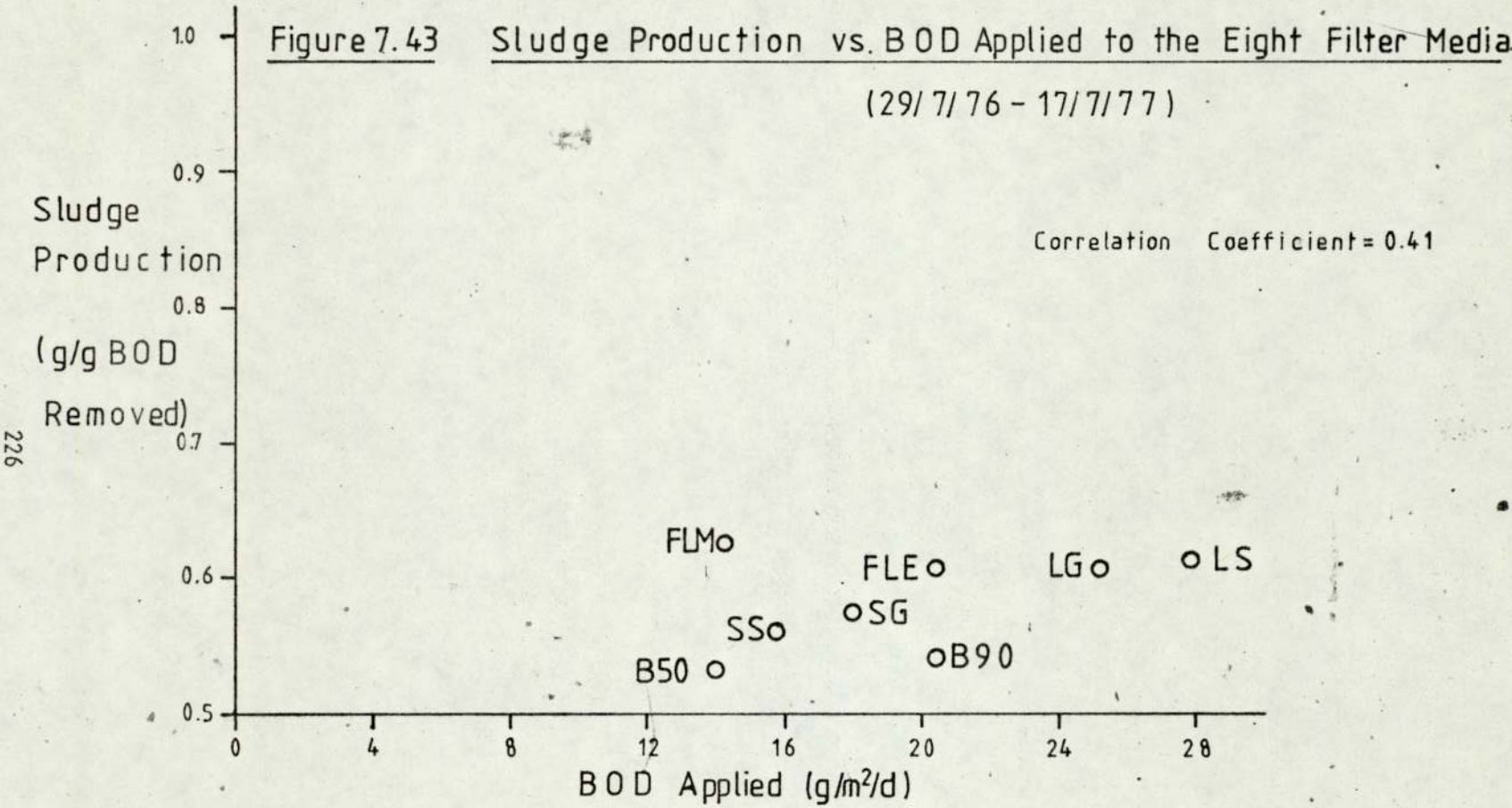


Figure 7.43 Sludge Production vs. BOD Applied to the Eight Filter Media

(29/7/76 - 17/7/77)



8. NATURE OF THE FILMS DEVELOPED ON THE HIGH RATE FILTERS

A. Physical Aspects of the Filter Films Developed

I. Results:-

i) Filter Volatile Solids Contents

At the outset of the project it was decided that a quantitative and qualitative assessment of the various filter films at different depths of the filter would be made at quarterly intervals. The facilites for conducting these surveys and the methods employed have been described in the section entitled 'Biological Analyses of Filter Film' in chapter 6. Whilst it was not possible to adhere to a strictly quarterly timetable, eight observations of the filter films were conducted during the project.

One survey was conducted in late October 1975 at the end of the first period of operation. A second survey was carried out in January 1976 at the end of the second period during which the filters received only a low flow of crude sewage. It was possible to carry out two examinations of the filter films during the third period in April/May 1976 and July 1976. During the fourth period, when a more consistent supply of settled sewage was available for almost twelve months, it was possible to conduct four examinations of the filter films.

In this section, the volatile solids contents in different filters and at various depths are presented. As explained in greater detail in chapter 6, a ten gram sample of wet filter film was taken from each depth to be first dried to 105°C to obtain the dry weight of film in a given volume. The dried film was ignited in a muffle furnace at 500°C to obtain the weight of non-volatile matter present after ignition. From the weight loss on ignition, it was then

possible to determine the volatile solids content of a given volume of filter media at each depth.

The results of these determinations are presented in terms of kilograms of volatile solids per cubic metre of filter media in appendix 8.A.1. A visual appreciation of the differences in volatile solids content of the filters and their variation through the depth of the filters can be obtained from figures 8.A.1 to 8.A.8. When considering the results, it should be recalled that the Biopac 50 and 90 and Flocor E filters received nominally twice the organic load applied to the natural media. Flocor M, however, in view of its reduced depth (1800 mm) received 2.22 times the organic load per cubic metre of media, compared to the mineral media.

As explained in chapter 6, for the modular Flocor media, it was only possible to obtain three samples of the filter film at different depths, whilst five samples of the random media covering the top 1800 mm of the filters could be obtained.

ii) Neutron Scatter Results

Throughout the period it was possible to make 22 observations of the film thickness using the neutron scatter probe, of which the first was carried out on the clean media prior to sewage application.

During the first period, three consecutive monthly determinations only were possible at the end of the period. This was due to difficulties in transport of the radioactive probe, which were overcome by September 1975, after which monthly readings were conducted.

In the fourth study period, when settled sewage from the main works was available, two months of readings were unfortunately omitted;

these being August 1976 and April 1977. The omissions were as a result of staff vacations and excessive workloads.

From appendix 8.A.2 for April 1975 it can be seen that the percentage of the filter not occupied, i.e. the voidage, was practically constant throughout the depths of all sixteen filters. The voidages recorded compared well to those determined during calibration of the neutron scatter probe using an oil drum full of the various media (see chapter 5, page 80 describing the void capacities calculated). However, it can also be seen from appendix 8.A.2 that within the first 100 mm of the surface of all the filters the apparent void capacities diminished. This apparent reduction in voidage was an artefact produced as a result of the effective neutron scatter zone including the air above the surface of the media, even though the source and probe were designed to minimize the vertical radiation and reception of slowed neutrons. However, this effect, when the filters developed a film, would be much reduced, since the effective diameter of the reflecting media decreased rapidly as the water content increased.

iii) Retention Time Results

Due to the limited number of occasions on which retention time determinations for the various filters were carried out, the date for the complete project period are presented in one section.

The determination of retention times by the methods employed (which have been described in chapter 5, and their significance discussed in chapter 2) are extremely time consuming necessitating serious disruption of the routine sampling and analysis. In view of the difficulty in obtaining regular analytical data due to plant maintenance, major works modifications and biological sampling, it

was only possible to make four determinations of retention times throughout the entire period, with one of these being on the clean media prior to commencing the project. The second determination carried out in late October and early November 1975 had to be limited to only the natural media filters due to the disruption of the settled sewage supply to the pilot plant.

Analysis of the collected effluent samples for chloride concentration during the first two sewage retention determinations was by titration against standardised silver nitrate solution, whilst for the last two determinations a potentiometric method described in chapter 5 was employed.

125 grams of sodium chloride (as a saturated solution) were applied via a weir box on one of the distributor arms over the surface of one filter. Appendix 8.A.3 indicates that a poor recovery was achieved in the effluent from each filter. The causes of the poor recoveries are discussed later in this chapter. Appendix 8.A.3. shows the percentile recovery times; that is the time after which 16% and 50% of the recovered tracer had left the filter in the effluent. The nature of the accum ulative recoveries is shown in figures 8.A.9 to 8.A.15.

II. Discussion

i) Period 1: 16/6/75 to 16/11/75 Using Old Works Primary Settled Sewage

During period 1, the retention times of the mineral media filters were observed in October 1975; the volatile solids contents of the filters were determined in October 1975, and the unoccupied void capacities of the filters determined by neutron scatter in September, October and November 1975.

Considering first the volatile solids contents determined in early October 1975, the quantities present per cubic metre of media are shown in figure 8.A.1. The most striking feature is the high quantity of solids developed in the Biopac 50 filter and also the manner in which the accum ulation varied with depth. There was a steady increase in the film from the surface down to the fourth sector where 43.3 kg of volatile solids were present per cubic metre. The greatest development of filter film at the depth of 1.00 to 1.400 metres below the filter surface could have been as a result of the high instantaneous flow rate applied to the surface. At the surface, the film had greater difficulty developing as a result of the rapid passage of the sewage over the media surfaces. Due to the random nature of the media and its numerous pathways through which the sewage may flow, the "plug flow" effect is reduced with increasing filter depth, presumably (combined with the change in quality) resulting in the most favourable condition for film development by one metre in depth from the surface of the filter. A similar though more restricted effect can be seen in the Biopac 90 filter. Considering the Flocor media, the trends are more difficult to observe due to there being only three depths at which the film weight was determined.

For Flocor E, it would appear that an even limited film development had occurred. Comparing the nature of the modular Flocor media to either size of Biopac, it would seem likely that the "plug flow" effect would be far less reduced by the highly regular pore shapes throughout the filter depth and the lack of horizontal surfaces on which sewage may remain between surface applications, therefore no particular depth of the filter may be advantageous for film development. This picture is not substantiated by the film weights developed at the three depths in the Flocor M filter; the 600 - 800 mm depth showing a far greater film development than observed in the Flocor E filter or at either of the other depths in the Flocor M filter. The Flocor M modules are 600 mm deep, so that the 600 - 800 mm depth represents the top 200 mm of the second layer of modules. As previously mentioned, each consecutive layer of modules was stacked at right angles to enhance the sewage distribution over the available surface area. To a limited extent this will restrict the sewage flow at the interface of each module, perhaps improving the conditions for film development. Unfortunately the quantity of film at the 400 - 600 mm depth was not determined (any development at 600 - 800 mm might also be accompanied by development at 400 - 600 mm).

Turning to the mineral media filters, the most obvious feature was the much lower quantity of volatile solids developed throughout the filter depth compared to the Biopac filters. The manner of the film development did not appear to be similar in the four filters; no comparative features occurring in the same types or grades of media. The nature of the films developing should also be considered; it is likely that the types of flora differ with depth and the different flow regimes developing within each type of media resulting in differing patterns of film accum ulation. The nature of the films

within each filter of each type is discussed in the biological film section.

The results of the neutron scatter examinations during the first period can be seen in appendix 8.A.2. Considering first the effects of film development on the void capacities of the plastic media filters, it can be seen that by September 1975 the unoccupied void capacities of the Biopac 50 filters had been markedly reduced from greater than 90% to as low as 43% at 200 mm below the surface of the filter, although in the other filter the unoccupied voidage was only reduced to 68% at 200 mm below the surface. Although there is a marked difference between the voidage in the two filters, the trend in both cases was similar. A similar pattern is also shown in the Biopac 90 filters but the extent of the void occlusion was much reduced. The development of film in both types of Flocor filters had resulted in little of the voidage being occupied by moisture. In all eight filters the same general trend was apparent; that is, the media near to the surface of the filters tended to have the greatest blockage of the voids, the trend being most pronounced in the Biopac 50 filters, with the duplicate filters differing significantly.

Turning to consider the mineral media filters, the reduction in unoccupied voidage by September (approximately 6%) can be seen to be similar at all depths and to be the same in the duplicate filters. No marked differences had occurred in the filters of the different media.

By the 30th of October 1975, the unoccupied void capacities of all the filters had changed dramatically. In the case of the plastic media filters, apart from Flocor E, the unoccupied voidage had fallen greatly to as little as 30% for the Biopac 90 and 50 filters about

300 mm below the surfaces of the filters. It is of interest to note that again the duplicate Biopac 50 filters showed marked differences in the available voidage, but that on this occasion the other duplicate had a greater percentage of its voidage occluded. The trend which had been seen in September of the least available voidage approximately 300 mm from the filter surface was repeated, being most pronounced in the two Biopac 90 filters. Flocor E did not appear to have much of the voidage occupied by filter film water, with a slight reduction in the occupied space at the surface of the filters. The Flocor M filters showed an interesting development in that there were changeable features in the blocked voidage. At the depths 600 mm and 1200 mm it can be seen that the voidage occupied was greatest. These two levels correspond to the position of the module interfaces. The mineral media filters also showed similar trends of greater void space occupation, the increases being of a similar magnitude to those shown by the Biopac filters. In comparing the four types of mineral media, the most obvious development was the smaller increase in voidage occupation in the 125/75 mm slag filters.

By mid November 1975, the pattern of void capacity blockage was markedly changed as a result of the reduced flow of settled sewage applied to the filters, particularly to the plastic media filters. The Flocor E and M filters had almost no voidage occupied, the Biopac 90 filters had very little of the void space occupied by film, however the Biopac 50 filters appeared not to have suffered to such a marked extent, with the pattern of greatest occupied voidage occurring at approximately 300 mm from the filter surface.

The mineral media filters also appeared to lose a significant quantity of film, particularly 300 mm from the filter surfaces, with very little change in the voidage occupied at greater depths.

This change in the voidage occupied relates to the change in the quantity and nature of the sewage available. However, it should not be considered that the increase in unoccupied void capacities was directly related to a loss of film; the nature of the film development may also have changed. Whilst the quality of the effluents did deteriorate in October and November 1975, there was no vast increase in solids present in the effluent. The neutron scatter probe indirectly measures the amount of water present at any particular level within the vicinity of the source and detector. Variations in the quality and quantity of sewage being applied to the filters can cause endogenous respiration to occur which can lead to a reduction in film thickness without a severe fall in the quality of the effluent. Also lysis of the micro-flora, whether fungal or bacterial, can lead to a reduction in the volume of the voidage occupied, without severe loss of film; that is, the structure of the film is altered, becoming weak with a loss of bridging links which may retain water. Also a change in the feed applied may result in a change in the relative species proportional composition of the floral community with a resultant change in the amount of water retained by the filter. Fungal growths tend to be less dense producing a greater sponge-like structure when compared to the development of zoogleal film; therefore for a given weight of volatile solids the amount of water held by the film may vary significantly. Comparing the voidage occupied by moisture, as determined by neutron scatter in October 1975, and the various weights of volatile solids present at different depths within the filters no obvious correlation can be obtained. This lack of correlation may most easily be observed in the case of the Biopac 50 filters where the greatest occupation of the pores by moisture may be seen to be at approximately 200 mm to 400 mm from the

filter surfaces whereas the greatest volatile solids contents were observed at 1000 to 1400 mm from the surface. This trend may be explained by the nature of the film development. If the film at 200 - 400 mm depth was predominantly fungal, whilst at 1000 - 1400 mm the film was predominantly bacterial, the greatest holdup of water may occur at the upper depth, yet the volatile solids could be greater at the lower depth. This feature will be further discussed in the biological section where the nature of the film at different depths will be described. Considering the retention time determinations made on the mineral media in October 1975 (figure 8.A.11), it can be seen that in all cases the 16%ile and the 50%ile times were increased; the increases in the 50%ile times being the most marked.

The greatest change in retention times occurred in the two small grades of media, with the 50%ile time for both duplicates of the 89/50 mm slag being greater than 30 minutes. Taking into account the volatile solids contents and the voidage occupied by moisture in the 89/50 mm slag and granite filters, the retention times for the two types of media in October might be expected to be comparable; however, the slag filter had much higher 16%ile and 50%ile times. In April 1975, when the retention times of the clean media were determined, the 89/50 mm slag had greater retention times than the 89/50 mm granite; therefore the greater retention times in October 1975 would appear to be a function of the media type. The same pattern was also shown in the four filters of the larger graded media, tending to support the idea that the nature of the media accounts for the difference in retention times. The retention times of the duplicate filters also differed by quite large margins in October 1975 as was shown in April 1975, however in the two instances the order was reversed.

The 125/75 mm granite filter containing the biological shaft had the shortest 16%ile retention times in October and the difference between the duplicates 50%ile times in October 1975 was greatly increased compared to April 1975. The order of the 89/50 mm slag duplicates 50%ile times was reversed in October 1975 with the filter having the biological shaft having the greater retention time. These reversals of order support the hypothesis that the presence of the biological shafts in the filters did not increase the short circuiting of the sewage through the filters.

ii) Period 2: 16/11/75 to 29/1/76 Using Comminuted Crude Sewage

During period 2, from 19/11/75 to 18/1/76, only low flows of comminuted crude sewage were applied to the pilot filters, which meant that the BOD strength of the sewage was greater, the solids content higher but the overall loading lower due to the low flows. No retention time determinations were made during this period and only three neutron scatter determinations made, of which the first in November 1975 was conducted on the first day of the crude sewage application. Only one examination of the filter films was made, in late January 1976.

Considering first the volatile solids content of the filters during this period, it can be seen that there was an appreciable change in the amounts and distributions within the filters.

As an exception to the changes, in absolute terms the Flocor E filter gained very little film during the period; the increase overall being due to an almost doubling of the volatile solids content at the 600 mm to 800 mm depth, whilst film was lost at the surface and towards the base of the filter. The Flocor M filter lost much of its film from the 600 mm to 800 mm section, the weight falling from

17.26 kg/m^3 to 4.9 kg/m^3 of volatile solids by late January 1976. Both types of Biopac lost volatile solids during the period (figures 8.A.1 and 8.A.2). In the case of the Biopac 50 filter, the change was quite dramatic; not only was there an overall loss of film but also a marked change in its distribution. In November 1975, the greatest film build up was in the centre of the filter. During the period it can be seen that from 600 mm downwards there was an overall loss of film. Averaging the depth from 1200 mm to 1800 mm there was a 62% loss in volatile solids. However, from 0 to 600 mm in depth, the Biopac filter film volatile solids content barely altered, with the result that the upper regions of the filter had the greater volatile solids content by late January 1976.

A similar trend occurred in the Biopac 90 filter with the 1200 - 1800 mm depth of the filter losing 51% of its volatile solids content (however, in absolute terms the weight loss was far less than in the case of the Biopac 50 filter). In the top 600 mm of the filter, there was only a slight decrease in the amount of film present. The overall effect in the Biopac 90 filter was therefore a relative increase in the film supported by the upper part of the filter compared to the middle and base of the filter.

In the mineral media filters, the change in film development was quite different. Apart from the 125/75 mm slag filter, the other three types of mineral media made large increases in the weight of volatile solids present at all depths. In the case of the 89/50 mm slag, a clear picture emerges of the greatest volatile solids content being supported at the surface of the filter with a gradual decline in solids through the depth of the filter. Although slight variations occurred, a similar pattern developed in the 89/50 mm and 125/75 mm

granite filters, with the 200 mm - 600 mm depths supporting the greatest weight of volatile solids. The change in the volatile solids content of the 125/75 mm slag differs completely to that which occurred in the other three mineral media filters, with very much less film being present at any depth of the filter, and the weight of volatile solids per cubic metre being greatest low in the filter.

Contrasting the two small grades of mineral media to the two larger grades , it can be seen that the smaller media supported the greatest weight of volatile solids near the surface of the filters, whilst the larger grades had their greatest weights of solids lower in the filters. The 89/50 mm grades of media had greater specific surface areas than the 125/75 mm grades and therefore a greater weight of anaerobic film could develop per cubic metre of media. As the developed film oxidised the sewage passing through and over its surfaces, the potential for growth decreased, that is the substrate concentration was reduced hence reducing the potential for further microbial development, thus the gradual decline in the volatile solids content with depth. In the larger grades of media, the amount of volatile solids developing at the surface of the filter was limited by the available surface area and the rapid passage of sewage through the filter. At the lower depths within the 125/75 mm filters, the instantaneous rate of sewage flow over the film surface reduced and an evening out of the plug flow effect occurred as a result of the retention effect of the media and developed film higher in the filter. Thus a more suitable environment was provided for greater film development at lower depths within the filters.

Considering the neutron scatter moisture determinations conducted during this period (appendix 8.A.2), it can be seen that in

the plastic media filters there was a decline in the voidage occupied by moisture whilst in the mineral media filters there was an increase in the voidage occupied by moisture.

In the plastic media filters between 19 November 1975 and 17 December 1975, there was a marked reduction in the occupied voidage particularly in the Biopac 50 filters. The situation attained by the December examination was then maintained for all eight plastic filters until January 1976. It can be seen that the two types of Flocor had very little of their void capacities occupied by water throughout the period, and that only slightly more of the voidage available in the Biopac filters was occupied by moisture.

Turning to the mineral media filters, it can be seen that all four types of media had similar voidages occupied by water. During the period, a trend was developing of greater voidage being occupied towards the centre of the filters than at the surface. This trend does not follow that shown by the volatile solids contents at each depth; in the cases of the 89/50 mm media it might be expected that greatest moisture contents would be observed near the surface of the filters. The explanation must be that differing types of film were developing within the filters which retained or contained water differentially.

iii) Period 3: 29/1/76 to 29/7/76 Using Pilot Plant Settled Sewage

During period 3, settled sewage was available for the pilot filters from converted cold sludge digestors being used as settlement tanks, which permitted greater flows to the filters than during period 2 with a much improved quality, having a lower BOD and suspended solids content.

During the period, it was possible to carry out two determinations of the volatile solids contents of the filters throughout the depths in April/May 1976 and July 1976. Coupled with the assessment of volatile solids made at the end of period 2 in January 1976, it was therefore possible to observe the change in volatile solids over two intervals. Considering first the plastic media filters, it can be seen from figures 8.A.2, 8.A.3 and 8.A.4 that in the two types of modular Flocor media filters there was a gradual increase in the volatile solids content throughout the period, most noticeable in the Flocor M filter where the film volatile solids contents more than doubled in the six months from approximately 4.8 kg/m^3 of media to 10.1 kg/m^3. Reflecting on the development of the filter film during the first two periods, the 600 - 800 mm depth contained the greatest volatile solids content; however, in this period the distribution of the film was quite even throughout the three depths of the filter.

Turning to the two Biopac filters, it can be seen from figures 8.A.2, 8.A.3 and 8.A.4 that both filters contained far greater quantities of film throughout the period than the Flocor filters with the Biopac 50 filter containing the greatest quantity. Between January and late April 1976, it can be seen that both filters increased their volatile solids contents with greatest increases in the 200 mm to 1000 mm depths of the filters. By July 1976, the pattern and quantities of the volatile solids contents had changed appreciably. The filters lost much of their solids throughout their depths but particularly between 200 mm and 1000 mm from the surface. In the case of the Biopac 90 filter in July 1976 this depth still had the greatest volatile solids content but in the Biopac 50 filter only the 600 mm - 1000 mm depth had a greater volatile solids content than the other depths. Comparing the volatile solids contents at

different depths within the mineral media filters it can be seen that a similar trend to the Biopac filters occurred; namely that between January and late April 1976 film accumulated in the filters particularly at the lower depths only to be lost by July 1976. It is of interest to note that all the mineral media filters increased their volatile solids contents from 600 mm to 1800 mm so that in April 1976 these depths had greater volatile solids contents than the upper regions of the filters. A further feature of note in April 1976 (figure 8.A.3) is the comparison between the two grades of similar media. Both slag filters had similar depth profiles of film accumulation, with the 600 mm - 1000 mm depths supporting the greatest film growth. In the case of the two granite media filters, it can be seen that both filters had similar depth profiles of film accumulation but that in their cases the greatest accumulations occurred between 600 mm and 1400 mm with greater amounts in the 1000 mm to 1400 mm depths.

By July 1976, the pattern of accumulation had altered in all four mineral media filters, with an overall loss of film in all four filters. This loss of film was particularly from the lower depths of the filters in the cases of the granite media filters with a more overall loss of film in the slag filters.

During the first two periods of study, the mineral media filters had appreciably less film than the two Biopac filters. In April 1976 it can be seen that the mineral media filters' film contents were approaching those in the Biopac filters. By July, after the unloading had begun, it can be seen that all the filters apart from the two Flocors had lost well over 50% of their volatile solids.

From chapter 7, it can be seen that all the filters between

April 1976 and July 1976 were unloading due to increased macrograzer populations. This unloading began towards the bases of the filters travelling upwards to the surface. In July 1976 the unloading was still occurring in the granite filters, which may account for the high quantities of film still present at the 200 mm - 600 mm depths.

Considering the neutron scatter determinations of moisture contents during this period, it may be seen that during January, February and March 1976 there was a gradual increase in voidage occlusion in the plastic media filters with an instability in April. In May 1976 the Flocor M filter increased its moisture content. Comparing the Flocor E and M filters, it can be seen from appendix 8.A.3 that the Flocor E filters lost much of their film in June and July whilst the Flocor M filter tended to maintain its film thickness.

Turning to the Biopac filters, it can be seen that the steady build up of moisture content during February and March was arrested in April with a divergence of moisture contents between the duplicate filters. The Biopac 50 filters lost much of their moisture content in May with apparently a new film build up in June and July leading to higher moisture contents at this time. The Biopac 90 filters however did not appear to lose their film and consequently moisture contents until June and July.

The break in settled sewage flow to the filters in late April 1976 did not appear to affect the moisture content too seriously apart from the Biopac 50 filters which perhaps began to unload film as a direct consequence of the drying out which occurred.

Unfortunately due to the biological sampling of the filter films at this time, no analytical data for the effluents is available to relate to the changes in moisture contents.

Considering the moisture contents of the mineral media filters during this period, it can be seen that overall much more of the voidage was occluded by moisture than in the plastic media filters.

In January and February the moisture contents of the mineral media filters was quite low suggesting a thin film with a greater moisture content in the 89/50 mm slag filters than the other three types of media. This pattern is endorsed by the volatile solids contents of the filters determined in January 1976 (figure 8.A.2). There appears to have been a gradual build up of film during March, April and May 1976 with a decline in June to much lower moisture contents in July in all four types of media. The high percentage occlusion of the voids shown by the filters in May suggests that the drying out effect during the period of no sewage application in late April was not as serious as appeared from visual observations of the filters' surfaces.

The neutron scatter measurements do not show quite the same sharp emphasis of film thickness changes with depth as the volatile solids determinations, partly as a result of the greater number of observations made through the depths of the filters smoothing out the apparent variations indicated by the volatile solids determinations.

iv) Period 4: 29/7/76 to 17/7/77 Using Eign Works Primary Settled Sewage

In period 4 which lasted practically 12 months, settled sewage was available from a newly commissioned primary settlement tank on the Eign site. Apart from occasional problems with the pump and teething problems of the settlement tank, a good quality tank effluent was available in suitable volumes for this period.

As a result of the continuity of supply it was possible to conduct four assessments of the film thickness and the associated fauna. For various reasons, these assessments could not be carried out at exactly quarterly intervals. Comparing figures 8.A.4 and 8.A.5 showing the volatile solids contents of the various filters in July and October 1976, it can be seen that in the cases of the plastic media there was little change in the overall pattern of the film distribution; the Biopac 90 filter tending to increase the weight of volatile solids throughout the filter particularly at the surface and the 1000 mm to 1400 mm depth. In the Biopac 50 filter there was little overall change in film weight, but a redistribution such that the amount of film supported by the media tended to decline with distance from the surface by October. The Flocor E and M filters showed little change in volatile solids contents.

Considering the mineral media filters, overall there was a reduction in the quantity of film in the filters; in the case of the 89/50 mm slag the reduction was confined to the upper 1 metre of the filter, whilst in the 125/75 mm slag filter, the lower regions of the filter tended to lose film whilst the upper two depths (0 - 200 mm and 200 - 600 mm) gained volatile solids. Turning to the two granite media filters, it can be seen that there were changes in distribution of the film, such that by October apart from the 0 - 200 mm segment of the filters the volatile solids supported by the media tended to decline with increasing distance from the surface.

By March 1977 (see figure 8.A.6), in all six filters it can be seen that there were marked gains in the volatile solids contents of the media at the 200 - 600 mm depth generally at the expense of the film at the other depths. In the cases of Flocor E and M the film

development at the three depths examined was very much restricted in March with slightly increased weights of film being supported at lower regions of the filters. This pattern of film distribution was very much altered by May 1977, when in the case of Biopac 90 (figure 8.A.7) the 200 mm to 1000 mm depths of the filter lost the majority of its film. In the Biopac 50 filter the change in volatile solids distribution between March and May 1977 was more complex. All the depths of the filter apart from 200 - 600 mm gained weight, whilst the 200 - 600 mm depth lost approximately 60% of its volatile solids contents. In both types of Flocor, the filters increased the film volatile solids contents particularly at the two upper levels. The most dramatic changes in volatile solids contents occurred in the mineral media filters, with most depths in all four types of filters increasing their solids contents. During this period between March and May 1977 there appeared to be changes in the distribution of film with depth in these mineral media filters; the 200 - 600 mm depth in particular losing volatile solids whilst the lower depths showed vast increases in the volatile solids produced.

By August 1977 (figure 8.A.8) the film distribution in the filters had again changed, with a marked loss of volatile solids at all depths within the mineral media filters, but essentially only minor changes occurred in the distribution of volatile solids in the plastic media filters. The Biopac 90 filter tended to gain film at the lower depths with a slight loss of film between 0 and 600 mm from the surface. In the Biopac 50 filter, there was a more even distribution of film in August 1977 compared to May, with overall a similar weight of volatile solids. In the two Flocor media filters there was a general loss of volatile solids. As previously noted, the Flocor filters

supported very much less film at any time than the two randomly packed Biopac filters, being approximately 25% of the weight supported by the Biopac filters, and per given volume supporting a similar amount of film to the mineral media filters.

Considering the results of the neutron scatter determinations carried out during the period (appendix 8.A.2), it may be seen that for the plastic media filters, there was a general increase in the occluded voidage during the autumn and winter, particularly towards the centres of the two Biopac filters and at the bases of the two Flocor filters. By January 1977, after a loss of film in November 1976, the Biopac filters retained very large quantities of water in the upper halves of the filters. In the Biopac 90 filter in January 1977 at 600 mm from the surface, less than 20% of the media volume was voidage. In the two Flocor media filters the pattern of voidage occlusion by moisture was markedly different. Apart from the bases of the filters, very little of the available voidage in the filters was occupied by moisture. These observations are in keeping with the results obtained from the comparative assessments of volatile solids contents at different depths within the different filters. The neutron scatter observations indicated the retention of much moisture in the bases of both the Flocor E and M filters. This moisture must have been retained by a denser film than higher in the filters, but it was not possible to tell whether the nature of the flora was different. Unfortunately, it was not possible to obtain samples of the filter media and associated film at the bases of these filters.

In February 1977, the moisture content of the filters was similar to that observed in January but by the neutron scatter

determinations in March, changes had occurred. Much of the moisture content present in February did not occur in any of the plastic media filters in March. This decline in March was followed by a new increase in the moisture content by May 1977; however in the Biopac 90 and 50 filters these increases in moisture content were at noticeably lower depths in the filters. A further interesting feature is the appreciable voidage occlusion in the Flocor M filter in May 1977. Unfortunately due to pump difficulties the flows were not maintained in March and April 1977, and therefore it is difficult to assess whether the loss of moisture content during this period was a direct result of the reduced organic loading to the filters or a natural unloading of the filter film. The average moisture contents of the filters in June and July was similar to that observed in May, but there was a change in the distribution, particularly in the Biopac 50 filter where the greatest moisture content tended to be higher in the filter than previously. Although the majority of the moisture contents at the bases of the Flocor E and M filters during the spring of 1977 was lost, there were indications that a slight hold up of moisture still occurred at the bases of the filters.

Comparing the changes in the moisture contents of the mineral media filters to those of the two Biopac filters during this period, it is immediately apparent that although the overall available voidage at any time was less in the mineral media filters, the voidage occupied by moisture was also less. This observation is in keeping with the smaller volatile solids contents determined for the mineral media filters. During the autumn of 1976, the build up of the moisture content in all four mineral media filters was slower than in the Biopac filters, with the 89/50 mm slag filters first showing a

reduction in the free voidage in December. During January and February 1977, all the filters increased their moisture contents particularly at depths between 200 mm and 800 mm from the surface of the filters. In March 1977, the moisture content of the filters declined, with a fairly evenly distributed moisture content being observed in all the filters during the early summer.

Throughout the period, apart from the more rapid increase in moisture content of the 89/50 mm slag in December 1976, all the filters behaved similarly, showing similar moisture contents. Another feature of the neutron scatter data shown for this period for all the filters was the marked comparability in moisture contents of the duplicate filters. None of the duplicate filters showed any consistent differences in moisture contents.

During this fourth study period, it was possible only to carry out two retention time determinations an all sixteen filters, one in October 1976 and the other in July 1977. From appendix 8.A.3, it can be seen that there were appreciable differences between the 16%ile and the 50%ile tracer retention times observed on the two occasions; the July 1977 determination showing very much slower tracer emergences than the October 1976 observation. It may be seen that on the two occasions, the percentile retention times of the duplicate filters differed greatly in several cases, a particularly marked one being the 50 percentile times for the Biopac 90 filters in October 1976. Considering the percentile recovery time for all the filters over the four sampling occasions, it can be seen that the presence of the biological sample shafts did not cause consistent differences between the two filters; therefore although the biological sample shafts may on occasion be responsible for short circuiting of tracer through

the filters, they were not wholly responsible for the variations between the duplicates. Further, it can be seen that the amount of the applied tracer recovered varied greatly between the various filters and duplicates. These variations were in the most part due to the inaccuracies inherent in the method of retention time determinations employed. As previously shown, the tracer tended to be washed out of the filters in peaks of flows and concentrations. If the effluent from the filter happened to be sampled seconds after each of these peaks, this would result in a depressed overall recovery of the tracer and also tend to increase the 16%ile and 50%ile recovery times since the major concentrations and variations occurred within the first few minutes of application. If the peak concentrations were not sampled during the initial emergence, then greater emphasis was laid upon the emergence of the tracer at a later time from the filters, tending to increase the percentile recovery times.

Comparing the results for the neutron scatter observations in October 1976 and July 1977 to the retention time results, it may be seen that although in general the retention times shown by the filters in July were greater than in October, the moisture contents were quite similar, with perhaps greater moisture contents in October; the exception to this trend was the Flocor M filters where the 16%ile recovery times in particular were less in July than in October, although the moisture contents were quite similar. If the retention time determinations were reasonably accurate, then the greater retention times shown in July 1977 than October 1976 (whilst the moisture contents were similar) must be due to a change in the nature of the film. Also, the lack of correlation between the retention times and the moisture contents could in part be explained by the

different times at which the determinations were carried out.

Comparing the volatile solids and neutron scatter results gathered during all four periods of this study to values obtained by other researchers, one of the similarities is the relatively uniform distribution of film throughout the depth of the Flocor filters (particularly Flocor E). Bruce and Merkens (1973), using a neutron scatter probe, showed that there was no significant variation of film thickness within the depth of the plastic media filter (Flocor E). Bruce (1970) had reported that a greater thickness of film developed on the mineral media than the modular plastic media. The neutron scatter data at Hereford indicated a similar trend, and the volatile solids in the Flocor filters tended to be slightly less than in the mineral media filters. However, this pattern was not followed by the two random packed plastic media Biopacs 50 and 90. The volatile solids supported by these media at Hereford was frequently twice as much per given volume as that supported by the mineral media.

Truesdale et al. (1961) found that the film thickness developed within low rate filters was proportional to the specific surface area, thus given surface areas tended to support similar quantities of film. From figure 8.A.16 showing the mean volatile solids supported by the different media throughout the study plotted against their specific surface areas, it can be seen that, apart from the modular plastic media Flocor E and Flocor M, the amount of volatile solids supported was proportional to the specific surface area of the media, and that on average all the media apart from the two Flocors supported 185g of volatile solids (dry weight) per square metre of available surface.

From the data presented in this section, it can be seen that there was only a limited correlation between the weight of film within the filters and their retention times. This can be as a result of short circuiting within the filters when a thick film has developed. Eden et al. (1964) found that there was no direct correlation between film weight and retention times and concluded that the use of retention times to predict the film weight within a filter was misleading. Peaks in retention times were shown to be associated with reductions in the rate of film accumulation or even a loss of film from the filters.

Figure 8.A.1. Volatile Solids in the Various Filters.

October 1975

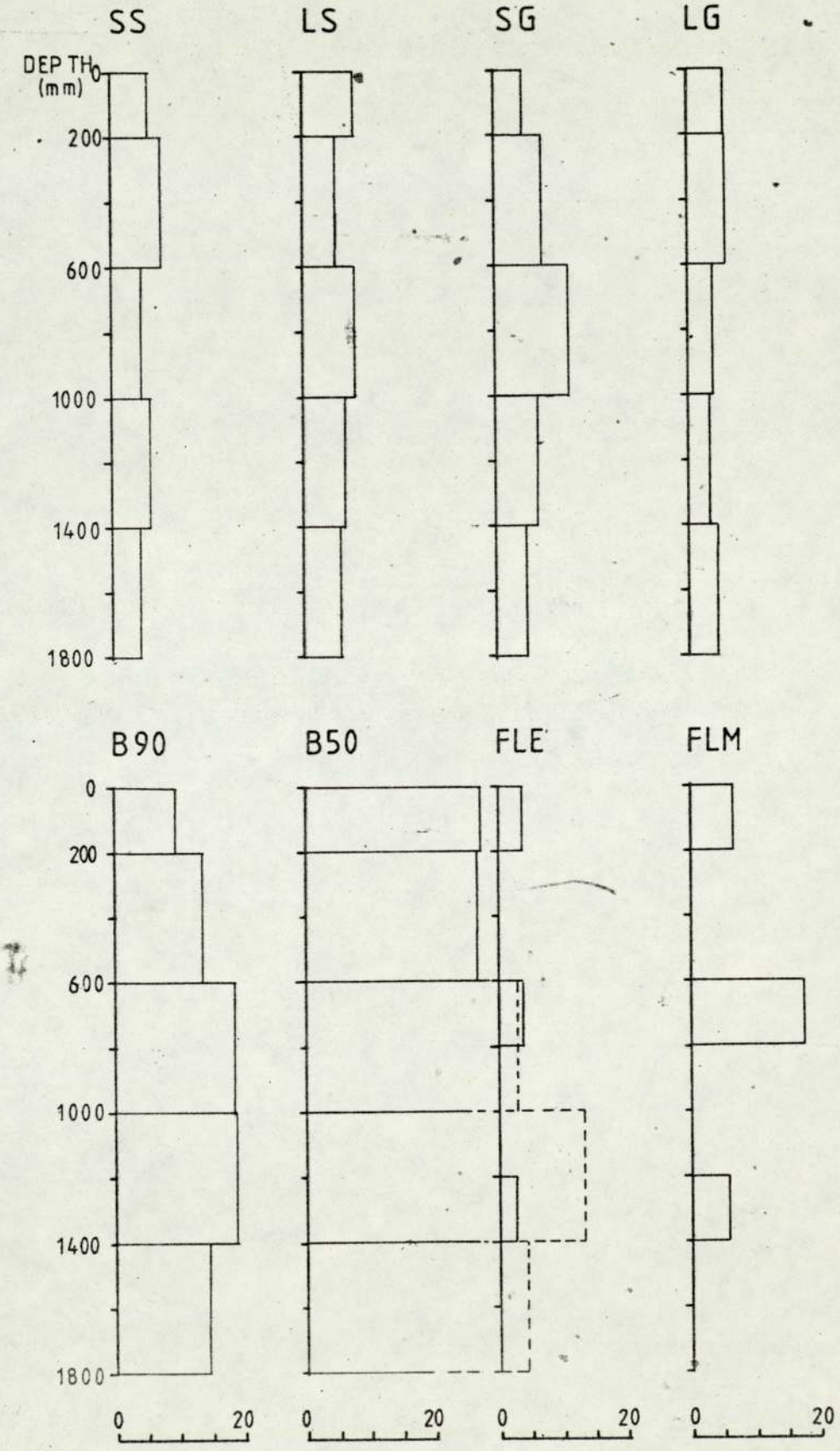


Figure 8.A.2. Volatile Solids in the Various Filters.

January 1976

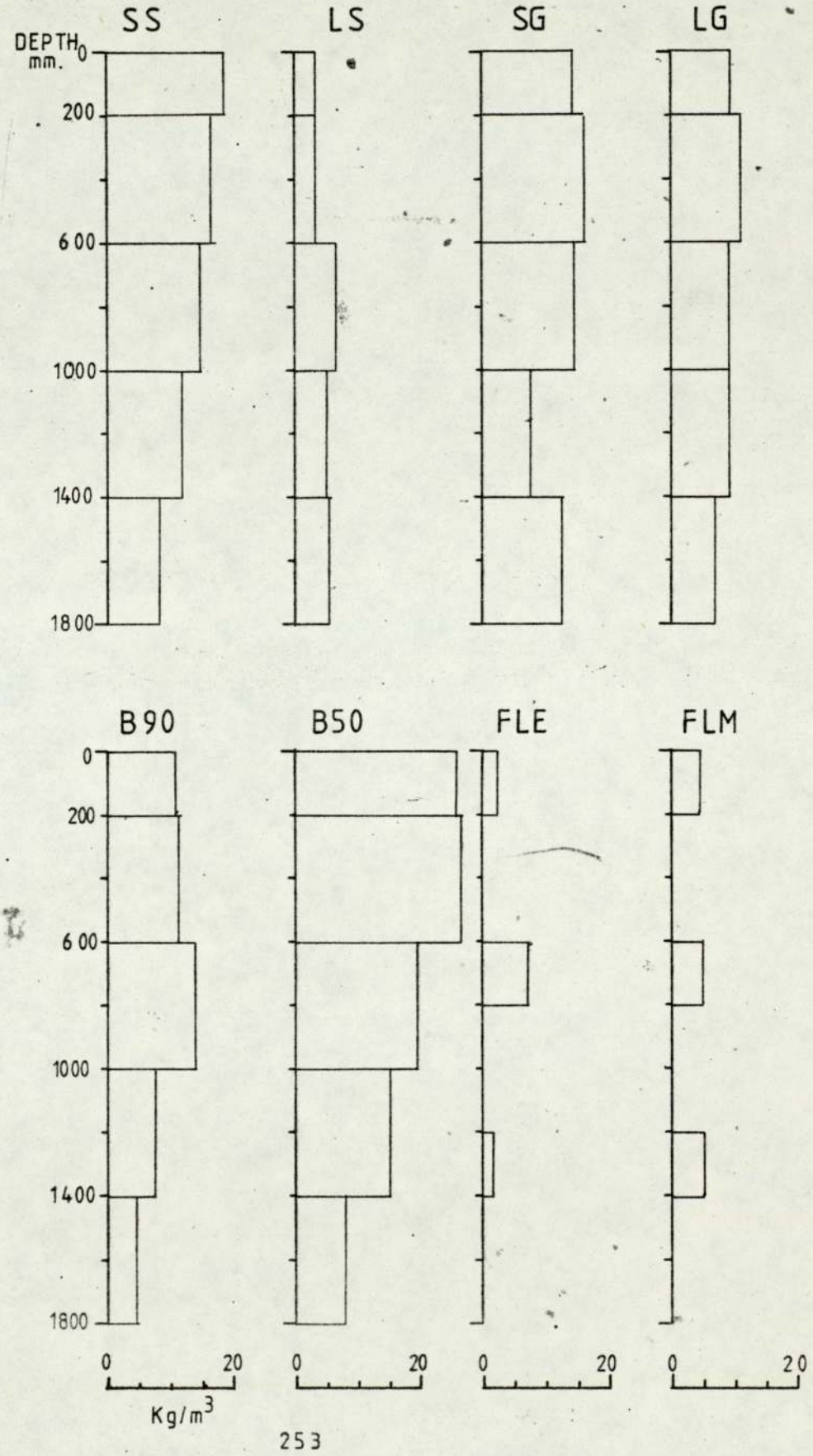


Figure 8.A.3. Volatile Solids in the Various Filters.

April / May 1976

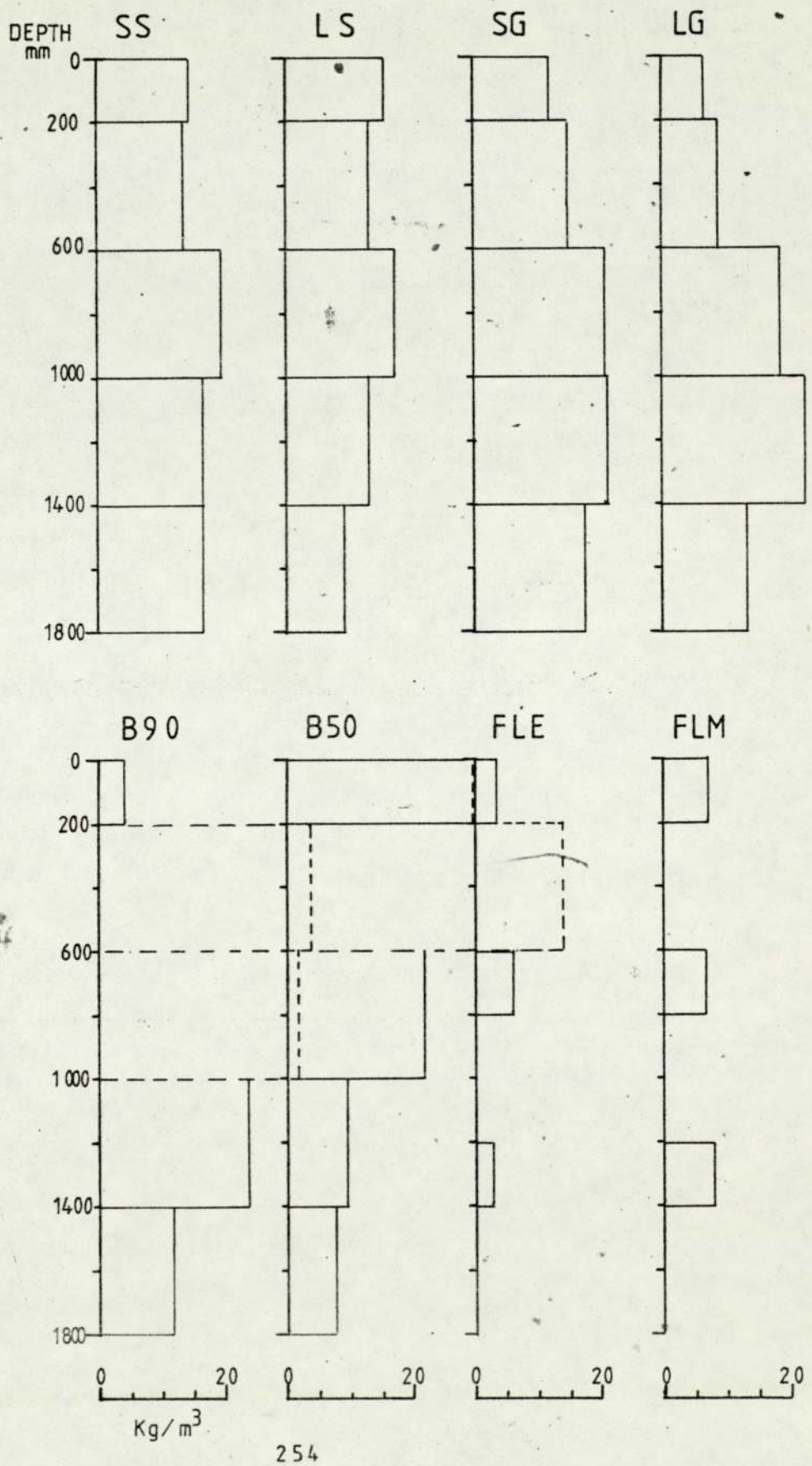


Figure 8.A.4. Volatile Solids in the Various Filters

July 1976

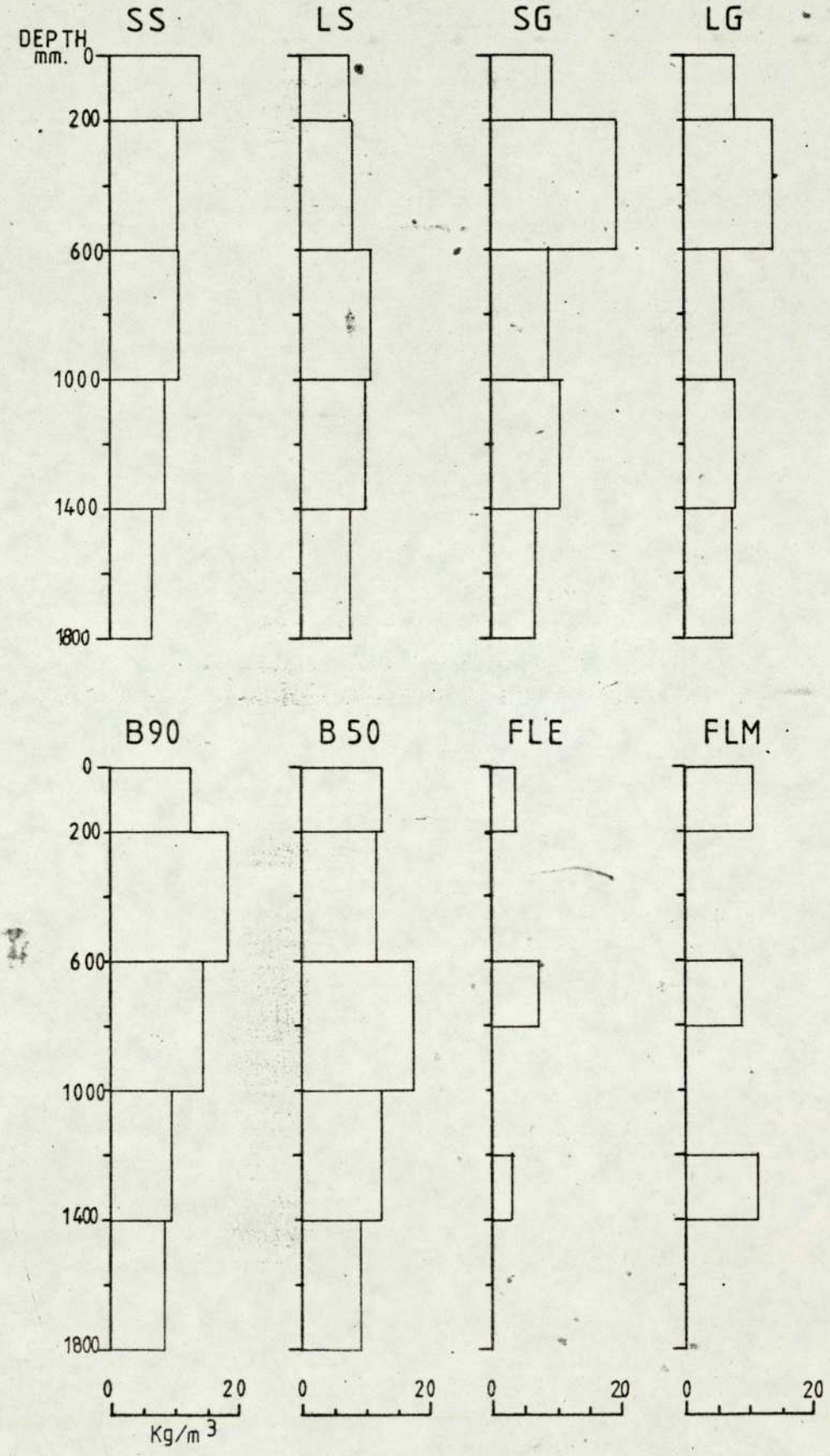


Figure 8.A.5. Volatile Solids in the Various Filters.

October 1976

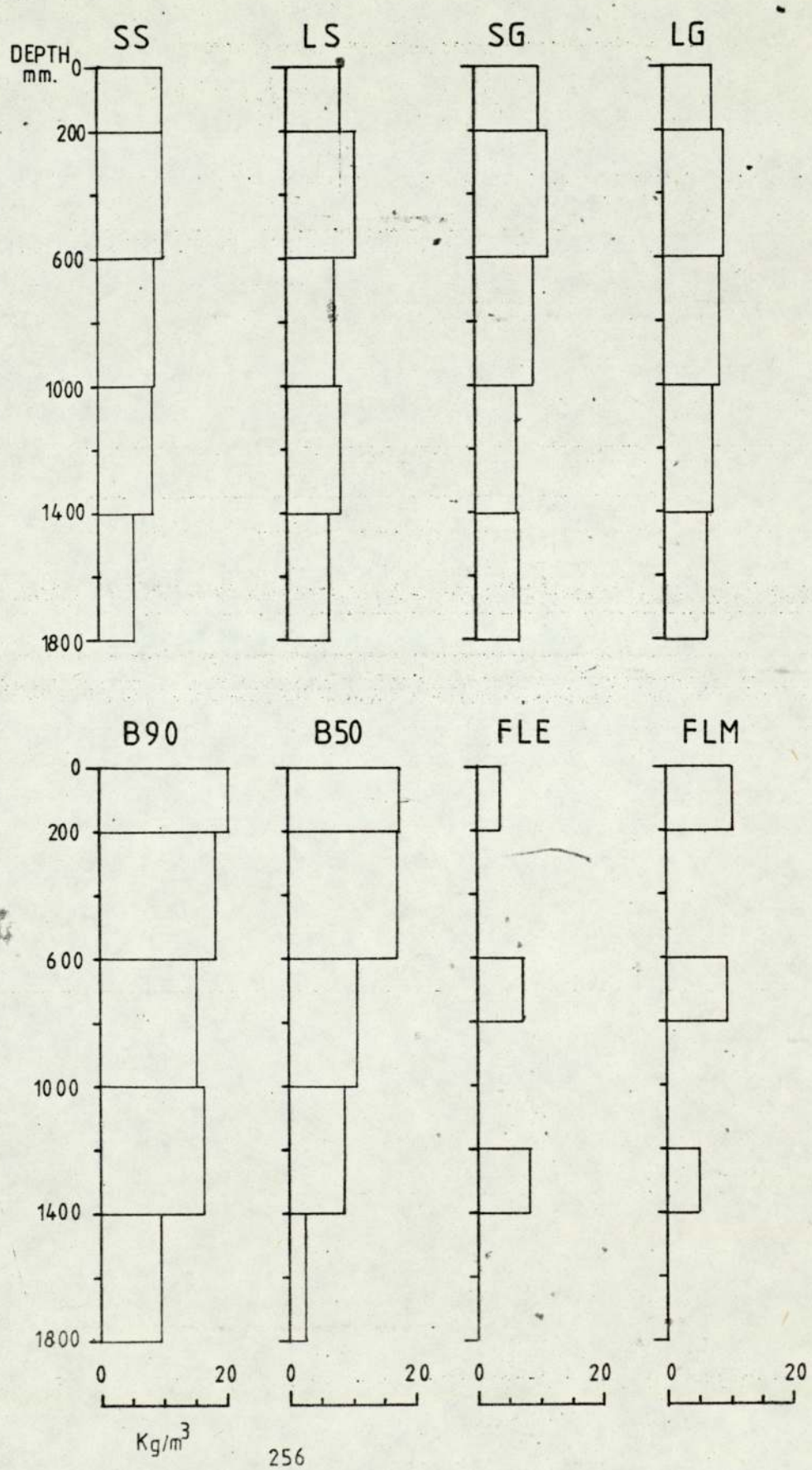


Figure 8.A.6. Volatile Solids in the Various Filters.

March 1977

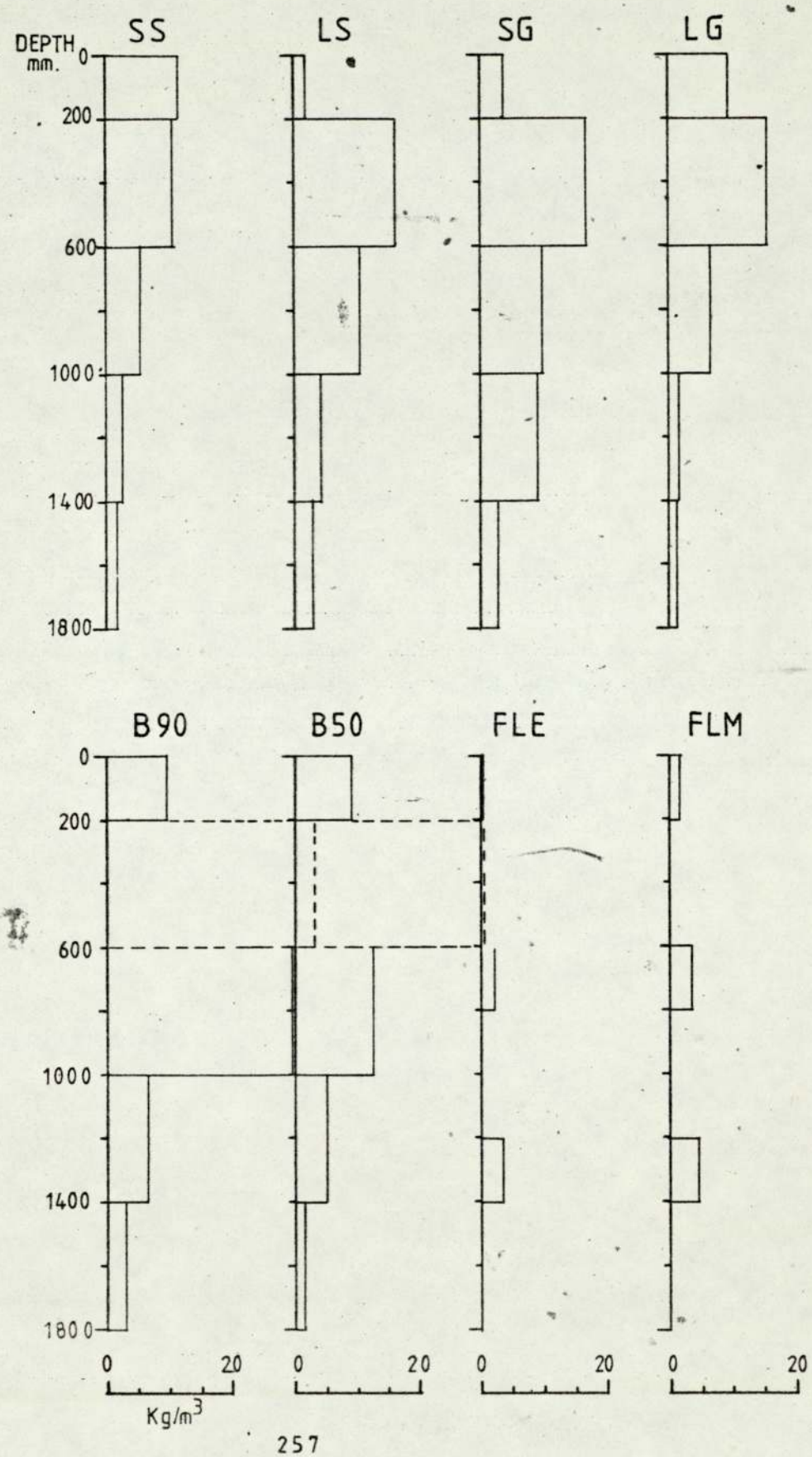


Figure 8.A.7 Volatile Solids in the Various Filters.

May 1977

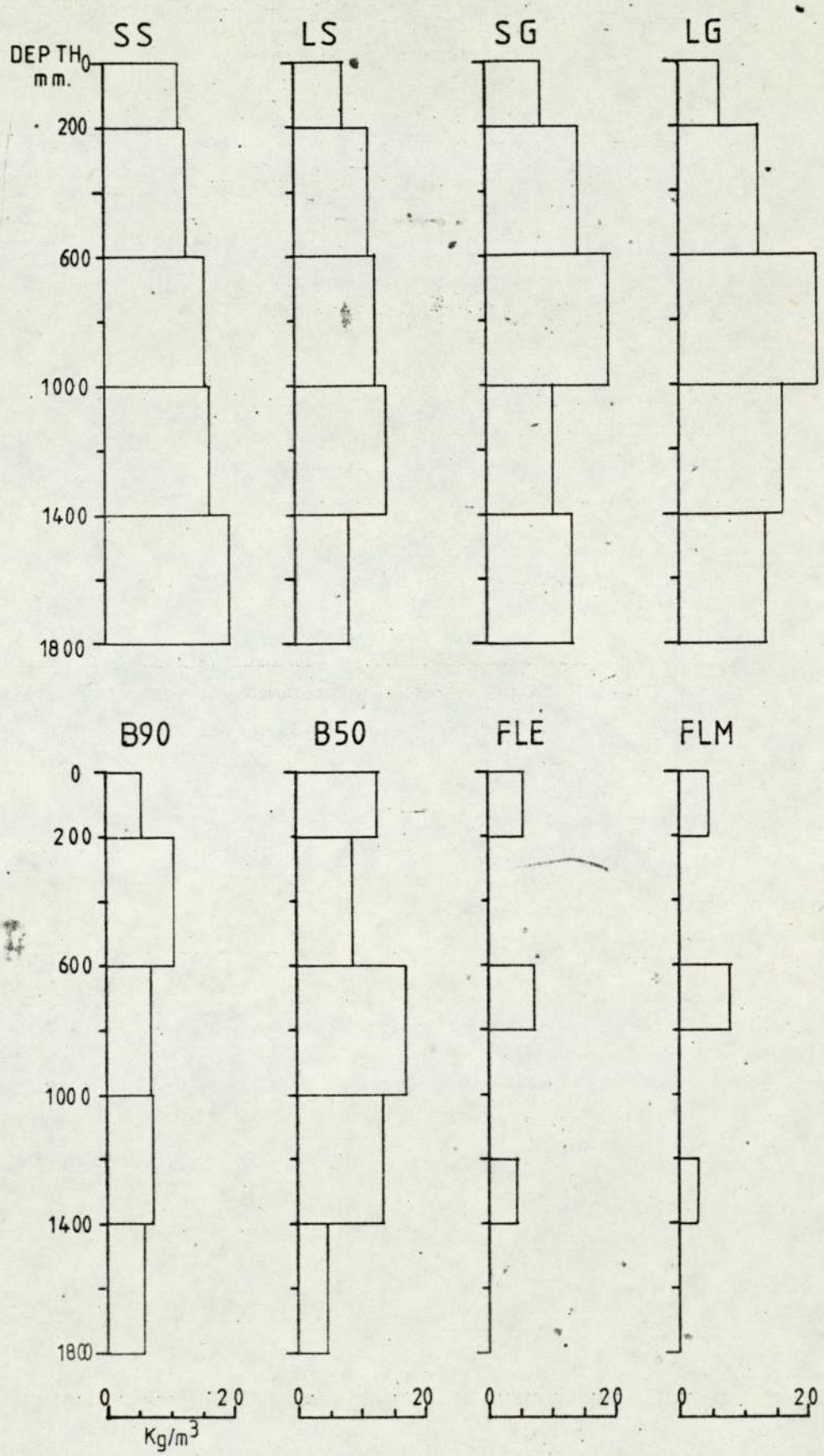
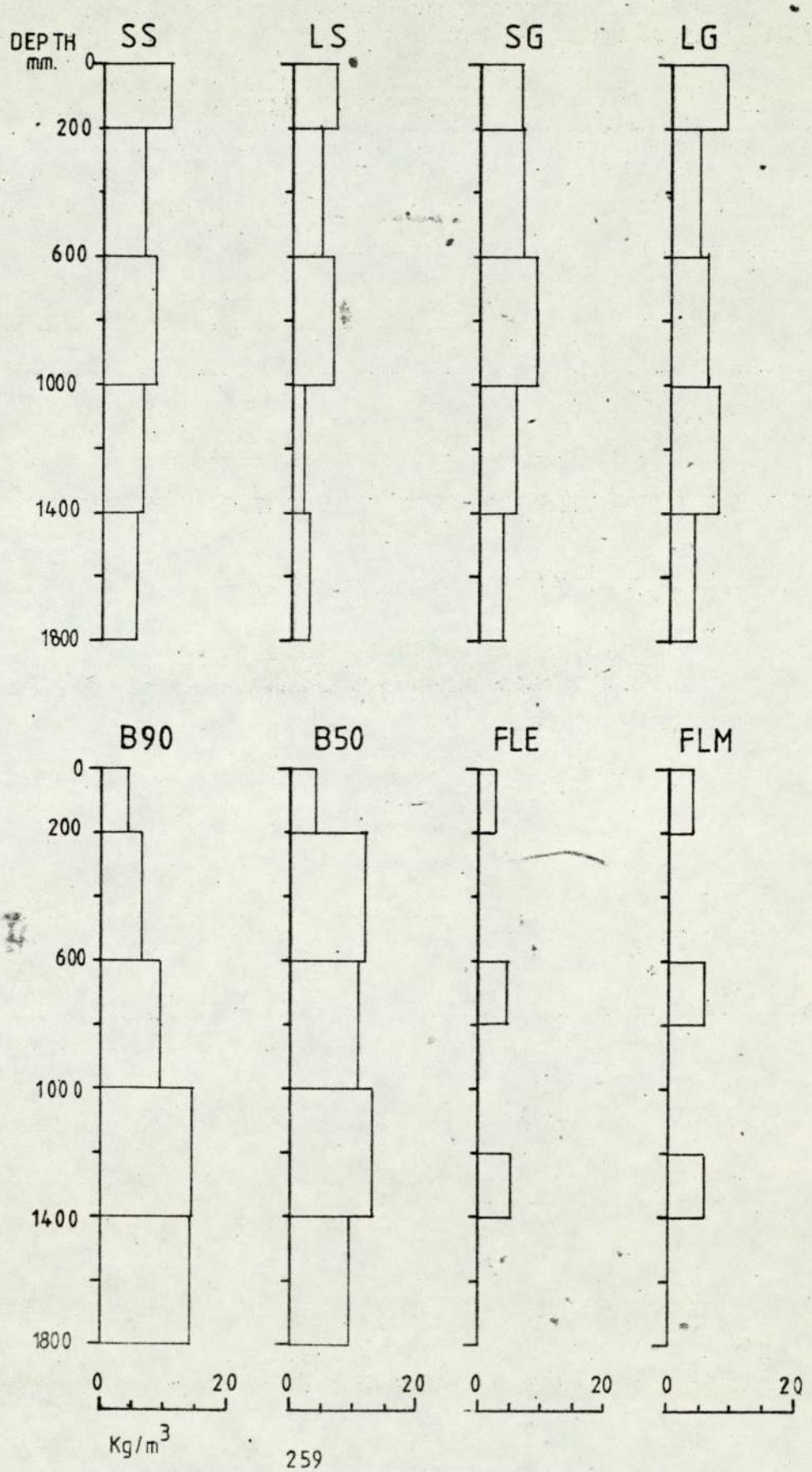
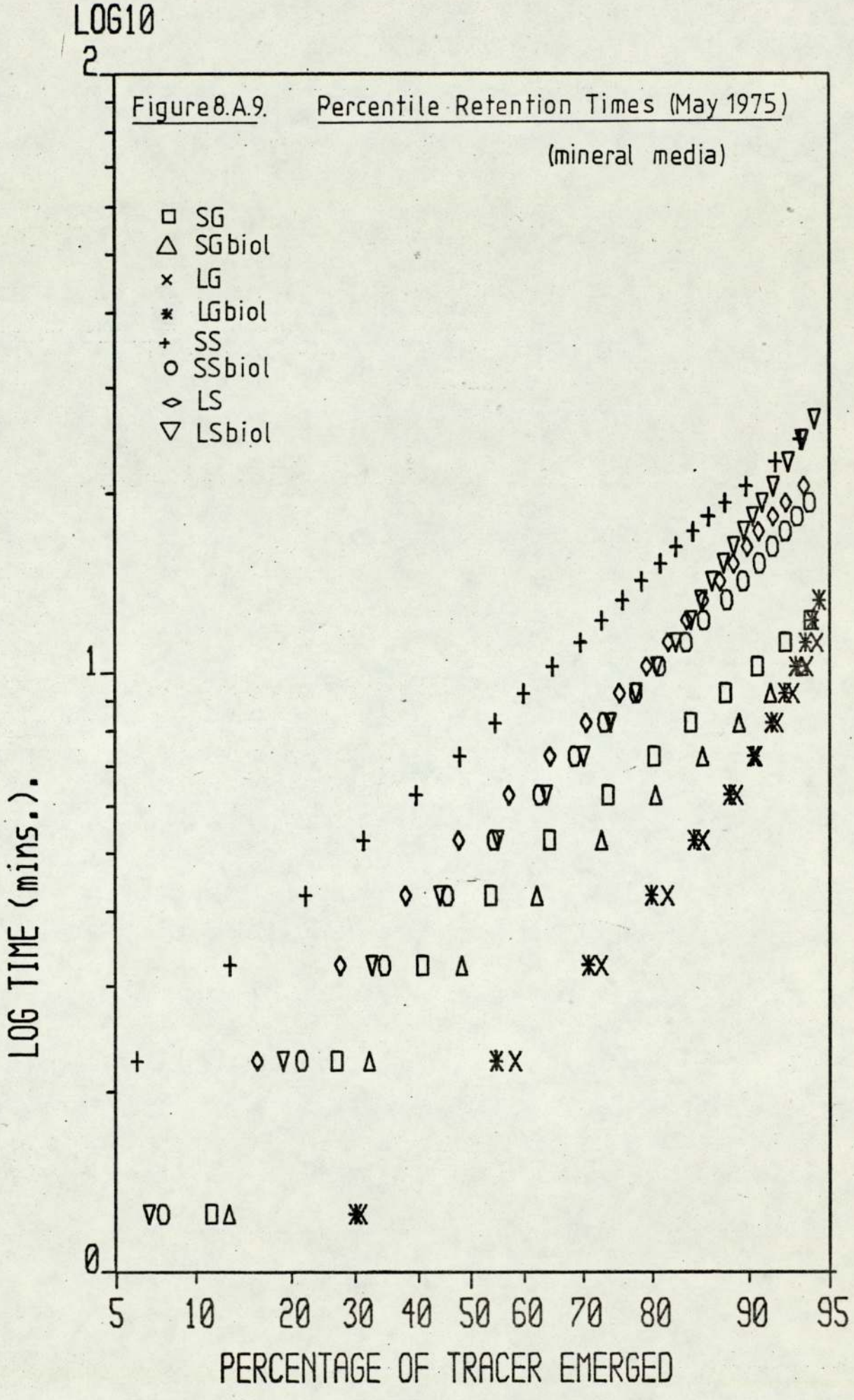


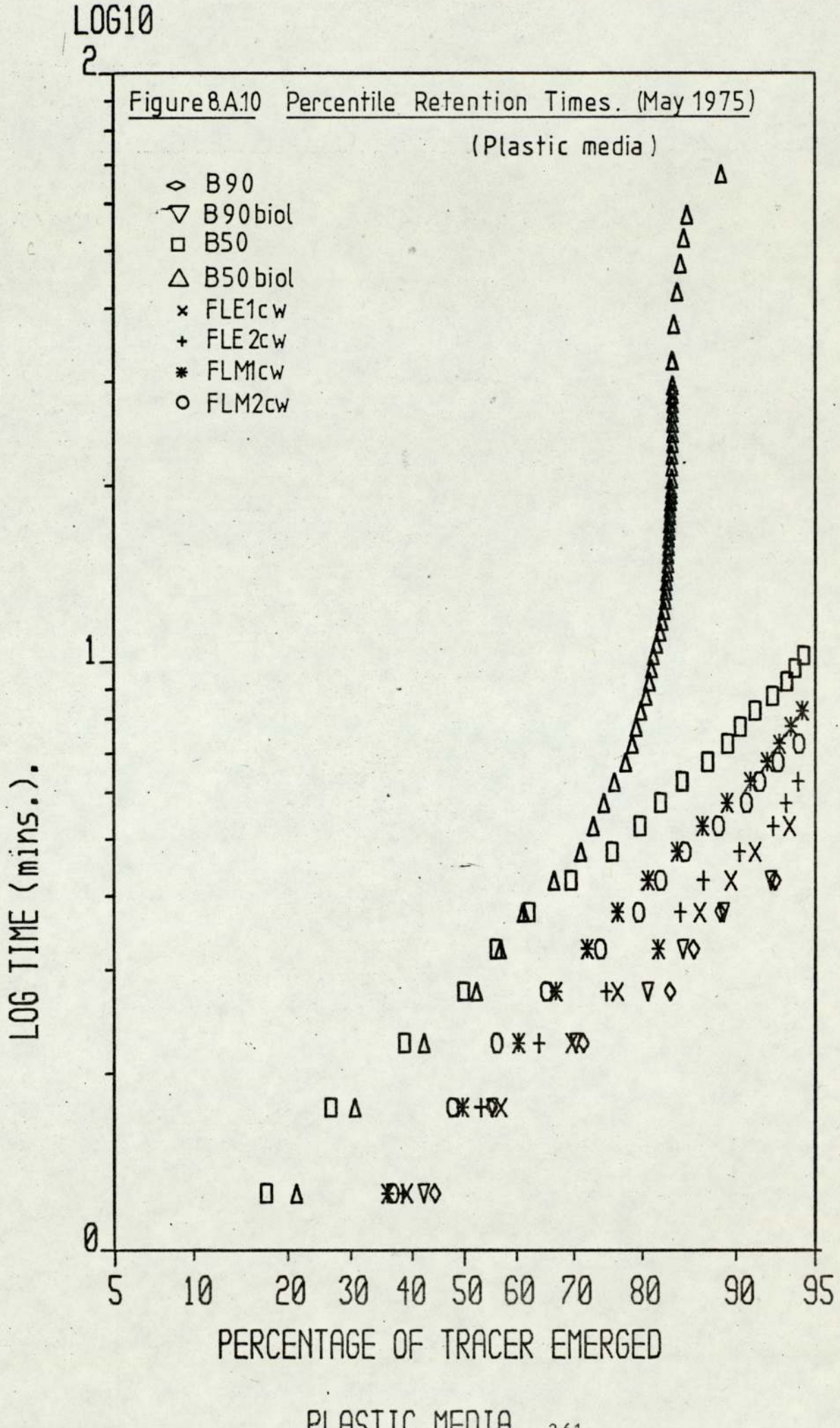
Figure 8.A.8. Volatile Solids in the Various Filters.

August 1977





NATURAL MEDIA.



PLASTIC MEDIA.

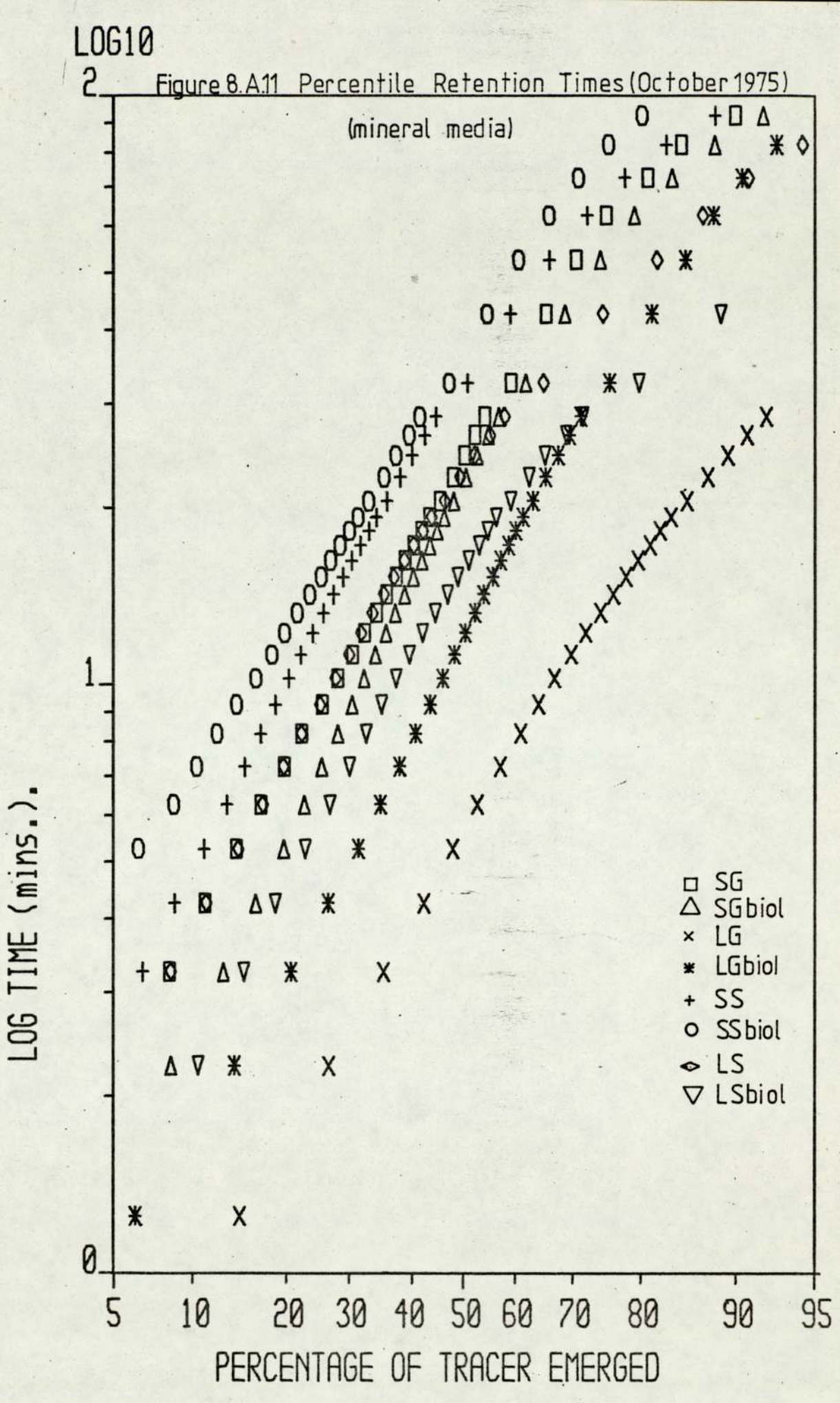


Figure 8.A.11 Percentile Retention Times (October 1975)

NATURAL MEDIA.

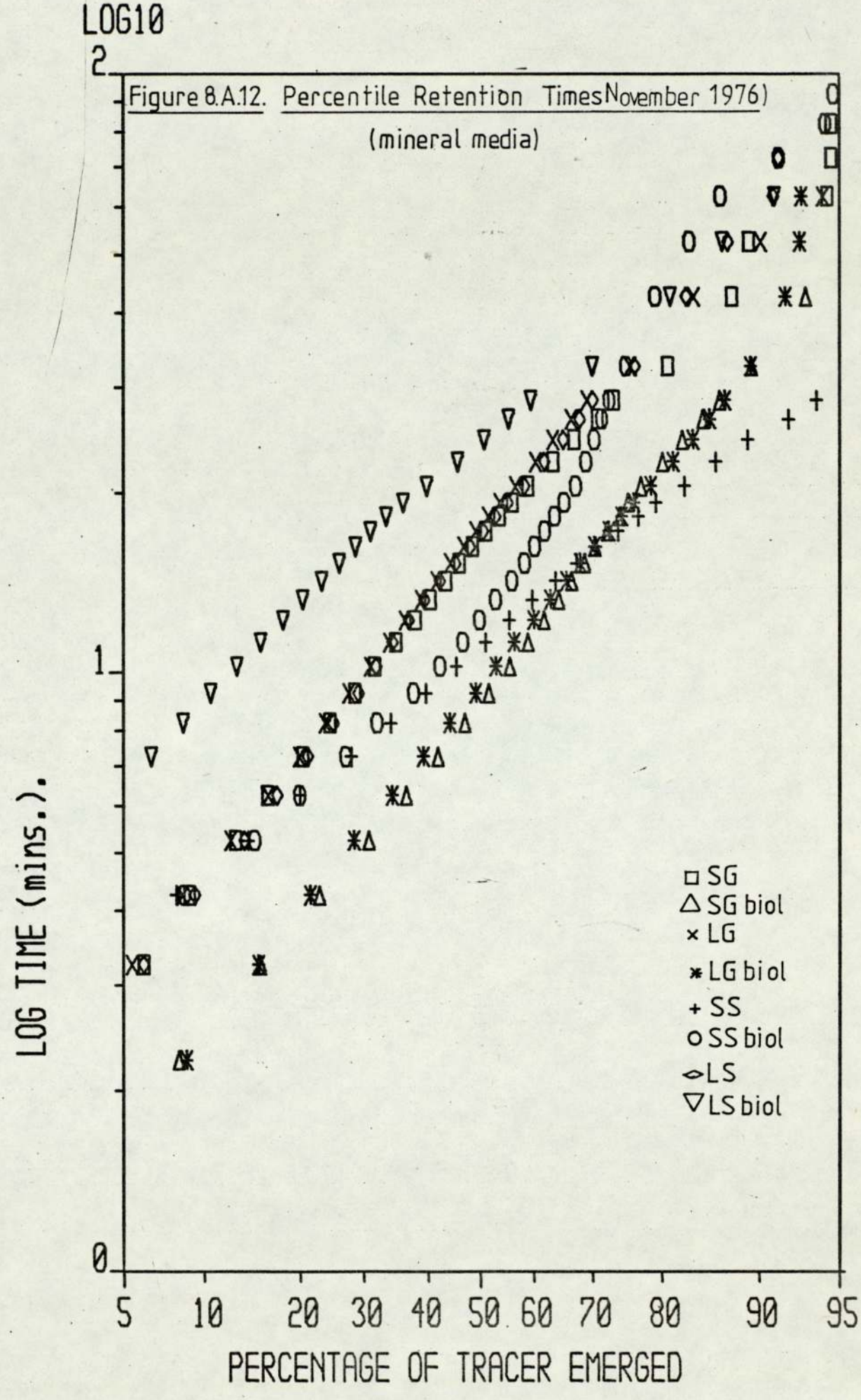
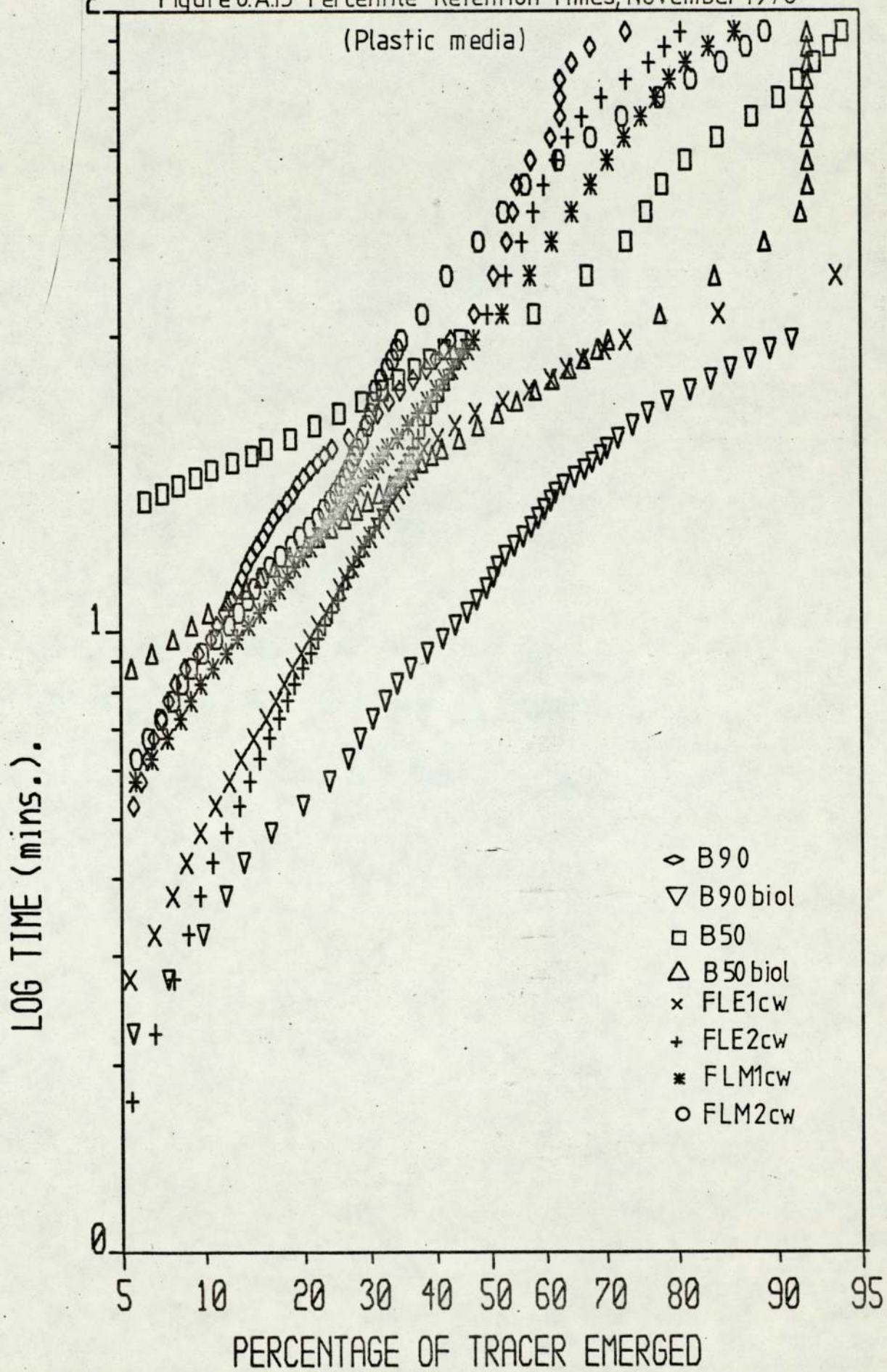


Figure 8.A.12. Percentile Retention Times November 1976)

(mineral media)

NATURAL MEDIA.

Figure 8.A.13 Percentile Retention Times, November 1976



PLASTIC MEDIA.

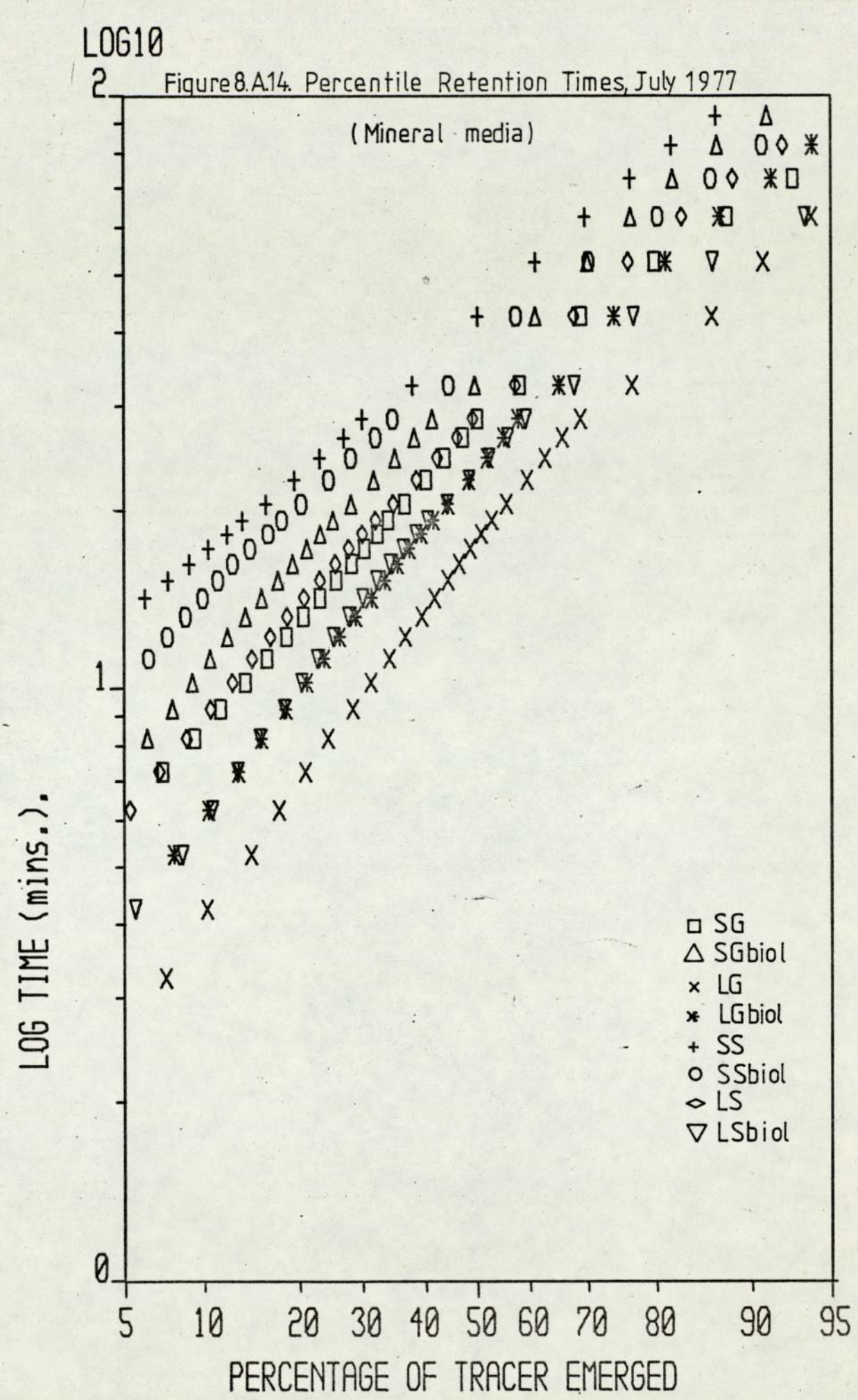


Figure 8.A.14. Percentile Retention Times, July 1977

NATURAL MEDIA.

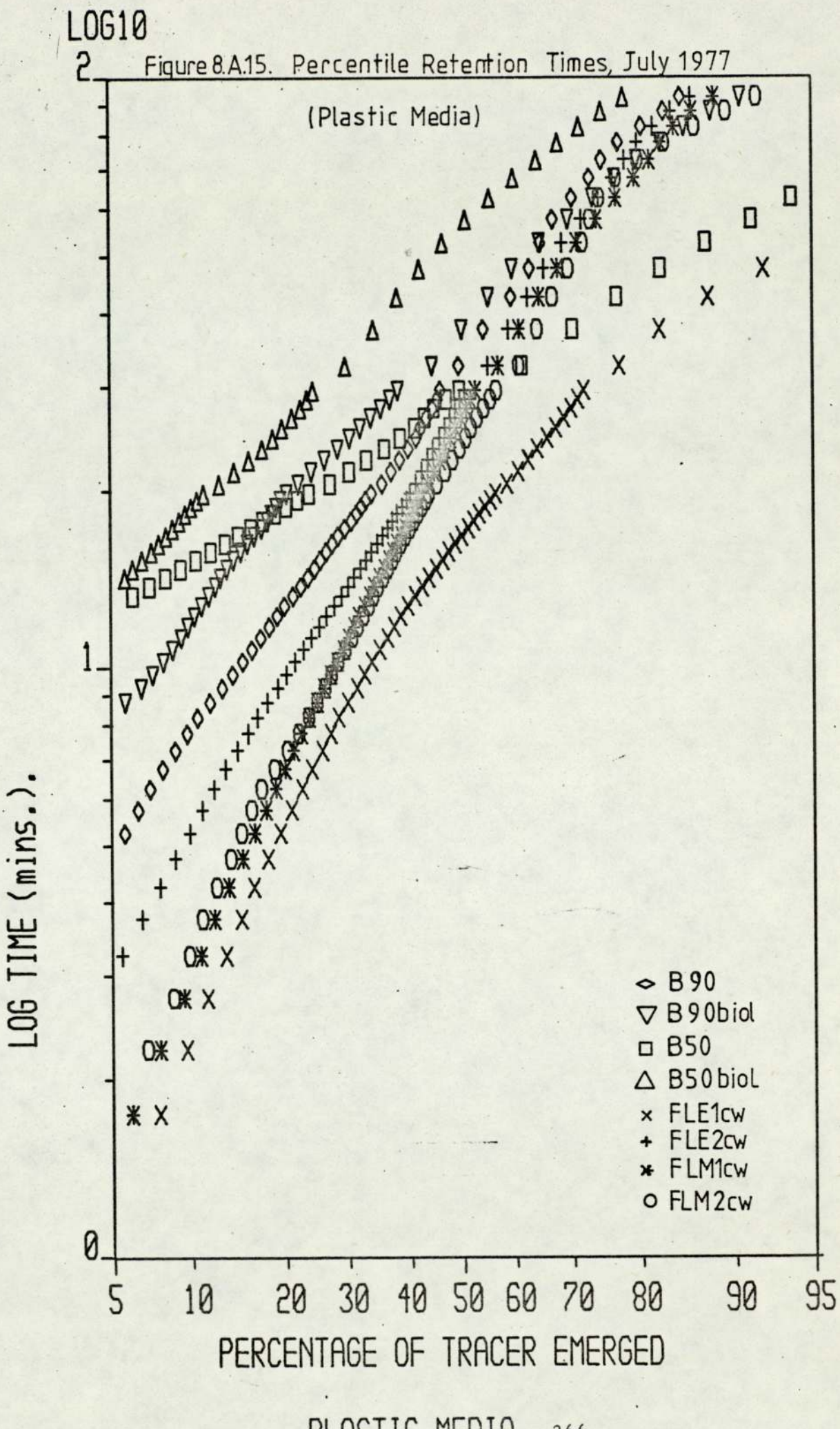
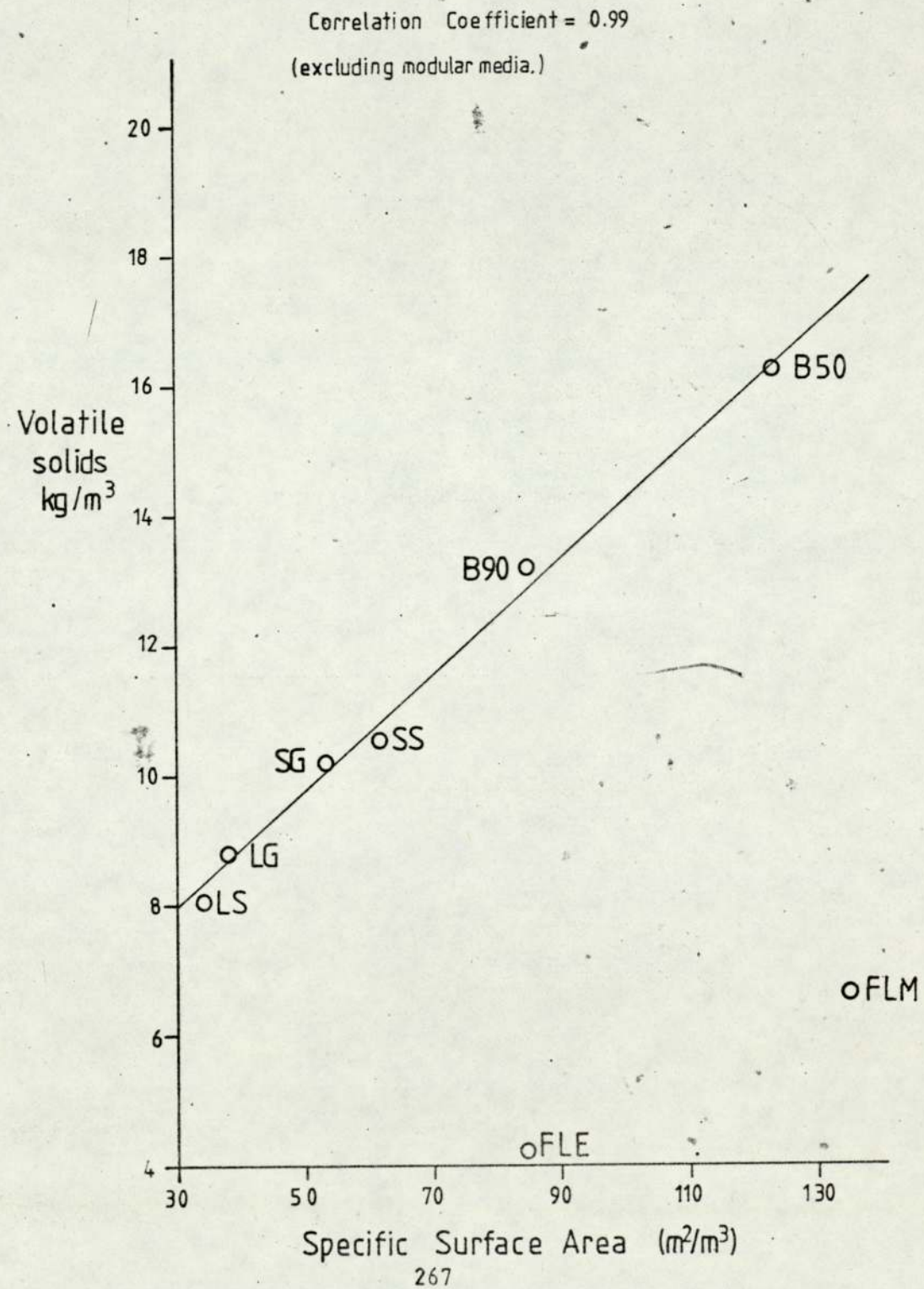


Figure 8.A.15. Percentile Retention Times, July 1977

PLASTIC MEDIA.

Figure 8.A.16. Mean Volatile Solids throughout the study vs. Specific Surface Area of the Various Media.



B. Biological Analysis of the Filter Films

During the preliminary planning of the project, it was envisaged that the filter films would be examined every three months. In order to obtain a sample of media and its associated film representative of the film in the body of the filter, three perforated steel shafts containing baskets of media were installed in each of the filters, thus permitting approximately nine months of uninterrupted re-colonisation for each basket of media within the shafts before removal for examination. A description of the shafts' dimensions and installation may be found in chapter 4. In the cases of the two modular media (Flocor E and Flocor M), it was only possible to obtain subunits from three different depths within the filters. The size and positioning of these units is also described in chapter 4.

On removal from the steel shafts, the 'Netlon' baskets of media were taken to the laboratory for removal of their film and examination. The method of removing the film from the individual pieces of media has been described in chapter 6. The determination of the weight of film, its volatile solids content and the keys used for identification of the flora and fauna are also detailed in chapter 6.

I. Results:-

As previously described, the study at Hereford was divided into four periods as a result of having four different supplies of sewage. The changes in sewage supply were dictated by reconstruction of the treatment works, and as a consequence the four periods were of differing lengths. Due to the discontinuity of supply to the pilot tank, maintenance operations and staffing difficulties, it was not possible to carry out the examinations of the biological film at

exactly quarterly intervals as originally envisaged, however, over the entire study period of two years, eight examinations were made.

One assessment was made of the filters' film in the first period in October 1975 after ten weeks of operation.

Only one assessment of the filter film was made during the second period in which crude sewage was supplied to the filters. This examination was carried out in late January 1976, just as the crude sewage supply was being cut off.

During the third period from 29th January to 29th July 1976, two examinations of the filter films were possible in April/May and July.

In the final period which lasted practically 12 months from 29th July 1976 until 17th July 1977, four examinations of the filter media and associated film were made; one in late October 1976, one in late February/early March 1977, another in May 1977, and the final examination in early August 1977.

Five examinations were also made of the protozoa present in the effluents from the high rate filters. These samples were collected and the protozoa identified by members of the Water Research Centre staff.

All the results of the biological analyses are tabulated in appendices 8.B.1 to 8.B.8.

II. Discussion

By October 1975, during the first period when settled sewage was applied to the mineral media filters at a nominal flow of 2.8 $m^3/m^3/d$ and to the plastic media at 5.6 $m^3/m^3/d$, it was evident that a large build up of film had occurred in all eight types of media; most particularly in the Biopac 50 and 90 filters. From appendix 8.B.1 it can be seen that the dominant members of the flora in most filters were zoogleal bacteria. In some of the plastic media filters however, their abundance was not as great as that of certain fungi. In Biopac 50 and 90, Fusarium aquaeductuum was a very significant member of the flora at all depths, in both prostrate and erect forms. Nematode worms showed rather limited occurrences in all the filter films and were not observed at certain depths within some filters. Considering the ciliated protozoa, it can be seen that the motile forms - holotrichida and hypotrichida - were far more common than the attached peritrichida. Rotifera were also rarely observed. At the surface of the filters a unicellular green alga was also noted. These microscopic observations of the filter films suggest that the films were unstable, probably due to their immaturity. More mature filters might be expected to have greater proportions of sessile ciliated protozoa. The W.R.C. protozoal examination of the filter effluents (23/10/75) (appendix 8.B.1) showed that the two granite media filters had the greatest diversity with perhaps surprisingly the Flocor E filter having the next greatest diversity. The Biopac filters had very restricted protozoan diversity. At the time of sampling the Biopac 50 filters were ponding and the Biopac 90 filters possessed very thick films, which probably restricted the protozoan development. As in the case of the microscopic examinations of the

filter films, the effluents contained a preponderance of motile protozoa.

In the mineral media filters, Psychoda alternata was the dominant macrograzer with limited numbers of Lumbricillus lineatus, Chironomus dorsalis and Enchytraeus albidus. In view of the difficulties of identification of enchytraeid worms and the similar niches occupied by the various species, the enchytraeid components of the fauna have been recorded as the family Enchytraeidae. Periodical identification of these worms indicated that they were predominantly Lumbricillus lineatus; however, doubt has been expressed (Solbe et al. 1967) as to whether specimen from biological filters identified as L. lineatus are not in fact L. rivalis.

Generally, in all the mineral media filters the Psychoda larvae outnumbered the pupae, and the numbers present were greatest towards the top of the filters; also it may be seen that the numbers were not directly related to the volatile solids contents. The enchytraeid worm populations were greatest towards the bases of the filters where the Phychoda were least represented. However, the number of enchytraeid worms present were much less than the pyschodid numbers. Chironomus dorsalis was only present in the 125/75 mm slag in the mineral media filters. This filter also had a small population of Enchytraeus albidus in its lower half; the population showed a marked tendency to increase with depth. Therefore, though of the mineral media the 125/75 mm slag had a low specific surface area, it had the greatest diversity of the macrograzers. This probably resulted from the greater immaturity; a stable fauna not having yet developed, whilst the three other mineral media filters were slightly more advanced.

Turning to the plastic media filters, it is of interest to note that the modular Flocor media showed the greatest diversity, although very much restricted when compared to the mineral media. Both types of Biopac had developed very thick films which were grazed solely by Psychoda alternata. Comparing the numbers of Psychoda alternata in the two Biopac filters, it can be seen that the Biopac 50 filter had a far greater proportion of pupae in its population than the Biopac 90 filter and a lower absolute number of larvae. This suggests that a generation of the Psychoda in the Biopac 50 filter were more advanced than in the Biopac 90 filter. Another interesting point is that the total number of psychodid larvae and pupae in the Biopac 50 filter were comparable to that in the Biopac 90 filter, even though a far thicker film was present in the Biopac 50 filter and the Biopac 50's greater specific surface area. This suggests that the film thickness was so great that grazing activity was restricted.

The Flocor filter films probably had greater diversity than the Biopac filters as a result of the excessive film development in the Biopac filters and the highly regular large voids in the Flocor media.

Both of the Flocor media tended to support less film and also less Psychoda alternata than the Biopac filters. The high volatile solids content at the 600 to 800 mm depth in the Flocor M filter was as a result of the packing arrangement of the modules which resulted in a redistribution of the sewage in the filter at the 600 mm level.

The second biological examination of the filters in January 1976 was at the end of the second study period during which low flows of crude sewage were applied to the filters. This second period of 9 weeks resulted in slightly reduced organic loadings being applied to the filters and a vast change in the nature of the sewage applied.

From figures 8.A.1 and 8.A.2, it can be seen that the volatile solids contents of the 89/50 mm slag had increased dramatically during the period; slightly less marked increases in volatile solids contents were also made by the 89/50 mm granite and 125/75 mm granite filters. The 125/75 mm slag filter showed a loss of solids throughout the depth, the loss being greatest at the surface, so that by January 1976 the quantity of film supported by the 125/75 mm slag was much less than the three other mineral media filters. Generally, the plastic media filters also lost film, particularly heavy losses being recorded in the Biopac 50 filter, which still supported greater solids content than the three other plastic media and also the 600 - 800 mm depth of the Flocor M filter, which lost its previously large accumulation of film.

Turning to consider the nature of the film, it may be seen by comparing appendix 8.B.1 to appendix 8.B.2 that the flora and associated microscopic grazers in the Flocor filters suffered a reduction in diversity between October 1975 and January 1976 which was particularly marked for the protozoa. However, in the cases of the two Biopac media, an opposite trend occurred. In the film examination of October 1975, no protozoa were noted in either of the filters whereas in January 1976 protozoa were observed at all depths in both filters. In the Biopac 50 filter, a general reduction in the number of filamentous bacteria also occurred between October and January 1976. The trends recorded for the Biopac filters suggest that a reduction in the quantity of volatile solids supported by the media resulted in improved conditions for protozoal development and the reduction in filamentous bacterial populations.

Considering the two grades of granite media; from appendices 8.B.1 and 8.B.2, it may be seen that the algal members of the surface

communities noted in October 1975 were absent in January 1976. This change was probably as a result of the change in the nature and flow of sewage applied to the filters. Also, less sunlight was available in January than October, and of differing quality, reducing the potential for photosynthesis. The increased strength and reduced flow of sewage during the second period caused an overall increase in the volatile solids contents of the two granite filters. The two other features in these two filters worthy of note were the overall increase in the number of sessile protozoa during this period and also the number of nematode worms present in both filters.

Considering the two grades of slag, it should be borne in mind that the 125/75 mm slag filter lost much of its film between October and January, whilst the smaller 89/50 mm grade filter increased its weight of volatile solids considerably; however the nature of the change in the flora and micrograzing members of the community were similar in both filters. There was an increase in the number of nematoda present and also an increase in the number of sessile peritrichida. Considering the floral members, there was an increase in the quantity of filamentous bacteria present in both filters.

The number of Psychoda (larvae and pupae) in the 89/50 mm slag filter increased slightly between October 1975 and January 1976, with the lower depths of the filter in particular having the greater increases in population, such that in January 1976 the number of Psychoda alternata present was in approximate proportion to the weight of volatile solids. In the 125/75 mm slag, the reduction in volatile solids was not reflected in the number of Psychoda within the filter. Overall, there was a general increase in the number present, particularly at the lower two depths of the filter.

In the two grades of granite, coupled with the increase in volatile solids seen in January 1976, compared to October 1975, there was an increase in the number of Psychoda present; as observed in the slag media, the increases were particularly noticeable in the lower depths of the filters. The most striking feature in the mineral media filters was the reduced diversity of the grazers present. Enchytraeus albidus, Chironomus dorsalis and the unidentified dipteran species had all disappeared by January 1976, whilst the number of enchytraied worms and Psychoda alternata had markedly increased. This reduction in diversity could be the result of three factors. The filters had been operating for 19 weeks by January 1976 and may therefore be more mature. The reduction in diversity might be a sign of instability due to immaturity; it is likely that the reduction reflects the exclusion of a few opportunists as larger more stable populations developed in the filters. The nature of the applied sewage (i.e. much stronger at a reduced flow rate) may also account for the reduced diversity. The reduction in ground temperature may also have had a restrictive effect upon the filter faunas.

The neutron scatter determinations carried out on the mineral media filters in January showed that the greatest voidage occlusion was at the centre of the filters, whilst the biological examination indicated that the greatest weight of volatile solids was present near the surface of the filters. From appendix 8.B.2 showing the relative abundance of the various microscopic components of the filter films in January 1976, it may be seen that the fungal component became more prominent in the film near the centre of the filters, where a greater proportion of coarse filaments were observed; these probably caused greater retention of water than a denser mat of fine

fungal filaments.

Considering the macrograzers in the plastic media filters, there was a reduction in the number of Psychoda larvae and pupae in the Biopac filters, with a general predominance of larvae by January 1976. This reduction in numbers did not proportionately follow the reduction in volatile solids. Also during this period the filters had suffered an invasion of enchytraeid worms. All five depths of both filters had significant numbers of enchytraeids present by January 1976.

In the Flocor filters, there was a general redistribution of Psychoda alternata larvae and pupae whilst the overall number did not alter greatly. The increase in the number of enchytraeid worms was very much more restricted in the Flocor filters than in the Biopac filters, and were present at approximately 1/100th of the level. In both the Flocor E and M there was a limited colonisation by the springtail Achorutes subviaticus in the bases of the filters.

From the table in appendix 8.B.2 showing the W.R.C. examination of the filter effluents on 29/1/76, it may be seen that a greater protozoal diversity was present in the effluents than in October 1975 in the Biopac 50 filters. A point of particular interest is the greater number of species present in the Flocor E effluents than in the Flocor M effluents on both occasions.

Although greater quantities of film were present in the Biopac filters than in the Flocor filters in January 1976, the neutron scatter graphs showed that the Biopac filters had little more of their voidage occluded by film; this disparity must be due to slightly differing natures of the films and also perhaps as a result of the differing natures of the voids, resulting in a greater quantity of moisture being retained in the filter for a greater weight of

volatile solids.

At the end of January 1976, settled sewage from the converted sludge holding tanks was applied to the pilot plant. Sufficient sewage was available to irrigate the filters at the originally intended nominal flow rates. In late April 1976, the Netlon baskets were removed from the perforated steel shafts to assess the weight of volatile solids and the nature of the film. The filters had been operating for 13 weeks using the settled sewage. It may be seen that there was a vast change in the quality and distribution of film in the filters. In the mineral media filters generally there was a loss of film from the top 600 mm of media and an increase in the volatile solids contents throughout the rest of the filter depth. However, the 125/75 mm slag was an exception to this trend. It had a vast increase in volatile solids throughout its depth with the greatest increases being near the surface of the filter; this increase however only brought its volatile solids contents to similar levels to those present in the other mineral media filters; for some reason the volatile solids present in the 125/75 mm slag in January 1976 appeared abnormally low. Turning to consider the volatile solids contents of the plastic media filters, it can be seen that the 0 - 200 mm depth of the Biopac 90 filter lost 6.8 kg of volatile solids per cubic metre of media, whilst throughout the rest of the filter, large increases in the volatile solids contents were made, with the 200 - 600 mm depth having a vast increase, and the trend then tapering off with depth. In the Biopac 50 filters a different pattern emerged; the upper 1000 mm of the bed showed an increase in the volatile solids content whilst the lower depths lost solids. In the two Flocor filters there was an overall increase in the volatile solids contents, but the total amount present was much lower than that in the

mineral media filters. In the mineral media filters, the loss of solids at the surface, with the concomitant increase lower in the filters, was probably a direct response to the increased hydraulic loading which reduced the liquor residence time at the surface of the filters and thus the potential for film development. Overall, in all the filters there was a net increase in the volatile solids content, although the increase in gravime tric loading was not severe. This trend was probably a result of the climatic conditions; the low spring temperatures restricting the macrograzing populations, whilst permitting film accumulation.

The accumulation of solids can be seen to have had a detrimental effect on the microbial community. In the mineral media filters it can be seen that the extent of the filamentous bacteria had increased greatly and that there had been a significant decrease in the number of nematodes present. The protozoal members of the community had been severely restricted with only limited observations of peritrichida in the filters. In the cases of the plastic media filters, it may be seen that similar trends occurred in the flora and fauna, with increasing filamentous bacteria in the two types of Biopac, yet no similar increase in the cases of the two Flocor filters. The Biopac filters also suffered a decrease in protozoal diversity with a similar indication being shown by the Flocor filters.

Overall, there was a large increase in the macrograzer populations within the mineral media filters between January and April 1976. Both the Psychoda alternata and enchytraeid populations had increased; the increase in the enchytraeid numbers being such that the populations in the various filters were comparable to the psychodid populations. In all four filters of mineral media the larval stage of the Psychoda greatly outnumbered the pupal stage. One feature of note was the very

limited number of enchytraeids and Psychoda at the 600 - 1000 mm depth of the 89/50 mm granite filter, with the invasion of Achorutes subviaticus. There was no previous indication that would cause one to expect the presence of Achorutes or the reduced numbers of the two dominant species. The number of Achorutes subviaticus was extremely small compared to the numbers of Psychoda and enchytraeidae.

Comparing the change in the volatile solids contents of the mineral media filters to the changes in the neutron scatter data between January and April/May 1976, it may be seen that the general increase in the weight of volatile solids present in the filters particularly at the lower depths was reflected by increases in the moisture contents recorded by neutron scatter.

In the plastic media filters there was little change in the volatile solids contents or the moisture contents of the two Flocor filters, however there were marked increases in the voidage occluded in the Biopac filters, which was also reflected by the volatile solids contents of the filters. In the case of the Biopac 90 filter, the increase in solids towards the base of the filter was insufficient to account for the increase in moisture content, however there was a change in the nature of the fungus; the fine filaments being replaced by coarse filaments, which presumably retained a greater quantity of water.

In the two Biopac filters, the numbers of macrograzers present were quite different. In the middle of the Biopac 90 filter very large numbers of Psychoda were present, yet in the Biopac 50 filter, although a similar weight of volatile solids was present, the populations of Psychoda were between one-tenth and one-third those observed in the Biopac 90 filter. In the Biopac 90 filter the

enchytraeid numbers were severely limited, and were also limited in the top of the Biopac 50 filter. The low number of Psychoda and enchytraeids in the Biopac 50 filter and the top 200 mm of the Biopac 90 filter was probably due to the very thick film development severely restricting oxygen transfer into the film and hence limiting the number of macrograzers supported. Where there was sufficient free voidage for adequate ventilation, the grazers could survive and thrive on the film. The Biopac 50 media consists of smaller pores than the Biopac 90 being more easily blocked by film thus restricting ventilation and causing ponding at a lower volatile solids content than in the Biopac 90 filters. This probably accounted for the limited number of grazers in the Biopac 50 filter compared to the Biopac 90 filter in April 1976.

Considering the Flocor filters, although by April 1976 the volatile solids had increased in both filters, the amount present was very much less than in the mineral media filters; however, particularly in the Flocor M filter, the number of Psychoda were as high as in the mineral media filters. This could be due to two causes; the film in the Flocor M filters was much more uniformly distributed over the surfaces and was thinner than in the mineral media filters, thus permitting a greater oxygen transfer into the film hence allowing the development of higher grazer populations. Both the Flocor filters had very limited presence of enchytraeids.

Between April and July 1976 (a period of 13 weeks during which settled sewage from the modified sludge tanks was applied to the filters), the mineral media filters lost much of their volatile solids, in such a manner that the film distribution with depth was more uniform by July. In the two Biopac filters a similar pattern

emerged with the Biopac 90 filter losing 50% of its volatile solids content in the centre of the filter. The top 600 mm of the Biopac 50 filter lost much of its volatile solids content. It may also be noted that the Biopac 90 gained a thicker film at the surface of the filter, whilst the Biopac 90 filter increased its volatile solids contents towards the base. Overall therefore, within the filters of both grades of media, there was a general redistribution of film more evenly throughout the depths of the filter which involved a significant loss of volatile solids. The Flocor filters continued their previously noted trend during this period of increasing film thickness. The increase in solids was most marked in the Flocor M filter, such that in July 1976 the Flocor M filters supported twice the weight of film present in the Flocor E filters.

Considering the results of the microscopic examination of the filter films in July 1976 (detailed in appendix 8.B.4), it can be seen that the major change to have occurred since April 1976 was a reduction in the amount of filamentous bacteria present, with an increase in the abundance of protozoa and nematode worms. The increase in the ciliated protozoal community was mainly in motile hypotrichida with only limited occurrences of peritrichida. The nature of the fungal member of the community appears to have altered. In July there was a predominance of fine filaments in the mineral media filters with the coarse fungal filaments being generally restricted to the plastic media filters only. The coarse filaments in the plastic media filters were the prostrate system of Fusarium aquaeductuum.

Comparing the macrograzers present in April and July 1976 in the mineral media filters, it may be seen that there was a general decline in the number of Psychoda alternata present. This decline was in

excess of the proportion that might be lost in sloughed film. Even more marked was the sharp decline in the number of enchytraeids, particularly in the two slag media; the lower depths of all four mineral media filters maintaining the largest enchytraeid populations. The decline in the volatile solids and the two macrograzers appears to have permitted the colonisation of the filters by an unidentified dipteran; the larvae and pupae were found in the various filters in sufficient numbers to suggest that their presence was more than just a chance casual innoculation. The smaller grades of mineral media tended to have the greatest numbers present.

In the Biopac 90 filter during the 13 week interval much of the film was lost from the filter through most of its depth with a large reduction in the Psychoda alternata population; however also during this period there was a large increase in the number of enchytraeids present, particularly at the surface and base of the filter. In the Biopac 50 filter, which also lost much of its film, there was a marked upturn in the number of Psychoda present with little overall alteration in the numbers of enchytraeids. In discussing the condition of the film in April 1976, it was suggested that the thickness of the film was such that it precluded successful colonisation of the filter by macrograzers due to severe limitation of oxygen transfer into the film. During the period between April and the July examination of the film, as the film sloughed a more suitable environment was established coupled with the increase in ambient temperature which permitted large numbers of Psychoda to develop; the large Psychoda population restricting the enchytraeid numbers.

In the two Flocor filters which increased their weights of volatile solids supported between April and July 1976, there was a

decrease in the number of Psychoda present, particularly in the number of larvae. This reduction in the Psychoda population and the increased temperature probably led to the increase in the number of enchytraeids present and the limited occurrence of Chironomus dorsalis near the base of the Flocor E filter.

In view of the very limited amount of film in the Flocor filters when compared to the Biopac filters and their highly regular large pores, the increasing film content would not create such conditions that the Psychoda could not obtain sufficient oxygen from the film surfaces. It is possible that the decline in numbers between April and July was due to an emergence of adult Psychoda as the temperature increased; the July sampling time happening to occur between successive generations of Psychoda.

Comparing the moisture contents of the mineral media filters in May and July 1976 with the volatile solids contents present in the filters at these times it may be seen that the neutron scatter determinations showed similar moisture contents in the filters in April/May and July. However, there were large losses of volatile solids in this period, and in view of the similarlity in the nature of the films in May and July these findings are inconsistent. Between the July neutron scatter and the biological examinations (a period of ten days) there were several short breaks in the sewage supply to the filters and also further unloading of the filter films could have occurred.

In the plastics media filters it may be seen that the Flocor M filters had greater moisture retention in July than in April/May and also a greater volatile solids content, though there was little change in the Flocor E filters. In the Biopac filters there were marked

declines in their volatile solids particularly at the upper and middle depths of the Biopac 50 filter and throughout the Biopac 90 filter, which was reflected by marked declines in their moisture contents. The decline in weights of film present was particularly at the expense of the fungal component of the filter film.

On July 29, a new source of settled sewage was used for the experimental plant. The source, new primary settlement tanks on the main Eign works, resulted in a more consistent supply of settled sewage to the pilot plant, although the filter loadings differed only slightly from those applied to the filters during the last period.

From figures 8.A.4 and 8.A.5 it may be seen that from July to October 1976 (fourteen weeks) various changes in quantities of filter films occurred. In the four mineral media filters, there were net losses of film although at certain depths in three of the filters there were limited gains in volatile solids. The two large grades of mineral media had less film near the filter surfaces than the small grades of media. This pattern might be expected, as a result of the packed media properties. As the concentration of organic material declines in the liquor passing through the filters, the potential for film development is reduced and thus less solids produced at lower depths. In the cases of the small grades of mineral media, the larger film accumulation at the surface had reduced the sewage organic content and thus the amount of film supported declined with depth. In the larger grade of the two media, less film developed at the surface of the filters due to more limited sewage retention and limited surface area, hence the potential for film development may be greater lower down the filter than in the filters containing the smaller media, thus causing greater film accumulation

than at the surface of the filters. Considering the Biopac filters in October 1976, the Biopac 90 filter had appreciably greater solids content than the Biopac 50 filter yet with its restricted specific surface area compared to the Biopac 50, it might be expected to have less film present. This apparently odd situation may be as a result of differing stages of filter maturity. In the case of the Flocor E filter, there was an increase in film accumulation particularly at the 1200 to 1400 mm depth; whilst in the Flocor M filter there was a net loss of film which was mostly accounted for by a loss at 1200 to 1400 mm. Overall, the Flocor M filter had a greater weight of film than the Flocor E filter.

Considering the results of the microbial examination shown in appendix 8.B.5, it can be seen that filamentous bacteria had colonised all the filters to a far greater extent than previously observed and also that the nematode population had sharply declined in all the filters apart from the two 89/50 mm grades of mineral media; however, the protozoal condition of the filters appeared to have improved appreciably with the establishment of sessile peritrichida in all the filters apart from Flocor E.

From the neutron scatter graphs between July and October 1976, there is evidence that the film increased and then declined in the filters; however all the filters appeared to have similar moisture contents and volatile solids contents in July and October, with quite similar floral components as mentioned in the preceding paragraph. These observations suggest that the slight change in the film natures did not affect the moisture retention of the filters.

From appendix 8.B.5, it may be seen that in all the mineral media filters the number of enchytraeids had increased since July and also

that the unidentified dipteran had become established, although the number of larvae greatly exceeded the number of pupae. Apart from the 89/50 mm granite media, the number of Psychoda (larvae and pupae) declined between July and October. In the lower regions of the 89/50 mm slag this reduction was such that the enchytraeid worms exceeded the Psychoda. In the 89/50 mm granite media, although the enchytraeids had increased their presence since July 1976, the number of Psychoda had also increased. This increase was in both larval and pupal forms of the fly, particularly near the surface of the filter, which suggests that the increase was perhaps due to an additional generation of the fly within the filter.

Turning to consider the plastics media filters, from appendices 8.B.4 and 8.B.5, it can be seen that although the amount of film in the Biopac 90 filter had greatly increased from July to October, the overall number of Psychoda alternata larvae had not altered much, though their distribution within the filter had changed. There were many more Psychoda alternata pupae present in October. The enchytraeid population had become more uniformly distributed throughout the filter and the unidentified dipteran had colonised the filter. In the Biopac 50 filter, the reduced film content had not led to a decline in either the psychodid or enchytraeid populations, and had also permitted the invasion of the unidentified dipteran, Achorutes subviaticus and Chironomus dorsalis. This increase in the macro-grazing populations was as a direct result of the rapid film development under summer temperatures providing sufficient food for the increased grazer populations. The net reduction in film being due to the comparatively greater grazing activity than in July 1976. It would have been of particular interest to note any development in

the Biopac 50 filter if summer temperatures had continued. It is possible that the increase in filter film between July and October 1976 was due to the summer temperatures increasing the floral development, whilst the grazing population lagged in its development. Continued summer temperatures might have led to an explosion in the grazing populations and a classical crash in the quantity of film present in the filters. In both the Flocor filters the high ambient summer temperature appeared to lead to the situation where the increased film development had supported increased numbers of macro-grazers and an increase in the diversity.

The next biological examination of the filter films was conducted in March 1977. Unfortunately this was preceded by breaks in the sewage supply to the filters in late February. For various reasons, the biological sampling was delayed until the beginning of March, thus the period between this examination and the previous one was 17 weeks. From the volatile solids results in appendices 8.A.5 and 8.A.6, it can be seen that there was an overall loss of film from all the filters; the reduction being particularly marked in the two Flocor filters. Considering the randomly packed media filters, it can be seen that in almost all cases the 200 to 600 mm depth contained the greatest film weight within the filters. In the 89/50 mm slag filters, the surface sample (0 - 200 mm) contained 0.7 kg/m^3 more volatile solids than the 200 - 600 mm depth. In five of the filters, the 200 to 600 mm depth gained film during this last period whilst several surface samples and lower samples lost volatile solids. It is of interest to note that yet again the Biopac 90 filter contained a greater weight of volatile solids than the Biopac 50 filter.

Considering the microscopic examination of the filter films, there

was a reduction in the amount of filamentous bacteria present in the mineral media filters, an increase in the number of nematode worms and a reduction in the number and extent of the protozoan community, whilst the fungus Fusarium aquaeductuum had increased its significance, developing both its prostrate and erect forms.

Similar trends occurred in the plastic media filters; the protozoan populations being severely curtailed. In the Flocor filters Fusarium had not developed so extensively as in the mineral media filters, being mostly present in its erect form.

Although all the mineral media filters had less film present in March 1977 than in October 1976, the number of Psychoda alternata in the filters had risen dramatically; in the two grades of slag there had been a 300 - 400 percentage increase in the numbers present; the largest increase being in the number of larvae. Similar though smaller increases in the sychod populations in the two granite filters were recorded. During the October to March 1977 period, a sharp fall in the number of enchytraeid worms occurred in all the filters, and a more restricted decline in the number of the unidentified dipteran was observed. However, in the two granite media filters, chironomid larvae were observed in limited numbers. In the Biopac filters, in contrast to the mineral media filters, there was a marked decline in the psychoda populations comparable in magnitude to the increase in the mineral media filters. The areas of the two filters occupied by enchytraeid worms was also severely reduced, with a consequent reduction in the number of individuals present. In the Flocor filters there was a decline in the number of Psychoda and enchytraeids present in March 1977 compared to October 1976; however the sharp reduction in numbers was confined to the Psychoda, with a more limited

fall in the enchytraeid population. All the plastic media filters suffered a reduction in the diversity of the macrograzers present from the levels in October 1976.

From appendix 8.A.2, it can be seen that in March 1977, the mineral media filters had similar moisture contents to their previous examination in October 1976, although the voidages occluded at approximately 400 mm from the surface were greater. These results were similarly reflected in the film contents in March 1977 which showed that the 200 - 600 mm depths of the filters contained the greatest weight of volatile solids.

In the Biopac media filters, a similar trend to the mineral media filters was observed where in March 1977, the 200 - 600 mm depth baskets of media contained the greatest weights of volatile solids, reflected by the greatest moisture contents as indicated by the neutron scatter data. In the Flocor filters there was an interesting increase in the moisture content at the base of the filters in March 1977. Unfortunately, due to the limited biological sampling, the weight of volatile solids at the base of the filters was unknown. Comparing the weights of volatile solids in October 1976 and March 1977 in figures 8.A.5 and 8.A.6, it can be seen that much of the film had been lost by March. The high moisture content at the bases of the two filters presumably being as a result of sloughed film accumulating at the base of the filters.

The next examination of the filter films was conducted in May 1977 after an interval of 11 weeks from the previous examination. Comparing the volatile solids contents of the filters in March and May 1977, it may be seen that apart from the Biopac 90 filter, there was a large increase in filter film during the intervening 11 weeks.

Not only did the filters increase their film contents, but there was also a redistribution of the film within the filters. In March 1977 the 200 - 600 mm depth of the mineral and the random plastic media filters contained the greatest amounts of solids. Generally the film at this level declined slightly, whilst the remaining depths of the filters increased their weights of film. In the case of the Biopac 90 filter, 22.6 kg of volatile solids per cubic metre were lost at the 200 - 600 mm depth and 12.7 kg/m^3 lost at 600 - 1000 mm. The net result was that by May the Biopac 90 filters had appreciably less film overall than the Biopac 50 filters. It can also be seen that in the mineral media filters, the least amount of film was supported at the top of the filters. The two types of Flocor also increased their amount of film supported and by May had comparable quantities of film present.

From Appendix 8.B.6 showing the microscopic examinations in May 1977, it may be seen that there was an increase in the occurrence of nematode worms in the granite filters, but that there was a reduction in the number of ciliated protozoa present, particularly marked in the 125/75 mm granite media. The nature of the film had also altered; filamentous bacteria extending their zone of activity and abundance. Fusarium aquaeductuum was also present at all depths in the filters in approximately similar proportions to those noted in March 1977. In the two grades of slag, similar trends were also recorded but the marked difference compared to the granite filters was the increased number of ciliated protozoa present. In the Biopac 90 filters, filamentous bacteria were observed only in the upper 1000 mm, whilst in March they were noted as present in the top 1400 mm of the filter. There was also a decrease in the number of nematode worms present,

however a marked increase in the number of ciliated protozoa occurred. In March 1977, no protozoa were recorded whilst in May peritrichida were observed at all five sample dep ths. In the Biopac 50 filter there was also a limited reduction in the nematode population, but an increase in filamentous bacteria and also an increase in the number of ciliated protozoa. In the two Flocor filters since March 1977 there was an increase in the abundance of Fusarium at the three sample depths in both filters. In the Flocor E filter filamentous bacteria were frequently observed at the 600 - 800 mm depth. In the Flocor M filter, the filamentous bacteria were noted in two depths. Compared to March 1977, there was a major increase in the number of sessile and motile ciliated protozoa in both filters, whilst the nematode popula-tion remained fairly static.

Turning to consider the macrograzing populations, comparing appendices 8.B.6 and 8.B.7, it can be seen that there was a marked increase in the number of Psychoda in the 89/50 mm slag; particularly Psychoda pupae, throughout the depth of the filter but the major concentration was noted at 200 - 600 mm. An almost tenfold increase in the number of enchytraeid worms occurred, with the highest popu-lations noted at depth within the filter. None of the unidentified dipteran were observed, their position apparently being filled by Achorutes subviaticus.

In the 125/75 mm slag filter, the number of Psychoda declined significantly whilst there was a marked increase in the number of enchytraeid worms present. The increase in enchytraeids was particularly at the lower three depths of the filter sampled. Again, as noted in the 89/50 mm slag filter, the unidentified diptera had disappeared being replaced in the 600 - 1800 mm depth by Achorutes

subviaticus and also Chironomus dorsalis larvae at the 1400 - 1800 mm depth.

In the 89/50 mm granite filter there was a marked upturn in the pupal Psychoda population, particularly at the 0 - 200 mm depth. There was also a large increase in the enchytraeid population predominantly towards the base of the filter. As noted in the two slag media filters, the unidentified dipteran population was markedly reduced with only a small number present at the 200 - 600 mm depth. In the 125/75 mm granite filter there was also an increase in the number of Psychoda pupae, but little variation in the larval population. There was also an increase in the enchytraeid population predominantly towards the base of the filter with a loss of the dipteran and chironomids.

In the Biopac 90 filter, although there was a marked loss of film, this was restricted to the 200 - 1000 mm depth of the filter. There was a large increase in the number of Psychoda present in the filter, particularly the pupal stage; however, there was no significant change in the enchytraeid population. In the Biopac 90 filter, there was a very large increase in the Psychoda population which was centred on the 600 - 1400 mm depth, and was mostly the larval stage. The enchytraeid population was unchanged, but there was a limited invasion of Chironomus at the base of the filter.

In the Flocor filters the increased weights of film was paralleled by an increase in the Psychoda populations generally throughout the depths observed, however there was a decline in the number of enchytraeid worms present which was focused on the lower sampling depth in the two filters.

Comparing the computer graphs of the mineral media filters' neutron

scatter observations in March and May 1977, it may be seen that quite similar voidages were occupied by moisture, yet the amount of volatile solids present in each filter had approximately doubled, thus one would perhaps expect a greater moisture retention. Turning to consider the nature of the films at the two biological examination it may be noticed that the nature of the fungal component had changed, with much less of the very coarse fungal hyphae being observed. Also, the nematode populations had declined slightly with an increase in the peritrichous and hypotrichous protozoa. Considering the macrograzers, there had been an increase in the numbers of Psychoda, but not quite in proportion to the increase in weight of the volatile solids. However, there was a dramatic increase in the number of enchytraeid worms, which may have been responsible for maintaining the film in a "healthy" porous condition, permitting ready drainage of the liquor. Therefore, overall, it would appear that the change in nature of the fungus present and the large increase in the number of enchytraeid worms may account for the comparable moisture contents in March and May 1977, although the weights of volatile solids were vastly different.

Considering the Biopac 50 filter in March and May 1977, there was a halving of the filter film, which was preferentially removed from the middle depths of the filter, which was reflected in the neutron scatter results. In the Biopac 50 filter there was an increase in the weight of film and a slight redistribution in favour of the lower depths. This trend was also reflected in the neutron scatter data. Considering the flora and fauna of the two filters, there were similar changes in the nature of the films as noted for the mineral media filters, with the exception of the macrograzers, where there were vast

increases in the density of the psychodid populations but little change in the number of enchytraeid worms present.

In the Flocor filters during this period, there was a marked increase in the weights of volatile solids supported, paralleled by an increase in the numbers of nematodes, protozoa and Psychoda present, but a decrease in the number of enchytraeid worms. There was a similar increase in the moisture retained in May compared to March 1977.

The filter films were next examined in early August 1977, when it was obvious that all the mineral media filters had lost volatile solids since May 1977. From appendix 8.A.1 it can be seen that the mineral media filters in fact lost over 50% of their volatile solids contents; these losses being particularly large towards the bases of the filters. The 125/75 mm slag media had significantly less solids present throughout its depth than the other mineral media filters; a pattern that was also present in May 1977, but had not occurred previously.

In the Biopac 90 filter an increase in film occurred by August 1977. There was also a redistribution of film within the filter with solids being lost from the upper 600 mm, whilst the remaining depth of the filter increased the weight of film it supported, such that the 1000 - 1800 mm depth supported the greatest weight of film. The Biopac 50 filter in August had its greatest accumulation of film within the middle depths. In May there was no consistent pattern to the film accumulation within the filter, the 200 - 600 mm depth having less film than the media directly above or below it. Since May 1977, there had been a slight overall loss of film.

The two Flocor filters had both lost film overall, with the losses being restricted to the two upper depths examined. At the 1200 - 1400 mm depth both filters increased the amount of film supported.

Considering the microscopic observations of the film in the two slag filters (appendix 8.B.8), it can be seen that there was little change in the nature of the film between the two sample periods. In August there was an increase in the abundance of peritrichida and a restriction of the hypotrichida populations. The two grades of granite media in August showed slightly greater diversity in their microscopic grazer populations than the slag filters with an increase in the abundance of protozoa recorded in August compared to May 1977. In the two Biopac filters it can be seen that the communities were similar, with a greater number of holotrichida being recorded in the Biopac 90 filter than the Biopac 50 filter, but a more limited occurrence of nematode worms. Since May 1977, both filters had shown marked increases in the extent of the filamentous bacteria; being observed at all depths in the two filters, however the protozoa and nematode populations also increased from the frequencies observed in May 1977. The Flocor filters both showed similar microscopic flora and fauna to the Biopac filters and also increased abundance of filamentous bacteria since May 1977. However, less change in the nematode and protozoal communities was observed.

In August 1977, the macrograzer populations of the mineral and plastic media alike (except for one isolated occurrence of Eristalis tenax) were restricted to Psychoda alternata and enchytraeid worms. In May 1977, although in limited numbers, three other grazers occurred in the filters.

Considering the changes in the macrograzer populations during the May to August period, it may be seen that in the mineral media filters there was an overall reduction in the psychodid and enchytraeid populations, which was most marked for the Psychoda population. The

reductions were throughout the depths of the filters, with no clear change in their distribution through the depths of the filters. The 125/75 mm slag filter supported the lowest grazer populations as a result of the more restricted film development. In the Biopac filters very high numbers of Psychoda and enchytraeid worms were present. Since May the weight of volatile solids in the Biopac 90 filter had increased; there was an increase in the number of Psychoda larvae and pupae, but little change in their relative distributions; however, there was an extremely large increase in the number and distribution of enchytraeids, so that its population was now approximately 50% of the Psychoda population. In the Biopac 50 filter a similar pattern emerged with a marked increase in the enchytraeid population. Again there was a general increase in their frequency as the filter depth increased.

In the two Flocor filters there were far less macrograzers present, and there was limited change betwen May and August 1977. The number of Psychoda declined slightly with increases in the enchytraeid populations. In the Flocor E filter Psychoda and enchytraeid worms were most frequent at the 600 - 800 mm depth, whilst in the Flocor M filter, although the numbers of Psychoda were greatest at 600 - 800 mm, the largest population was observed at the 1200 - 1800 mm depth.

Between May and August 1977, in all the mineral media filters there was a 50% fall in the weight of volatile solids supported, yet examination of appendix 8.A.2 indicates only slight reductions in the voidage occlusion, with little change in the nature of the microflora.

In the cases of the plastic media, it may be seen that there was limited change in the volatile solids supported between May and August 1977, and only limited variation in the moisture contents as shown by

neutron scatter.

Both the mineral and plastic media filters had their moisture contents determined in late July; the plastic media filter films were examined on the first and second of August, whilst the mineral media filter films were examined on the third of August. Unfortunately, due to remedial work to the main works primary settlement tank, the sewage supply to the experimental plant had to be curtailed on the second, which resulted in films in the various filters drying out and also the loss of solids by endogenous respiration. The mineral media filters were examined after the sewage supply had been cut off. The microscopic flora and fauna of the plastic filters appeared to have changed little from that observed in May, but in the Biopac filters large increases of enchytraeids had occurred increasingly towards the bases of the filters, which resulted in the chironomid larvae being displaced. Less change had occurred in the Flocor filters.

In the mineral media filters, the observed differences in the macrofaunal populations between May and July 1977 were probably distorted by the break in the sewage supply. Although the film within the filters was still moist, many Psychoda were observed to emerge, which may account for the lower number of pupae counted in July compared to May. However, this break in the sewage supply was unlikely to be wholly responsible for the drop in the psychodid larval numbers or the reduced diversity of the filters.

The changes in the quality and quantity of sewage applied to the filters was not conducive to a steady continuous maturation of the film, however there were indications that the media of highest specific surface area tended to mature fastest; unfortunately no

examination of the filter films was made between the initial application of sewage to the filters and the biological examination in October 1975, by which time very thick films had developed on the smaller grades of mineral media and in the Biopac 50 filter which restricted both the diversity and number of grazers present. In November 1975, sewage of a different nature was applied to the filters which altered the pattern of film development, and thus the process of maturation was disturbed.

The Biopac 50 and both small grades of mineral media tended to pond under winter conditions which had deleterious effects upon performance. However, in the spring of 1976, there was a break and change in the sewage supply to the filters which may have precipitated the unloading which occurred. Without the rest period at this time it is possible that the volatile solids contents would have continued to increase having a more noticeable effect upon relative filter performances. Generally the Flocor filters maintained the least and also the most stable quantities of volatile solids.

In all the filters, when compared to low rate filters, the species diversity was extremely limited, Psychoda alternata being overall the dominant macrograzer. The enchytraeid population gradually increased in the filters so that by August 1977 it was present in comparable numbers to Psychoda alternata. These two grazers, whilst possibly competing within the filters, occupied differing positions in the filters. The Psychoda was always dominant in the upper regions of the filters where the enchytraeid worms were frequently absent. However, at the lower depths in the filters, enchytraeids were present in greater numbers, sometimes exceeding the number of Psychoda.

The very thick films which developed in the filters also

encouraged limited colonisation by the rat-tailed maggot Eristalis tenax which is more frequently associated with sludge holding tanks and drying beds. Fusarium aquaeductuum was abundant in all the filters, frequently being the substratum for zoogleal bacterial development. The Fusarium aquaeductuum freely sporulated within these filters, a feature less commonly observed in low rate filters. The diversity of the ciliated protozoa was also very limited with particularly restricted numbers of the sessile varieties.

Because of the limited periods under each loading regime, the differing times of year for the regimes and also the immaturity of the filters, it was not possible to correlate variations in the chemical performances of the filters to changes in their ecology.

The observations above concerning the ecology of the filters are in general agreement with the findings reported by other workers. Wheatley and Williams (1976) noted that whilst the Psychoda colonised plastic media filters loaded at intermediate rates within the first few months of operation, enchytraeid worms did not colonise the filters until the second year of operation. Also they noted that Achorutes subviaticus was restricted to the lower regions of the low rate filter (1.2 $m^3/m^3/d$), and that ciliated protozoa and nematodes were the dominant microfauna. Bruce and Merkens (1970) observed Psychoda alternata and large populations of nematode worms in high rate filters using settled Stevenage sewage, but no enchytraeid worms, even after two years of operation; however, high rate filters at Northampton reported by the same workers contained Psychoda alternata, Lumbricillus rivalis and nematode worms. At Stevenage adult Psychoda were not observed emerging from the filters. Mohlmann (1936) also noted that Psychoda did not emerge under normal conditions but that

when no sewage was applied to the filters, adults did emerge. At Hereford, limited numbers of adult Psychoda emerged from the filters, but if application of sewage to the filters was interrupted, large scale emergence of the adults occurred.

In this high rate study, there was no difference between the mineral and plastic media in the types of flora and fauna developed, only in the extent of the development. Compared to low rate filters, the organisms present were similar but the diversity much restricted. These finding are in accord with studies reported by Thompson (1942), Reynoldson (1941 and 1942) and Heukelukian (1945) where high organic loadings tended to reduce species diversity. Reynoldson (1941) noted the absence of oligochaete worms in high rate filters which Terry (1951) attributed to the size of the media employed. In filters of large grades of media and thus large sized pares, oligochaete populations were limited. Ingram (1959) and Curds and Cockburn (1970) refer to the ciliated protozoa as the dominant protozoa in filters.

C. Summary

The high rate filters appear to have similar flora and fauna to low rate biological filters, but with a restricted diversity, resulting in larger concentrations of few species. Fungi, particularly Fusarium aquaeductuum played a more dominant role in the communities of the high rate filters which increases the likelihood of ponding problems. Large populations of the dipteran, Psychoda alternata, were observed which under certain conditions could lead to problems of fly nuisance.

There appears to be no significant difference in the weight of

volatile solids supported per unit of specific surface area of randomly packed mineral or plastic media. However, the regular modular media, Flocor, tended to support a much lower weight of film on a given specific surface area, thus limiting the likelihood of ponding.

There is evidence to suggest that the study periods were of too short duration for full maturation of the filters to have occurred, as shown by the increase in numbers of enchytraeid worms throughout the two years of study; it seems reasonable to expect further increases in the removal performances of the filters as maturity is achieved.

The thick films present in the 89/50 mm slag and the Biopac 50 filters in the spring of 1977 might have increased further if a break in the sewage supply had not occurred; such increases might have led to severe ponding which could have resulted in a reduction in removal performance.

At greater organic loadings the smaller mineral media and the Biopac 50 filters would certainly suffer from severe ponding, thus the other filters might provide greater removal of organic matter and effluents of superior quality.

The ultimate choice of mineral media for biological filters is therefore the smallest grade offering the largest specific surface area which would not pond under winter conditions at the desired operational loadings. Similar considerations prevail for the random plastic media; however, the Flocor media having very large regular pores may tolerate even greater loadings before the onset of ponding, although the quality of the effluent would deteriorate as the loadings increased.

Figure 8.B.1 PlasticMedia Volatile Solids & Principal Macrograzer Populations at the 8 Examinations.

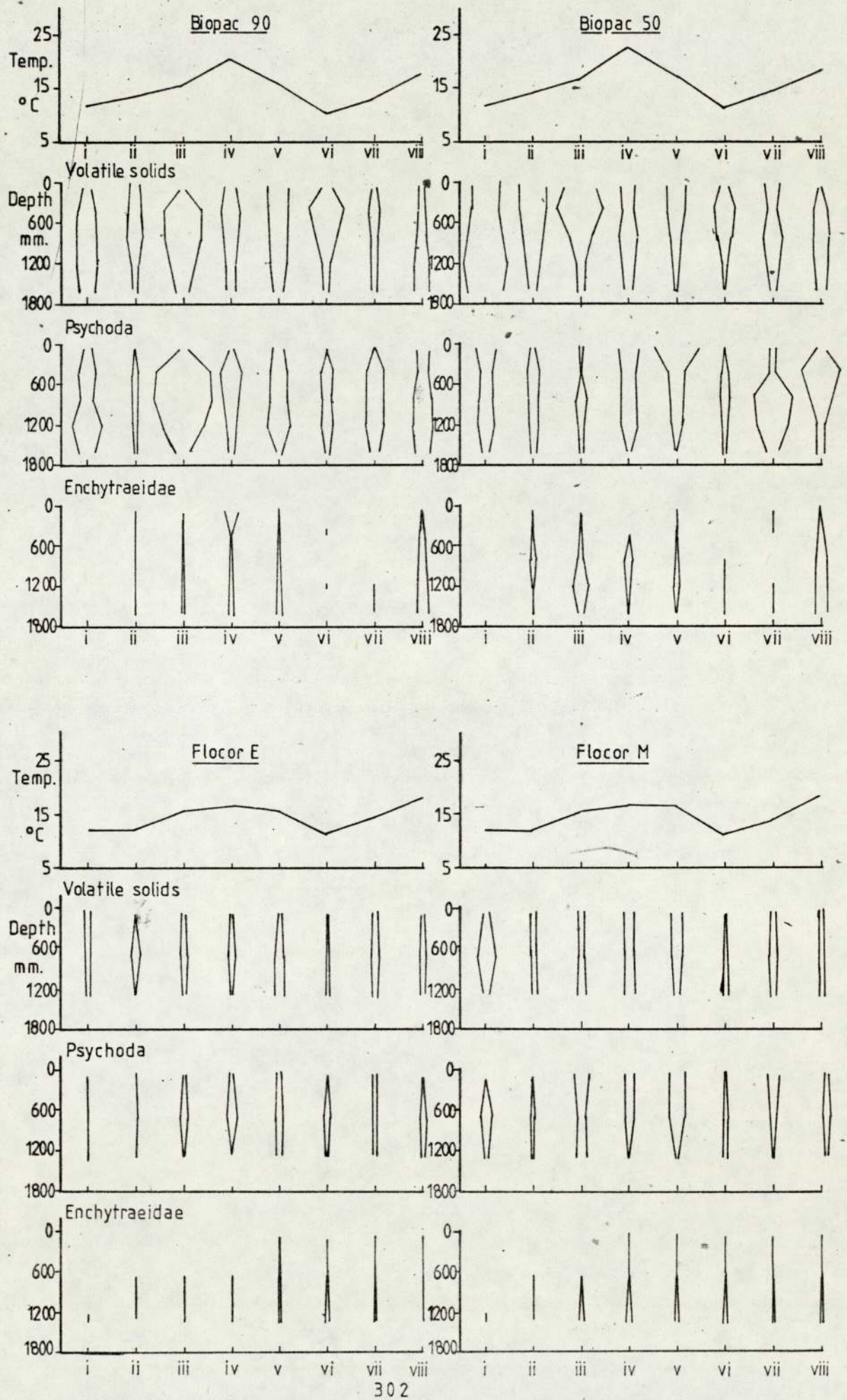
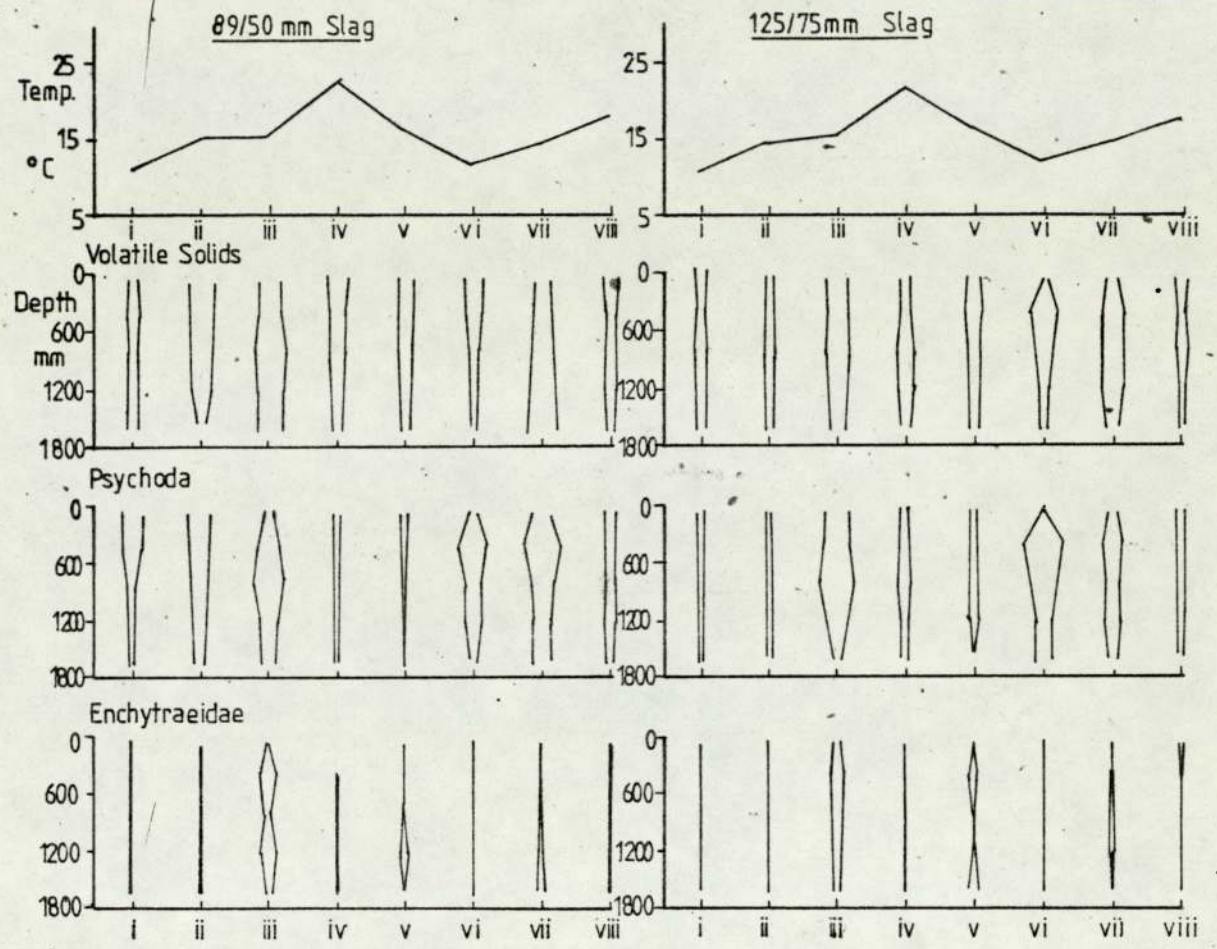
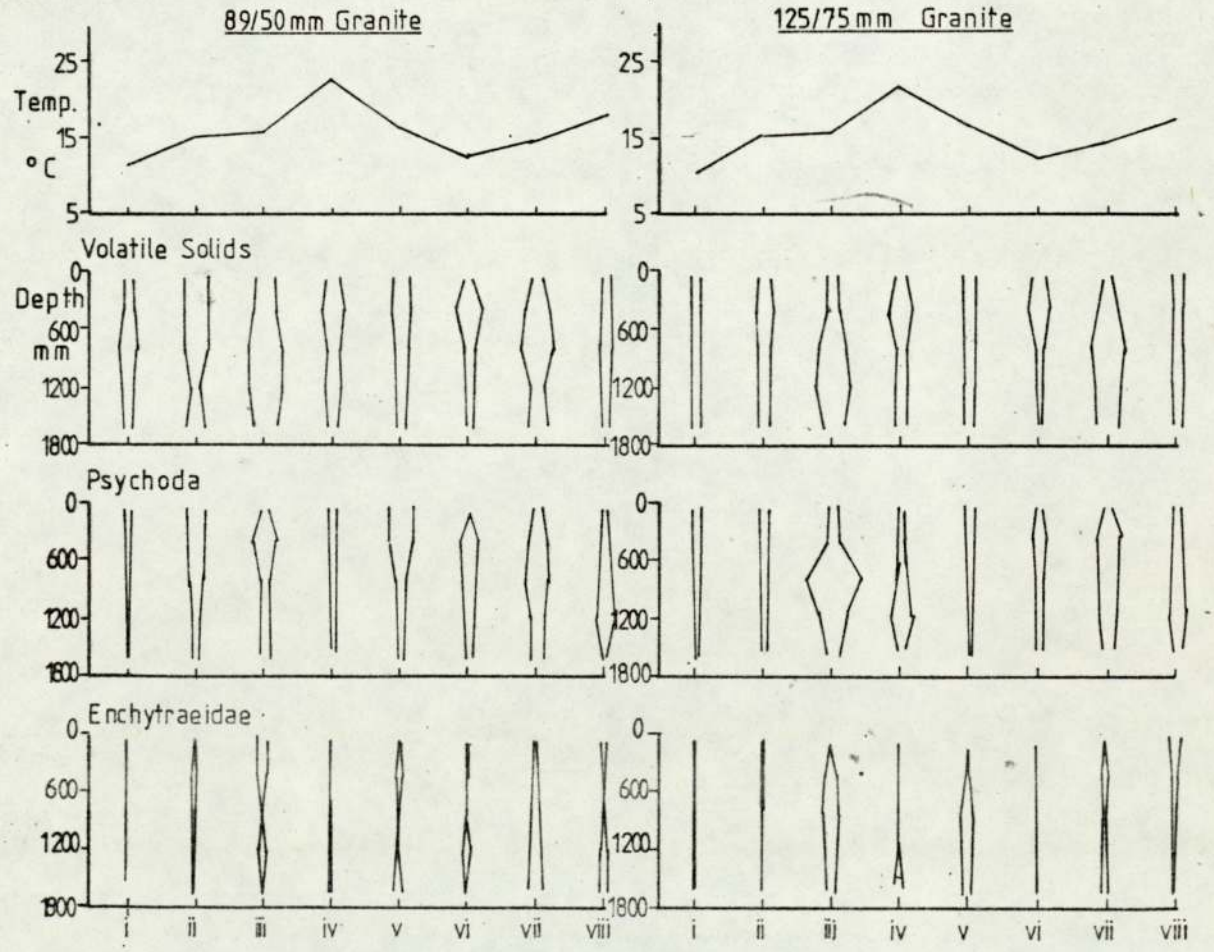


Figure8B2 Mineral Media Volatile Solids & Principal Macrograzer Populations at the 8 Examinations.





9. LABORATORY SCALE NITRIFYING FILTERS USING HIGH RATE FILTER EFFLUENT

A. Purpose of the Nitrification Study.

As previously explained in chapter 2, the effluent from a high rate filtration plant had the bulk of the carbonaceous oxidisable matter removed, whilst little nitrification, if any, occurred.

In chapter 3, containing a literature review on nitrification by biological filtration, the evidence from previous studies has been shown to be conflicting. What hydraulic loadings of the settled primary effluent may be applied to secondary filters? The temperature drop in the primary treatment stage and interstage settlement may be so great during the winter months that nitrification cannot occur in secondary filters. It has been previously mentioned that nitrification at low temperatures may suffer due to an interplay of factors. The low temperature may result in a large zone of the secondary filters being required to facilitate the heterotrophic oxidation of carbonaceous matter leaving little room for autotrophic nitrification to occur. The temperature also has a direct effect upon the activity of the nitrifying organisms.

Laboratory scale studies were initiated to determine the possible limitations on nitrification of the effluent from the Hereford high rate filters.

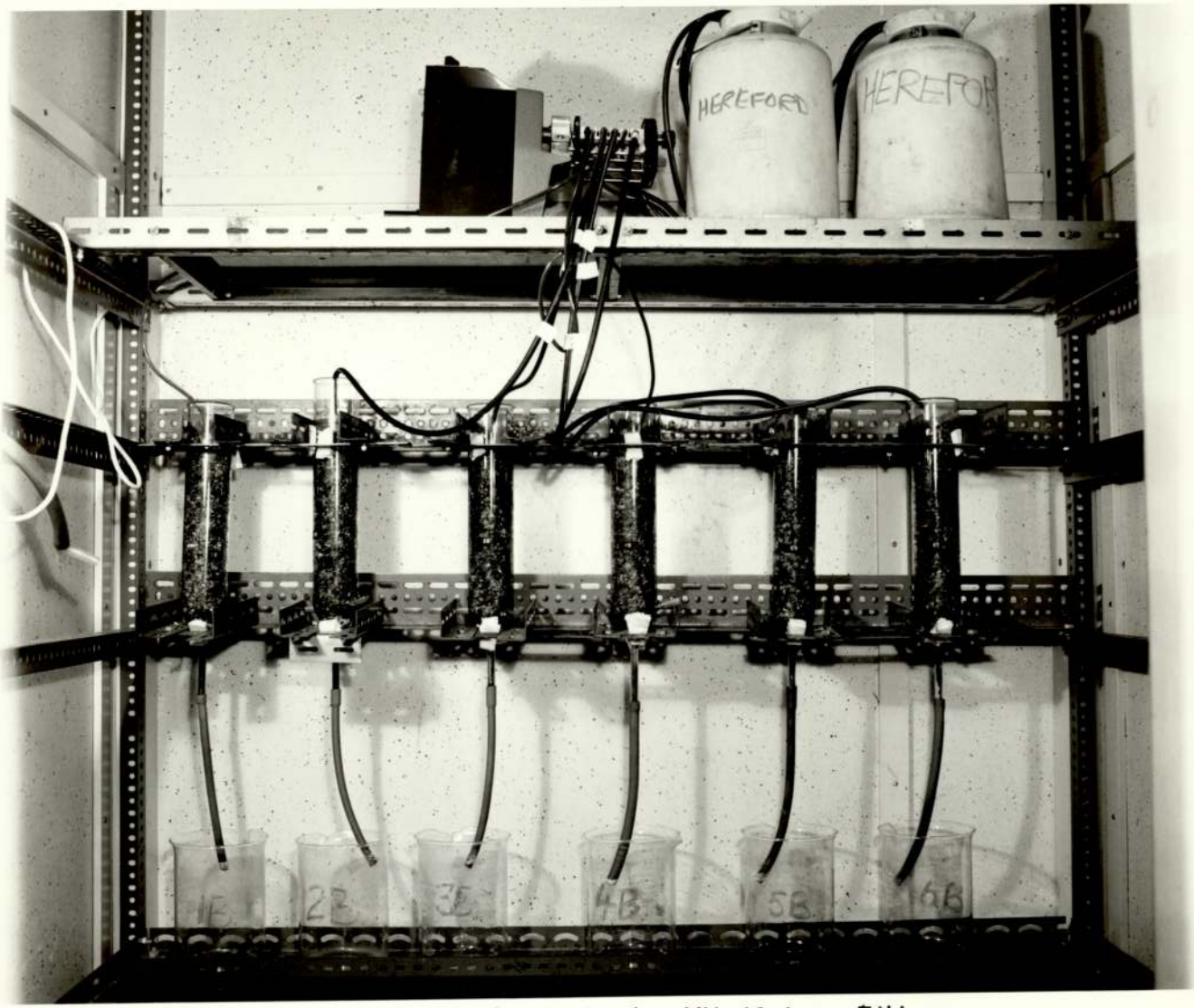


Plate 9.1 LAB. Scale Nitrifying Filters

B. Description of the Apparatus and Sampling Programme Employed.

Since one of the objectives of the study was to determine the effects of temperature on nitrification, it was necessary to maintain the desired temperatures accurately. Two controlled environment cabinets were available at Aston. The cabinets included both heating and refrigerating equipment which were automatically switched on or off to maintain a stable temperature. (They were able to maintain the desired temperature in the range 5°C to 40°C to within ± 1°C). Also included in the cabinets were fans which minimised temperature stratifications. The cabinets were permanently in darkness except during periods of sampling and maintenance.

The decision to carry out the work at Aston led to problems concerning the transport of primary filter effluent from Hereford. This limited the volume of effluent available and hence the number, dimensions and volumes of the filters which could be used. The effluent from a filter containing 125/75 mm blast furnace slag was chosen as the supply for these laboratory scale secondary filters. This effluent was used because it was considered to have a higher BOD strength than effluent from the smaller grades of mineral media, and yet would hopefully not be subject to marked fluctuations in strength. The effluent was collected weekly at approximately 13.00 hours each Wednesday and transported back to Aston in 25 litre polythene canisters. At Aston the effluent was sieved through a 180 micron mesh to simulate interstage settlement. This also had the effect of minimising the likelihood of innoculation of the filters with large populations of grazing organisms which might severely affect individual filter performance. This was recognised as an artificial limitation on the filters; however, it would allow more comparative studies of the filters'

performances. After sieving, the effluent was transferred to 10 litre polythene canisters which were stored in a refrigerator at 4°C until required.

As previously mentioned, two cabinets were available, therefore identical dosing regimes could be carried out at two temperatures simultaneously. It had been decided that duplicate filters would be employed to ascertain to what extent the variation in performance was due to the regimes employed. Due to the limitations of transport and storage of the primary effluent, twelve filters could be constructed, thus allowing duplicates of three different flows at two temperatures to be observed simultaneously.

The filters consisted of 50 mm internal diameter glass columns containing 0.75 litres of pea gravel. The base of each column had been drawn into a funnel shape over which tubing could be fitted to convey the effluent to the receiving beakers. To prevent the pea gravel being washed out of the filters and also the possibility of blocking the exit, the media in each filter was supported on an ASL Airflow practice golf ball. This also had the added advantage of increasing the surface area of the base of the filter available for ventilation. The sieved primary effluent was applied to the surfaces of the filters via one piece of tubing to each filter. The tubing was kept in position just above the centre of the filter surface by a push fit insertion through a hole in a plastic petri dish inverted over the glass column. Additional holes were molten through the dish in order to provide adequate ventilation to the filters.

Accurate determination of the specific surface area of the pea gravel was not carried out prior to its placement in the filters. Severe practical difficulties were envisaged concerning the method of determining their surface area. An approximate estimate of the

specific surface area could however be made by assuming the pieces to be spherical of diameter 10 mm., and that the packed volume included 50% voidage. The pieces were in fact of quite uniform dimensions and had quite regular smooth surfaces. The specific surface area was calculated as 300 m^2/m^3. Prior to inserting the media in the filters, it had been thoroughly washed in running tap water for one week. During this time, at least twice a day, the media was vigorously shaken and stirred to remove any dirt which might have been firmly adhered to the surface. In order to obtain the same volume of media in each filter, after being allowed to dry, the media was poured into a measuring cylinder to 750 mls. The media was then placed in the filters.

After filling, each filter was firmly tapped on the side to ensure a stable packing within the glass cylinder. The filters were then run under the experimental conditions to be studied, for a period of six weeks using tap water. This procedure ascertained whether the desired flow rates could be maintained and whether a single tube at the surface of the filter would provide adequate distribution of the effluent to the filter media and also as a final wash of the media in position. The wetting of the pea gravel using the distribution system was carefully observed for the first few days, particularly the first 24 hours. After 8 hours, approximately 30 mm from the surface of each filter and thereafter, all the pieces of media appeared to be wetted, and no short circuiting of the water down the sides of the glass columns appeared to be occurring. After 24 hours, all the media apart from the first two surface 'layers' appeared to be wetted.

The effluent was applied to the filters via a single Watson

Marlow MHRK 18 flow inducer sited above the surface of the filters as shown in plate 9,1. The pump had a single 10 tubing induction rotor fitted, of which only six were required. Tubes of three different bores were wrapped about the rotor to provide the three flows used. In order to simulate the dosing obtained on large scale filters, the electrical power supply to the Watson Marlow pumps were governed by an electro mechanical time switch. Both pumps were connected to the same timer to ensure identical dosing frequencies and flow rates. The pumps were switched on for 90 seconds in every 10 minutes.

The sieved primary effluent was contained in 10 litre canisters above the pump rotor ensuring a positive head at all times. The canisters were recharged three times a week with sufficient only for the ensuing period, to minimise the variation in the quality of the effluent supplied. However, deterioration did occur and had to be tolerated. The supply tubes were kept at equal and constant depths within the canisters by being attached to a rubber bung which kept their ends 25 mm above the base of the canister. The canisters were replaced weekly and thoroughly washed before re-use. The effluents from these filters were collected in 2 litre glass beakers, which were emptied on Monday, Wednesday, Thursday and Friday each week.

Sampling of the supply and effluents for BOD analysis was carried out on Thursdays. The sample from the supply canister was obtained by inserting a pipette to the level and adjacent to the supply tubes, and slowly withdrawing the sample. Samples were taken at 8.00 a.m. on Thursdays when the primary filter effluent collected the previous week was still in use. Immediately after sampling, the canister containing the old primary effluent was replaced by a canister of new sieved primary effluent. The volume collected in each beaker by

12.30 was recorded and discarded. This procedure was carried out to displace old primary effluent in the filters, prior to taking samples at 15.00 for BOD analysis.

At 9.00 each Thursday, the delivery tubes were washed out with new effluent, after being checked for any damage, and replaced. At regular intervals, it was found necessary to apply a small quantity of olive oil to the tubing wrapped round the rotor to reduce the friction between the rotor and each tube. Failure to oil the tubing led to rapid deterioration and eventual rupture of the tubes. Also, the oil enabled a more consistent tension to be maintained on the tubing which consequently minimised the variation in flow rates. The sieved primary effluent and secondary effluents were also sampled three times a week for ammonia and oxidised nitrogen concentrations. The samples of the filter effluents were taken from unsettled effluents. These samples were taken on Mondays, Thursdays and Fridays, and stored in 25 ml screw cap universal bottles under refrigeration until analysed To prevent sample deterioration during storage, 5 drops of concentrated hydrochloric acid were added to the samples by Pasteur pipette immediately after being taken. The hydrochloric acid prevented any biological activity which might alter the ammonia and oxidised nitrogen concentrations. Physico chemical conversion of the nitrogenous materials was minimised by refrigeration.

To provide comparative data from the various analyses used, the results were averaged on a weekly basis, beginning on Thursdays using the freshly collected effluent and ending on the following Thursday to coincide with the application of the next week's primary filter effluent. The ammonia and oxidised nitrogen analyses were carried out using Technicon AutoAnalyser and the determinations made by the methods

described by Chapman et al. (1967). The methods have been described in detail in chapter 6. The oxidised nitrogen results include both nitric and nitrous forms. Initially, analysis of the effluents for nitrites was carried out, which showed that on all the occasions sampled, less than 1 mg/l of nitrite nitrogen was present and that the values commonly observed were less than 0.5 mg/l. It was therefore decided to cease independent determinations of nitrites and analyse only for oxidised nitrogen; that is, both nitrite and and nitrate forms. All the results presented for oxidised nitrogen therefore include both forms; in view of the low concentrations of nitrite present, the results are also expressed as "nitrate".

The determination of BOD used has also been described in chapter 6. During the first phase of the study between 24/6/76 and 13/1/77 the BODs were determined without the use of ATU (allyl thiourea) to suppress nitrification. After 13/1/77 all BOD determinations were made using the ATU nitrification suppressed method described in 'Analysis of Raw, Potable and Waste Waters" H.M.S.O.1972.

These laboratory scale studies were carried out in several phases (tables 9.1, 9.2 & 9.3). In the first phase, the three flow rates chosen were 0.22, 0.44 and 0.66 $m^3/m^3/d$, and the two temperatures chosen were 7.5°C and 10°C. These temperatures were chosen to mature the filters, and as the initial experimental conditions, because they were considered likely temperatures to be encountered in full scale secondary filters.

During the period 13/1/76 to 17/3/77, all twelve filters were supplied with sewage at a nominal flow rate of 0.66 $m^3/m^3/d$, and the temperatures of both cabinets were raised to 20°C oyer a period of three days. The filters were exposed to identical conditions during this

Table 9.1 Environmental Conditions for the Various Filters, (24/6/76 - 13/1/77).

Nominal Flow ($m^3/m^3/d$)	Filter Numbers.
0.22	1A,4A,(A1); 1B,4B,(B1).
0.44	2A,5A,(A2); 2B,5B,(B2).
0.66	3A,6A,(A3); 3B,6B,(B3).
Temperature (°C).	
10	A filters.
7.5	B filters.

Table 9.2 Environmental Conditions for the Various Filters, (31/3/77 - 21/7/77).

	A Filters.	B Filters.
Temperature (°C)	10	20
Flows ($m^3/m^3/d$)	0.66	0.66

Table 9.3 Environmental Conditions for the Various Filters, (28/7/77 - 25/8/77)

	A Filters.	B Filters.
Temperature (°C)	10	20
Flows ($m^3/m^3/d$)	0.72	0.72

period to obtain similar performances, prior to investigating their relative performances under other environmental conditions.

After 17/3/77, the temperature of cabonet A (which during the first phase had been at 10°C) was lowered in seven equal daily stages of approximately 1.5°C to 10°C. The temperature of cabinet B was maintained at 20°C. Because all the filters under the loadings employed in the first phase produced effluents of comparable nitrate concentrations by the end of the period, the hydraulic loadings were increased. However, as will be discussed later, there was a variation between the replicates in their BOD removals. Due to this variation, it was decided to maintain all six filters in each cabinet at the same nominal loading of 0.66 $m^3/m^3/d$, to minimise the effect upon the variations due to other factors. The temperatures were maintained at 10°C and 20°C until 25/8/77.

On the 21/7/77, the hydraulic and hence the gravimetric loadings to the filters were increased by 10% until the end of the experimental period, 25/8/77.

C. Results.

The weekly means of the flows, feed and effluent BOD, ammoniacal and oxidised nitrogen are shown in appendices 9.1, 9.2 and 9.3. Tables 9.1, 9.2 and 9.3 indicate the loadings applied to, and the temperatures experienced by the various filters during the three study phases. In the three tables 9.4, 9.5 and 9.6, the letters in brackets under the least significant differences column in the Analysis of Variance indicate the L.S.D. is associated to differences between the loadings (L), replicates (R), or temperature (T).

I. Flow data:- From table 9.4, it can be seen that the flows varied significantly with time at the 0.1% level of probability, during the period 24/6/76 to 13/1/77, (29 weeks). However, the variations were only significant on the first and last weeks. During week 1 the flows were higher than average and for week 29 the flows were appreciably lower than the overall average of 0.3795 $m^3/m^3/d$. Observation of the weekly means in appendix 9.1 indicates that the flows received by filters 1A, 4A, 1B and 4B were higher than their nominal flow of 0.22 $m^3/m^3/d$. Also from the appendix, it can be seen that the flows to all the filters were far lower than their nominal values during the 29th. week.

From tables 9.4, 9.5 and 9.6, it can be seen that the analysis of variance of the flow rates did not show any significant differences either over the respective study periods or between individual filters.

During the first phase, it can be seen that for all the filters the nominal flow rates were not attained, but that the three flows received were approximately in the ratio 1:2:3 as desired.

II BOD data:- From appendix 9.1, it can be seen that during the first phase only 17 weeks BOD data were collected. This was due to staff shortages when BOD analysis had to be suspended. The results of the analysis of variance carried out on the BOD data for the three phases are shown in tables 9.4, 9.5 and 9.6. During the first phase, it can be seen from table 9.4 that there were significant differences between the applied BOD loads to the three sets of replicates, and that in the case of the BOD removed, four sets of replicates varied significantly in their removal performances. The variation between the replicates is shown below:-

Table 9.4 Analysis of Variance of Chemical Data for Laboratory Scale Nitrifying Filters, Phase 1 (1/7/76 - 13/1/77).

Parameter	A1.	A2.	A3.	B1.	B2.	B3.	L.S.D.
Temperature (^{o}C)	10.0	10.0	10.0	7.5	7.5	7.5	-
Nominal Flow ($m^3/m^3/d$)	0.22	0.44	0.66	0.22	0.44	0.66	-
**** Actual Flow ($m^3/m^3/d$)	0.2033	0.3602	0.5636	0.1774	0.3978	0.5750	(L)0.0443
**** BOD Applied ($g/m^3/d$)	26.2038	** 43.6049	70.3481	22.3899	** 42.2890	** 64.0225	(L)4.8025 (R)3.9212
**** BOD Removed ($g/m^3/d$)	23.3953	** 37.2199	** 60.0004	19.0147	** 41.5529	** 52.6278	(L)4.1935 (R)3.4240
**** Effluent BOD ($g/m^3/d$)	2.8085	6.3850	10.3476	3.3751	7.7361	11.3947	(L)2.1308
**** Effluent BOD (mg/l)	11.5735	18.1618	17.7206	16.0735	18.8823	19.8382	(L)4.1701
**** Effluent NH_3 (mg/l)	3.9153	4.6374	5.2129	3.4067	4.2638	5.0176	(L)0.4217 (T)0.3443
**** NH_3 Applied. ($g\ N/m^3/d$)	2.8210	4.9982	7.8076	2.3950	5.3890	7.7230	(L)0.2769
**** Effluent NH_3 ($g\ N/m^3/d$)	0.8564	1.7689	3.0528	0.6292	1.7446	2.9704	(L)0.2899
**** NH_3 Removed ($g\ N/m^3/d$)	1.9648	3.2292	4.7548	1.7657	3.6445	4.7526	(L)0.9708
**** NO_3 Produced (mg/l)	7.7097	7.1488	6.6652	7.6174	6.9524	6.6650	(L)0.1701
**** $N\ O_3$ Produced ($g\ N/m^3/d$)	1.5069	2.5345	3.6431	1.2207	2.6810	3.7517	(L)0.9733

** Replicates displaying significant variation.

**** Results varying significantly in time at a 10% probability level or greater.

Table 9.5 Analysis of Variance of Chemical Data for Laboratory Scale Nitrifying Filters, Phase 2 (31/3/77 - 21/7/77).

Parameter	A1.	A2.	A3.	B1.	B2.	B3.	L.S.D.
Temperature (^{o}C)	10.0	10.0	10.0	20.0	20.0	20.0	-
Nominal Flow ($m^3/m^3/d$)	0.66	0.66	0.66	0.66	0.66	0.66	-
Actual Flow ($m^3/m^3/d$)	0.6441	0.6400	0.6556	0.6753	0.6253	0.6126	0
**** BOD Applied ($g/m^3/d$)	43.9662	44.2560	45.3090	43.1784	39.7811	39.7434	0
**** BOD Removed ($g/m^3/d$)	41.3409	41.5784	42.5256	41.6035	38.6572	38.7041	0
**** Effluent BOD ($g/m^3/d$)	2.6268	2.6747	2.8128	1.5748	1.1481	1.0386	(T) 0.6787
**** Effluent BOD (mg/l)	4.1441	4.2618	4.4118	2.3059	1.8529	1.6618	(T) 1.0631
**** Effluent NH_3 (mg/l)	4.3221	3.0426	2,1794	0.4632	0.4529	0.4338	(T) 0.9420
**** NH_3 Applied ($g\ N/m^3/d$)	7.7038	7.5952	7.8670	8.0871	7.4429	7.3517	0
**** Effluent NH_3 ($g\ N/m^3/d$)	2.6921	1.8363	1.4421	0.3144	0.2791	0.2663	(T) 0.5822
NH_3 Removed ($g\ N/m^3/d$)	5.0117	5.7589	6.4249	7.7727	7.1638	7.0854	0
NO_3 Produced (mg/l)	10.7326	12.4147	12.4997	13.4174	13.9456	13.9382	0
NO_3 Produced ($g\ N/m^3/d$)	6.9866	7.9783	8.2215	9.0015	8.6055	8.4347	0

** Replicates vary significantly

**** Results varying significantly in time at a 10% probability level or greater.

Table 9.6 Analysis of Variance of Chemical Data for Laboratory Scale Nitrifying Filters, Phase 3 (28/7/77 - 25/8/77).

Parameter	A1.	A2.	A3.	B1.	B2.	B3.	L.S.D.
Temperature (^{o}C)	10.0	10.0	10.0	20.0	20.0	20.0	-
Nominal Flow ($m^3/m^3/d$)	0,72	0.72	0.72	0.72	0.72	0.72	-
Actual Flow ($m^3/m^3/d$)	0.6950	0.7010	0.7380	0.7430	0.7190	0.6930	0
BOD Applied ($g/m^3/d$)	37.9721	36.6287	40.1904	60.7273	59.1840	55.6391	0
BOD Removed ($g/m^3/d$)	33.0408	32.6617	35.3442	58.3971	55.6326	53.4924	0
Effluent BOD ($g/m^3/d$)	** 4.9313	3.9670	** 4.8462	2.3302	** 3.5514	2.1467	(R)2.5081
Effluent BOD (mg/l)	** 6.7300	5.6200	** 6.4300	3.0500	4.2900	3.0900	(R)2.6812
**** Effluent NH_3 (mg/l)	** 2.0500	** 1.9100	** 1.7400	1.1000	** 1.1950	** 1.2650	(R)1.0512
NH_3 Applied (g $N/m^3/d$)	13.5620	13.3010	14.5038	14.6498	14.2019	13.5946	0
Effluent NH_3 (g $N/m^3/d$)	** 1.3889	** 1.3605	** 1.3057	0.8324	** 0.9004	** 0.9058	(R) 0.7742
NH_3 Removed (g $N/m^3/d$).	11.9992	11.4794	11.8000	12.2733	10.6671	10.0421	0
NO_3 Produced (mg/l)	17.3390	16.6740	16.0670	16.7350	15.0620	14.5960	0
NO_3 Produced (g $N/m^3/d$)	12.0522	11.5319	11.8399	12.2494	10.7065	10.0817	0

** Replicates displaying significant variations.

**** Results varying significantly in time at a 10% probability level or greater.

Table 9.7 - Variation in the BOD Applied to the Replicates (g BOD/m^3/d).

(1/7/76 - 13/1/77)

	A2	B2	B3
R1	47.2029	51.4038	70.3009
R2	40.0068	47.1741	57.7441

L.S.D. between replicates = 3.9212 g BOD/m^3/d.

Table 9.8 - Variation in the BOD Removal of the Replicates (g BOD/m^3/d).

(1/7/76 - 13/1/77)

	A2	A3	B2	B3
R1	39.6124	62.1744	44.5688	56.5591
R2	34.8274	57.8265	38.5369	48.6965

L.S.D. between replicates = 3.424 g BOD/m^3/d.

During the second phase, analysis of variance of the results indicates that the significant variations were due to time and temperature only.

During the third phase, analysis of variance of the BOD results indicates that significant variations were due to replication only. The variation between the replicates is shown below:-

Table 9.9 - Variation in the BOD Concentration in the Replicates' Effluents (mg/l)

(28/7/77 - 25/8/77)

	A1	B2	B3
R1	9.680	8.040	6.020
R2	3.780	4.820	2.560

L.S.D. between replicates = 2.6812 mg/l.

Table 9.10 - Variation in the Weight of BOD in the Replicates' Effluents (g BOD m^3/d.)

(28/7/77 - 25/8/77)

	A1	A3	B2
R1	7.5118	6.4632	5.4488
R2	2.3508	3.2292	1.6540

L.S.D. between the replicates = 2.5081 g BOD/m^3/d.

III Inorganic Nitrogen Data:- The results of the analysis of variance of the inorganic nitrogen data are shown in tables 9.4, 9.5 and 9.6. From the tables, it may be seen that the variation due to time was significant for all three phases for various aspects of the nitrogen results. However, variation between replicates was confined to the ammonia levels in the effluents during phase 3. The variation between the replicates is shown below:-

Table 9.11 - Variation in the Replicates' Effluents Ammoniacal Nitrogen (mg N/1)

(28/7/77 - 25/8/77)

	A1	A2	A3	B3
R1	2.93	2.72	2.43	1.92
R2	1.17	1.10	1.05	0.61

L.S.D. between replicates = 1.0512 mg N/1).

Table 9.12 - Variation in the Ammoniacal Nitrogen Weights in the Replicates' Effluents (g $N/m^3/d$).

(28/7/77 - 25/8/77)

	A1	A2	A3	B2	B3
R1	2.0722	2.0599	1.9109	1.3511	1.4135
R2	0.6940	0.6611	0.7004	0.4496	0.3980

L.S.D. between replicates = 0.7742 g N/m^3d.

Figure 9.1 Laboratory Scale Secondary Filters, Overall BOD Loading, Removal, and Percentage Removal.

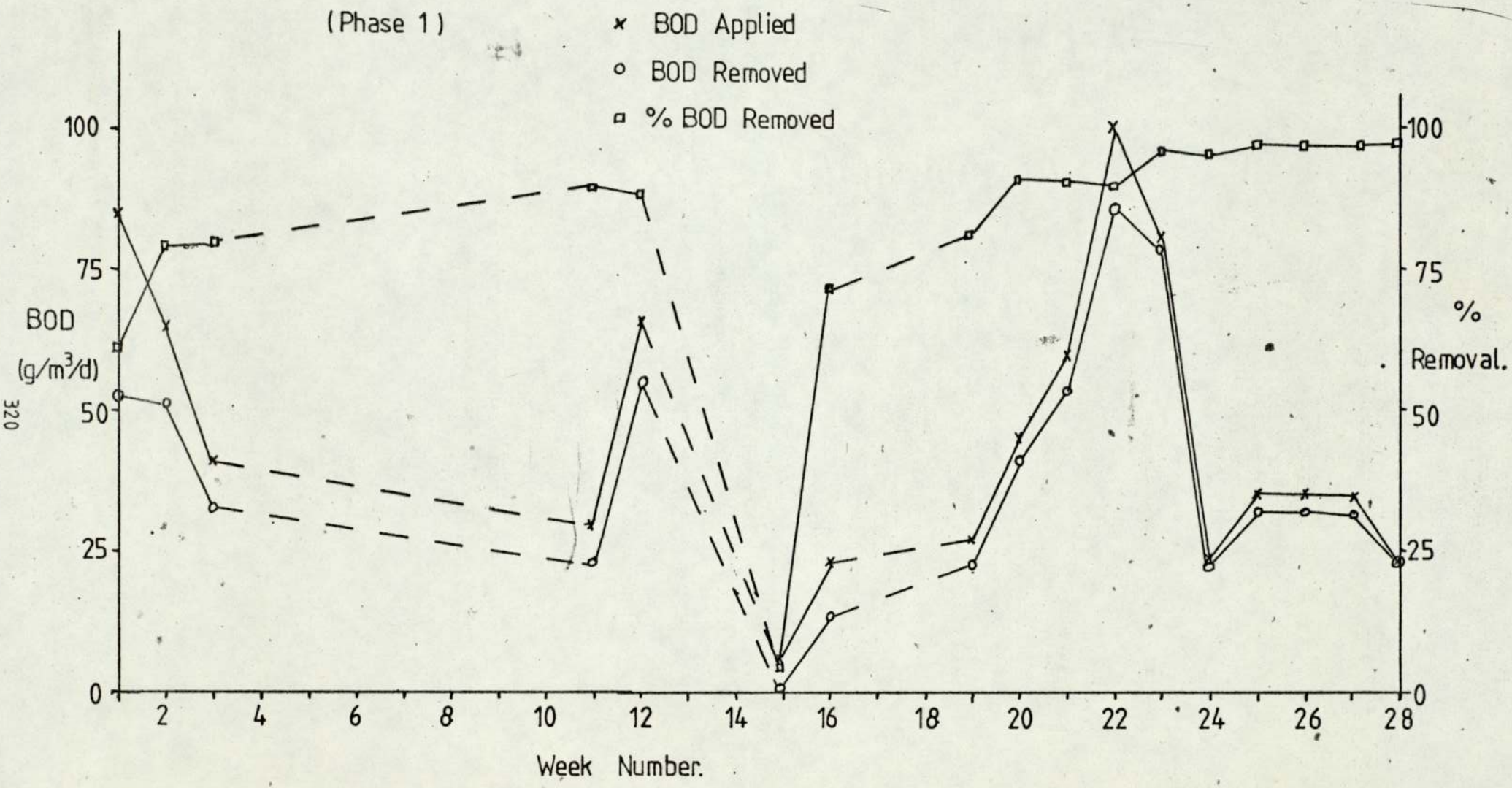


Figure9.2 Laboratory Scale Secondary Filters, Overall Percentage Ammonia Removal and Nitrate Production.

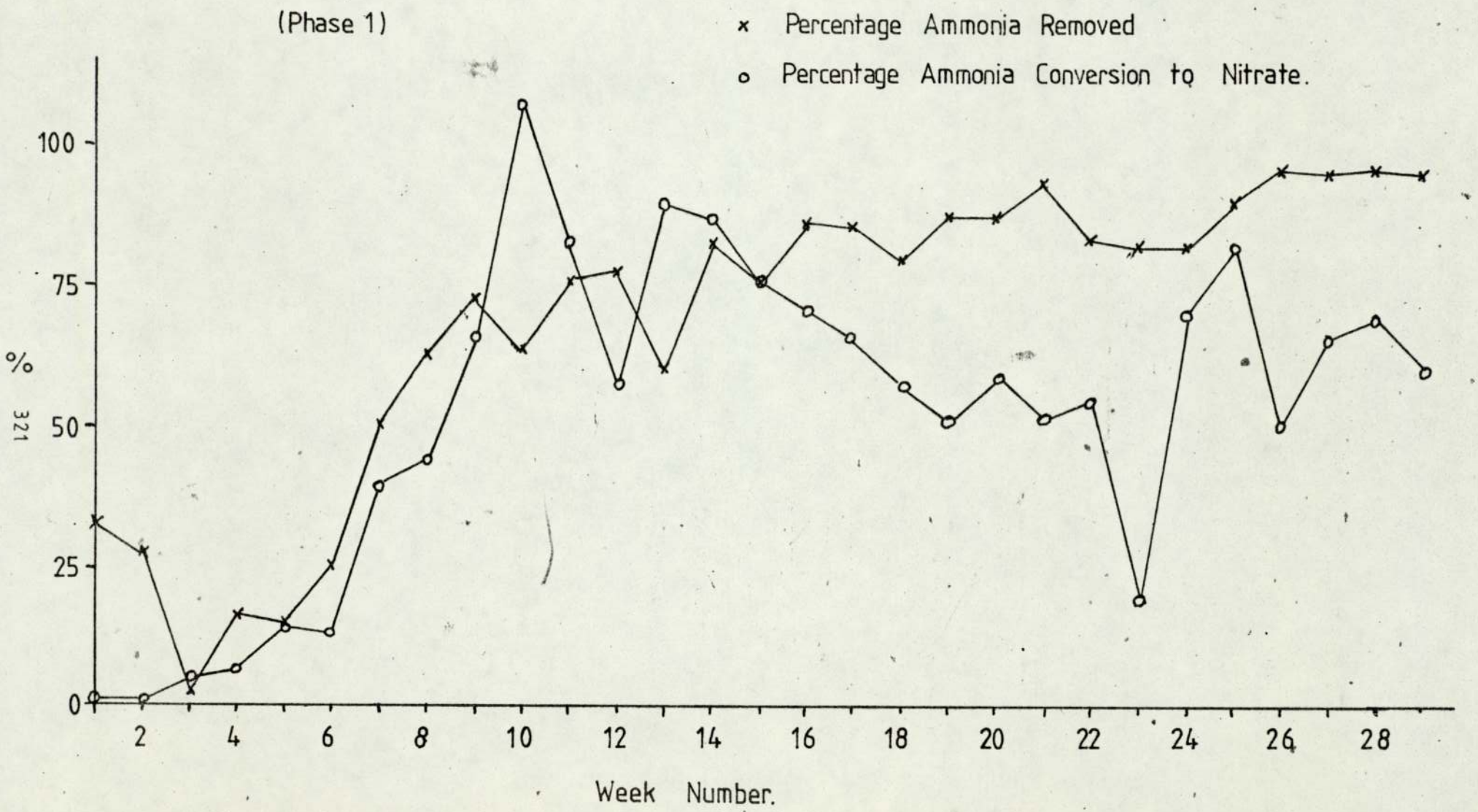


Figure 9.3 Laboratory Scale Secondary Filters, Ammonia Loadings and Nitrate Production.

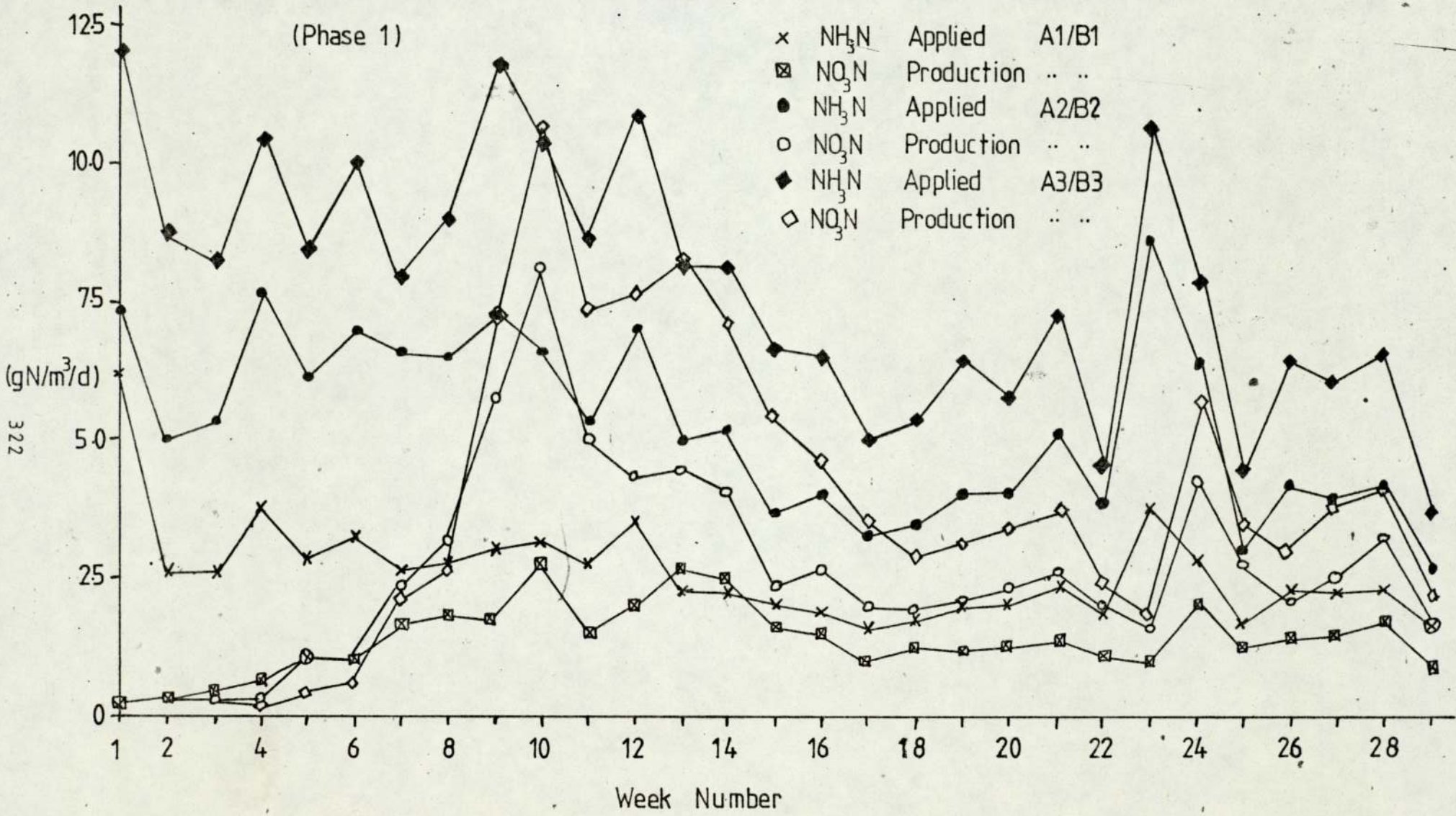
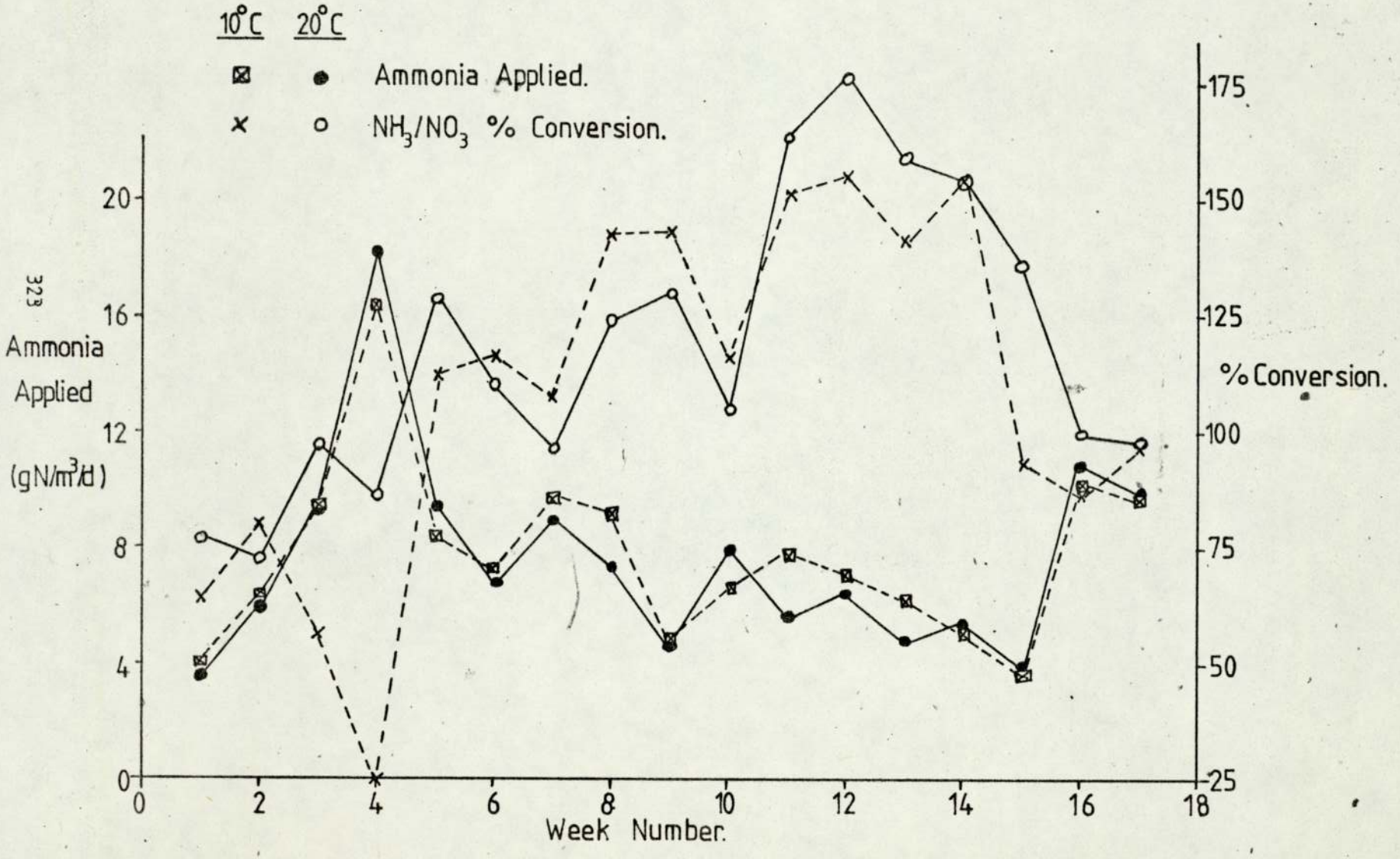


Figure 9.4 Laboratory Scale Secondary Filters, Ammonia Applied and Conversion to Nitrate. (Phase 2)



D. Discussion.

1 Phase 1.

This phase was one of maturation for the filters. The temperatures of 7.5°C and 10°C were used as likely temperatures to be encountered during maturation of full scale filters. The sieved primary high-rate Hereford filter effluent was first applied to the filters on 17/6/76 but chemical analysis could not be commenced until 24/6/76. From appendix 9.1, it can be seen that only 17 weeks BOD data was collected during this period; an unfortunate consequence of staff shortages during which BOD analysis had to be suspended. The BOD analyses were made without the use of A.T.U., to suppress nitrification, due to the non-availability of the reagent at the beginning of the period. Figure 9.1 indicates that by the twentieth week, the filters were mature in terms of BOD removal. Figure 9.2 showing the overall percentage ammonia removals of the twelve filters shows a gradual increase in removal throughout the period which did not reach the maximum of 95% until the twenty sixth week. However, it should also be noted that the percentage conversion to oxidised nitrogen does not follow the same trend. Initially there is a rapid increase to a high percentage conversion, although after the tenth week there is a decline in the percentage conversion. Inspection of figure 9.3 indicates that apart from weeks 23 and 24, there is a general decline in the quantity of ammonia applied to all the filters. As the quantity of ammonia applied to the filters declined in time, the percentage conversion of ammoniacal nitrogen to oxidised nitrogen declined since a greater proportion of the ammoniacal nitrogen available in the feed was required for film synthesis and hence rendered unavailable for oxidation. The initial increase in nitrogenous oxidation occurs during a period of relatively stable

ammoniacal nitrogen concentration in the applied feeds, (see figure 9.3), when colonisation of the filters was rapid. Unfortunately, due to the limited data collected, it is not possible to determine whether this decline in ammonia concentration applied is also applicable to the BOD concentrations in the feed; however, from BOD data relating to the primary filter effluent during this period, there does not appear to be a marked decrease in BOD concentration, but, rather marked variations in the quality of the effluent.

The ammonia removed which does not appear as oxidised nitrogen in the effluent must therefore be:- 1) utilised within the filters to synthesise filter film, 2) present in the effluent as organically bound nitrogen, 3) or lost as nitrogen gas due to denitrification.

Table 9.13 - Temperature Effect upon Effluent Ammonia Concentration.

	7.5°C	10°C	L.S.D.
Ammoniacal N Concentration (mg/l).	4.2294	4.5886	0.3443

* Difference significant at 5% probability level.

Table 9.13 shows the mean effluent ammoniacal nitrogen concentrations of the three loadings at 7.5°C and 10°C. It can be seen that the effluents from the filters operating at 7.5°C contain a significantly lower concentration of ammonia than at 10°C. This could be due to filter film still accumulating; at the lower temperature the filters may be at a less advanced stage of maturation, utilising the ammonia to synthesise a film, and also mineralising less of the organic nitrogen. At 10°C the filters could be more mature leading to greater mineralisation of the organic nitrogen than at 7.5°C, but the nitrifying flora may not yet be sufficiently established to convert the additional ammoniacal nitrogen to nitrite and nitrate. Unfortunately

the fate of the organic nitrogen was not monitored during this study.

From table 9.14 below, it can be seen that the quantity of inorganic nitrogen supplied but not appearing in the filter effluents increased with hydraulic loading although the concentration of inorganic nitrogen removed decreased; this lends further support to the theory that the filters were not fully mature.

Table 9.14 - Overall Average Inorganic Nitrogen Balance at the Three Loadings

Filters	NH_3N Applied ($g\ N/m^3/d$)	Oxidised N Produced ($g\ N/m^3/d$)	Percent Conversion	NH_3N Remaining ($g\ N/m^3/d$)	Inorganic N Removed ($g\ N/m^3/d$)	Concentration of N Removed (mg/l)
A1 + B1	2.6080	1.3638	52.3	0.7428	0.5014	2.6340
A2 + B2	5.1936	2.6078	50.2	1.7567	0.8291	2.1878
A3 + B3	7.7651	3.6974	47.6	3.0116	1.0561	1.8551
L.S.D.	0.2769	0.2899		0.7933		

From table 9.14, it can also be seen that the percentage nitrification is reduced as the hydraulic loading increases; this effect could be caused by two factors, either individually or as a combination of both; namely, the result of the increased carbonaceous oxidation demanded of the filters, or the reduced retention time caused by the increased hydraulic loading.

Table 9.15 shows that the BOD removals increased in quantitative terms with increased hydraulic loading. However, between the two highest hydraulic loadings the BOD concentrations of the effluents did not differ significantly, but were significantly greater than for the filters given the lowest hydraulic loading, whilst it might be expected that a greater concentration of BOD would be present in the effluents from the filters receiving the greatest loading.

It is of interest to note that the ratio of inorganic nitrogen removed to that of the BOD removed (table 9.16) by the filters at each loading decreases with increasing hydraulic loading. This suggests that at increased gravimetric loadings, the maturation of the filters was more rapid and that a greater proportion of the organic matter was mineralised.

Table 9.15 - Overall Average BOD Data for Phase 1.

Filters	BOD Applied ($g\ BOD/m^3/d$)	Effluent BOD ($g\ BOD/m^3/d$)	BOD Removed ($g\ BOD/m^3/d$)	Effluent BOD (mg/l)
A1 + B1	24.2968	3.0918	21.2050	12.8235
A2 + B2	46.4469	7.0605	39.3864	18.5221
A3 + B3	67.1853	10.8711	56.3142	18.7794
L.S.D.	4.8025	2.1308	4.1935	4.1701

Table 9.16 - BOD and Inorganic Nitrogen Removals during Phase 1.

Filter	Inorganic N Removal ($g\ N/m^3/d$)	BOD Removal ($g\ BOD/m^3/d$)	Inorganic N/BOD Removal Ratio
A1 + B1	0.5014	21.2050	0.024
A2 + B2	0.8291	39.3864	0.021
A3 + B3	1.0561	56.3142	0.018

Due to wide fluctuations in the quality of the applied primary effluent and the maturation nature of this phase the variations were sufficiently great to mask any significant differences that might have existed in the data collected. However, there are indications that higher temperatures increase the rate of maturation, and that increased hydraulic loadings and hence organic loadings may increase the rate of maturation. Although, on average the filters had

stabilised at approximately 95% removal of BOD and applied ammoniacal nitrogen by the twentieth and twenty sixth week respectively, they were not mature and filter film was still developing.

II Equilibration Phase. (13/1/77 - 17/3/77).

This period was one of equilibration in the performance of all twelve filters, in order that further studies of the effect of various environmental parameters could be made without the previous histories of the filters causing significant variations in their performances. The flows during the period were maintained at a nominal 0.66 $m^3/m^3/d.$, and the temperatures of both cabinets maintained at 20°C (after being raised in three equal daily intervals to 20°C.

By the end of the period, analysis of variance indicated that there was no significant differences in the qualities if the effluents. The mean percentage ammonia removal by the twelve filters for the last two weeks of the period was 93.4 %; (the standard deviation being 2.2%), and the mean BOD removal was 95.5 % (with a standard deviation of 1.3%). However, on average, there was virtually no removal of inorganic nitrogen within the filters or increase in inorganic nitrogen in the effluents compared to that applied, suggesting that the filters might still not have been fully mature and might still be assimilating inorganic nitrogen into the filter film.

III Phase 2. (31/3/77 - 21/7/77).

During this period the temperature of cabinet B was maintained at 20°C, whilst cabinet A was lowered to 10°C in view of the significant differences in the BOD data between several of the replicates during the first phase, which was responsible for masking

any statistically significant differences in the performances of the filters under different conditions, all six filters at each temperature were supplied with the same volume of primary effluent. The analysis of variance was carried out on the data using the format employed during the first phase, in order to detect any possible differences in performance related to previous experiences of the filters. Observation of table 9.5 shows that the only significant differences in performances were due to the temperatures employed and variations due to the changing nature of the primary effluent in time. The BOD analysis during this phase involved the use of allyl thiourea to suppress nitrification.

Table 9.17 - Temperature Effects on Filter Effluent BODs and Ammoniacal Nitrogen Values.

	10°C	20°C	L.S.D.*
Effluent BOD (mg./1)	4.2725	1.9402	1.0631
Effluent BOD ($g\ BOD/m^3/d.$)	2.7048	1.2538	0.6787
Effluent Ammonia (mg N/1)	3.1814	0.4500	0.9420
Effluent Ammonia ($g\ N/m^3/d.$)	1.9901	0.2866	0.5822

* Differences significant at 0.1 % probability level.

Table 9.17 shows that although the quantity of oxidisable organic matter supplied to the filters at both temperatures did not differ significantly, the effluent BODs had highly significant differences; the filter effluents at 20°C having lower BODs than at 10°C. Therefore it is concluded that the higher temperature allowed a greater heterotrophic oxidation of the carbonaceous matter to occur, as might be expected. Considering the ammoniacal results, it can be

seen that a similar trend to BOD removals occurred; therefore the higher temperature also enhanced the removal of ammonia. Overall during this phase, a greater quantity of inorganic nitrogen was present in the effluents than in the feeds applied to the filters. This was probably due to the mineralisation of organic nitrogen present in the high rate filter effluent applied to the filters. It can further be seen from appendix 9.3 that there was an increase in the excess of inorganic nitrogen present in the effluents during this phase; that is, the filter performances were not stable throughout the phase but improved during it. Figure 9.4 shows that the conversion of ammoniacal nitrogen to oxidised nitrogen was greater at higher ammoniacal loadings on the filters. This was due to the greater concentration of ammonia available for oxidation acting as the 'driving force' for the process. At higher ammoniacal nitrogen concentrations, a smaller proportion would be utilised by the heterotrophic bacteria, leaving a higher concentration available throughout the filter to supply the autotrophic nitrifiers.

Although the difference is not significant, the filters at 20°C did not have such a great excess of nitrogen in the effluents as at 10°C. The effluent ammoniacal nitrogen results suggest that nitrification was greater at 20°C, and the BOD data also indicate that greater heterotrophic activity occurred; therefore greater ammonification would be expected also. The difference between the observed results and the expected results suggests that another process might also be involved; that of denitrification. Several previous studies (Solbe, Williams and Roberts 1967 , Duddles, Richardson and Barth 1974, Bruce, Merkens and Haynes 1975) have shown ammoniacal to oxidised nitrogen conversions of between 45% and 90%, and that the

total nitrogen in the effluents from filters was less than that applied.

Although no references could be found in the literature to show that denitrification does account for any nitrogen loss within the filters, several authors suggest that denitrification can occur in conventional treatment plants. Johnson and Schroepfer (1964) suggest that denitrification occurs in plants in which full nitrification occurs. Mohlmann (1938) in an editorial on nitrification refers to the difference between applied ammoniacal nitrogen and the oxidised nitrogen in the effluent and indicates that some of the nitrogen may have escaped from the plants as nitrogen gas. Bayley (1970), in a review of nitrogen removal methods suggests that denitrification occurs in many waste treatment plants to a limited extent and refers to the incidences of rising sludge in humus tanks as indicators of the occurrence. Bishop, Heidman and Stamberg (1976) state that denitrification will occur in both anoxic and anaerobic zones, although under anoxic conditions the rate is far greater.

The present study differs from the references cited in that there was no loss of inorganic nitrogen through the filters, but an increase, which was less at 20°C than at 10°C. It is probable that the filters were not mature (as indicated by the increasing nitrification during the phase). Although nitrification was occurring at both 10°C and 20°C, the bacterial flora responsible for denitrification were not fully established.

IV Phase 3. (28/7/77 - 25/8/77)

On 21/7/77, the flow to all twelve filters was increased to an average flow of 0.71 $m^3/m^3/d$. In order to supply sufficient primary

effluent to the filters during this phase, it became necessary to use two partly filled 10 litre header tanks, instead of one full canister. One 'replicate' of the filters (as operated during phase 1) was supplied from each canister. During this phase the temperatures were maintained at 10°C (cabinet A) and 20°C (cabinet B).

Table 9.6 containing the results of the analysis of variance on the chemical data shows that the use of two supply vessels had a significant effect upon the replicate effluent BODs and ammoniacal nitrogens. It is curious to note that the applied and removed BODs and ammoniacal nitrogen values did not have significant variations in the replicate qualities, and that there were no significant differences in the oxidised nitrogen concentrations produced; it would be expected that filtration of the sewage would tend to reduce the variations in quality, not apparently increasing the variations occurring. Time only had a significant affect upon the effluent ammonia concentrations produced. Temperature appeared to have no significant effect upon the filter performances.

Table 9.18 shows the average data for the period at each temperature. Although not statistically significant, differences did occur. There was a marked difference in the applied BOD loads. Since there was no statistical difference, it indicates wide variations in the quality of the effluent applied to the filters. In keeping with the results of phase 2, the effluent BODs at 10°C were worse than at 20°C. The ammoniacal nitrogens in the effluents were also higher at 10°C than 20°C, but the reverse was true for the oxidised nitrogen results. At both temperatures there is an overall loss of inorganic nitrogen during passage through the filters, which is more pronounced at 20°C. This indicates that denitrification was occurring in both

sets of filters, but that the rate was greater at 20°C. The filters subjected to 20°C had lower ammoniacal and oxidised nitrogen concentrations in their effluents than that of the filters at 10°C.

Table 9.18 - Averaged Analytical Data for Phase 2.

	10°C	20°C
BOD Applied ($g/m^3/d$)	38.2637	58.5168
Effluent BOD (mg/l)	6.2600	3.4767
Effluent BOD ($g/m^3/d$)	4.5815	2.6761
Ammonia Applied ($g\ N/m^3/d$)	13.7889	14.1487
Effluent Ammonia (mg N/l)	1.9000	1.1867
Effluent Ammonia ($g\ N/m^3/d$)	1.3000	0.8795
Ammonia Removed ($g\ N/m^3/d$)	12.4389	13.2692
Oxidised Nitrogen Produced ($g\ N/m^3/d$)	11.8080	11.0125
Loss of Inorganic Nitrogen ($g\ N/m^3/d$)	0.6809	2.2567

* The values shown in the above table do not vary significantly.

In view of the increased loading to all the filters during this phase compared to the second phase, it is surprising that denitrification appeared to be occurring to such an extent, when there was only a slight indication of the activity during phase 2. The increased denitrification indicates that the filters were still maturing.

However, compared to the other studies previously cited, the removal of inorganic nitrogen was only 5% and 16% at 10°C and 20°C respectively.

E. Summary.

Overall, during the three phases reported, the data indicates that the filters were not mature. By the twenty sixth week of phase 1 the filters all gave fairly stable ammoniacal removals and BOD reductions. Also during the first phase there was a loss of inorganic nitrogen through the filters at all three loadings. It appears that the loss is related to a build up of filter film. During the second phase, when all twelve filters received the same loadings, the BOD removal was greater than during phase 1, and there was an increase in the inorganic nitrogen present in the effluents. This was due to further maturation of the filters. The increase in inorganic nitrogen relates to less active film development and greater BOD removal producing more ammoniacal nitrogen in the filters.

During phase 3, employing higher organic loadings, there was a loss of inorganic nitrogen through the filters. This was a result of further maturation when the autotrophic nitrifying bacteria were more fully established, producing greater quantities of oxidised nitrogen which were further converted to gaseous nitrogen by a developing denitrifying population. Also the increased BOD loading encouraged further development of the filter film incorporating organic nitrogen. The BOD removal during this phase was reduced when compared to the second phase.

Increasing the temperature, in the range 7.5°C to 20°C, had the effect of accelerating maturation of the filters.

From the data presented and discussed, it can be seen that during all three phases the filters were not mature and therefore not showing their optimum performance. During the first phase the three hydraulic loadings employed gave rise to significantly different performances. The BOD and ammonia removals increased with hydraulic loading, whilst the effluent BOD and ammoniacal nitrogen concentrations deteriorated with increased hydraulic loadings. Nitrate production increased with hydraulic loading although the effluent oxidised nitrogen concentration was reduced by increased hydraulic loadings. The two temperatures used (7.5°C and 10°C) gave little significant difference in filter performance. However, in the second phase where only one hydraulic loading was used, the variation between replicates was removed and the two temperatures were shown to give rise to significantly different performances. At the higher temperature (20°C) there was greater BOD reduction and enhanced ammoniacal nitrogen removal. During the third phase when the temperatures of 10°C and 20°C were again employed, any significant difference in the performance of the filters was masked by large variations between the replicates; however, there are indications that maturation had reached a further stage at 20°C than at 10°C.

During the third phase, at the average hydraulic loading of 0.71 $m^3/m^3/d.$, the BOD concentration was 70 mg/l., and the ammoniacal nitrogen concentration approximately 20 mg/l. These gave rise to BOD and ammoniacal nitrogen loadings of 50 $g/m^3/d$ and 14 g $N/m^3/d$. The media employed had an estimated specific surface area of 300 m^2/m^3; using conventionally sized media with a specific surface area of 80 m^2/m^3, the loading necessary to obtain the performances

achieved at phase three would be:- a BOD loading of 13.33 g /m^3/d, an ammoniacal N loading of 3.73 g N/m^3/d, and a hydraulic loading of 0.19 m^3/m^3/d. It can be seen that these loadings are quite low, comparing to conventional values used in full scale practice. However, the filters did not achieve maturity and indicated that a further increase in efficiency could have been achieved in time. Unfortunately, the extended periods required by the filters to achieve maturity did not allow study of their possible performances at much higher hydraulic loadings.

In conclusion, it can be said that the filters indicated that a long period is required to establish a stable nitrifying filter population and that the effluent from the primary high-rate filters at Hereford could be nitrified at conventional filter loadings. The study indicated that a settled sewage of an average 70 mg/l. BOD could be nitrified at hydraulic loadings of 0.19 m^3/m^3/d on conventional media and that the secondary filters could accommodate large variations in the applied loads. The laboratory scale filters, although heavily colonised by nematode worms, did not contain any macrograzers which might have affected their performance.

10. LABORATORY SCALE NITRIFYING FILTERS USING SYNTHETIC SEWAGE.

A. Introduction.

As previously mentioned in chapter 3, the presence of organic matter in effluents to be treated in nitrifying biological filters is thought to affect the oxidation of ammonia to nitrate. In order to ascertain the effect of organic matter on this conversion, it is desirable to study identical nitrifying filters using differing strengths of carbonaceous matter, whilst maintaining similar concentrations of ammonia. Since the effluent obtained from primary filters treating a supply of natural sewage is subject to changes in its strength and nature over a period of time, synthetic sewage of known composition might gainfully be employed. Also, to determine the nitrifying ability of autotrophic organisms in the absence of organic matter, control filters treating a liqour containing a similar concentration of ammonia may be considered desirable.

B. Experimental Work.

In order to study solely the effect of organic matter upon nitrification, variations in other parameters such as temperature, flow rates and nitrogen concentrations had to be minimised. The time available and the cost of producing synthetic sewage on a large scale limited the size and number of filters which could be observed in the present study. Eight laboratory scale filters identical to those described in chapter 9 were constructed and installed in one of the cabinets also described in chapter 9.

The filters were washed out with tap water for two months before the application of sieved primary effluent from the Hereford pilot scale high-rate biological filters. From 8/2/77 until 31/3/77, all eight filters were supplied with the Hereford effluent at a nominal flow rate of 0.66 $m^3/m^3/d$. The temperature during most of this maturation period was maintained at 20°C.

On the 17/3/77, the temperature of the cabinet was reduced in daily 1.5°C intervals to 10°C by 24/3/77. The sieved primary effluent was applied in order to obtain nitrifying filters of similar performances to commence the study. If the sterile synthetic sewages had been applied to 'clean' filters, the production of a nitrifying flora would be by chance innoculation and could lead to differing performances of the eight filters.

On the 31/3/77, the filters were supplied with synthetic sewages of four different organic contents but similar ammonia concentrations. The flow rates were maintained at a nominal 0.66 $m^3/m^3/d$. The substrate was applied to the eight filters in a similar manner to that described for the nitrifying filters using sieved Hereford primary filter effluent; the sampling procedures and the analytical routines being identical (all BOD determinations carried out nitrification suppressed with allyl thiourea); only the volume of the supply tanks differed. The four pairs of duplicate filters were supplied from four separate 5 litre canisters which were cleaned weekly and recharged on Thursday and Monday each week.

Two of the filters were supplied with a solution of 400 mg/l sodium bicarbonate and 160 mg/l of ammonium sulphate prepared with distilled water; the sodium bicarbonate being present as a buffer. Also added were trace nutrients in concentrations listed in table 10.1 to prevent nutrient inhibition of nitrification. The other three pairs of filters were provided with three differing concentrations of glucose, bacteriological peptone and laboratory lemco, but similar concentrations of ammonium bicarbonate and trace nutrients as described in table 10.1. Weekly stocks of the organic substrates were prepared by autoclaving concentrated volumes of the organic reagents. These were diluted when required,ammonium

bicarbonate being added. To the diluted solutions trace nutrients were added, and then the solutions made up to 5 litres. Table 10.1 shows the various concentrations applied to the four pairs of filters.

Table 10.1 Concentrations of Nutrients in the Synthetic Sewages.

(mg/l)

Nutrient	A	B	C	D
Peptone	-	30	60	90
Lab. Lemco	-	30	60	90
Glucose	-	10	20	30
Sodium bicarbonate	400	40	80	120
Ammonium bicarbonate	-	200	200	200
Ammonium sulphate	160	-	-	-
Ferric chloride ($.6H_2O$)	0.125	0.125	0.125	0.125
Calcium chloride	27.500	27.500	27.500	27.500
Magnesium sulphate ($.7H_2O$)	25.000	25.000	25.000	25.000
Potassium dihydrogen phosphate	42.500	42.500	42.500	42.500
Sodium hydroxide	8.800	8.800	8.800	8.800

C. Results.

The weekly means of the flow rates, BOD concentrations, ammoniacal nitrogen concentrations and nitrate production are shown in appendix 10.1. The different treatments are denoted by A,B,C and D in the appendix and the following tables. A filters were supplied with inorganic nutrients only; B,C and D filters received synthetic sewages of increasing organic strength.

I Flow Results

Analysis of variance of the flow results shows that there was no significant variation between the flows received by any of the filters and that there was no significant variation in time. The

mean flow value for all eight filters over the 20 week study period was 0.742 $m^3/m^3/d$, and a standard deviation of $\pm$ 0.056 $m^3/m^3/d$. The mean flow to the filters were as follows :-

A	B	C	D	Std. Dev.
0.742	0.772	0.750	0.735	$\pm$ 0.056 $m^3/m^3/d$.

II BOD Results.

Analysis of variance was also carried out on the weekly mean BOD results. Table 10.2 indicates the results of the analysis. In all cases there were significant differences between the treatments but no significant differences between the replicates.

Table 10.2 Means and L.S.D.s of BOD Data.

	A	B	C	D	L.S.D.*
BOD Applied (mg/l)	5.33	26.15	61.15	89.12	4.43
**** BOD Quantity Applied ($g/m^3/d$)	3.93	20.17	45.73	65.41	2.55
**** Effluent BOD (mg/l)	4.02	4.26	5.63	13.57	2.14
**** BOD Removal (mg/l)	1.31	21.89	55.53	75.41	3.55
**** BOD Quantity Removed ($g/m^3/d$)	1.00	16.82	41.60	55.41	8.75
Percent BOD Removed.	25.4	83.4	91.0	84.7	

L.S.D.* Least Significant difference, calculated at 10% level of probability.

**** Results vary at 0.1 % level of probability with time.

III Inorganic Nitrogen :- The results of analysis of variance on the ammonia and nitrate data are presented in table 10.3.

Table 10.3 Means and L.S.D.s of Inorganic Nitrogen Data.

Parameter	A	B	C	D	L.S.D.*
**** NH_3 Applied (mg N/l)	36.75	38.15	40.08	40.32	2.12
**** NH_3 Applied ($g\ N/m^3/d$)	27.23	29.36	30.24	29.75	1.27
**** Effluent NH_3 (mg N/l)	5.09	15.20	15.10	20.17	1.41
**** NH_3 Removed (mg N/l)	31.67	22.96	24.98	20.15	0.99
**** NH_3 Removed ($g\ N/m^3/d$)	23.56	17.68	18.81	14.77	1.23
**** NO_3 Applied ($g\ N/m^3/d$)	0.0415	0.1260	0.0283	0.0201	0.0676
**** Effluent NO_3 (mg N/l)	32.34	28.10	32.54	27.72	2.04
**** NO_3 Produced (mg N/l)	32.29	27.94	32.50	27.69	2.08
**** NO_3 Produced ($g\ N/m^3/d$)	24.02	21.46	24.38	20.23	1.47

L.S.D.* Least Significant Difference, calculated at 10% level of probability.

**** Results vary at 0.1 % level of probability with time.

Figure10.1 BOD Quantities Applied and Removed..

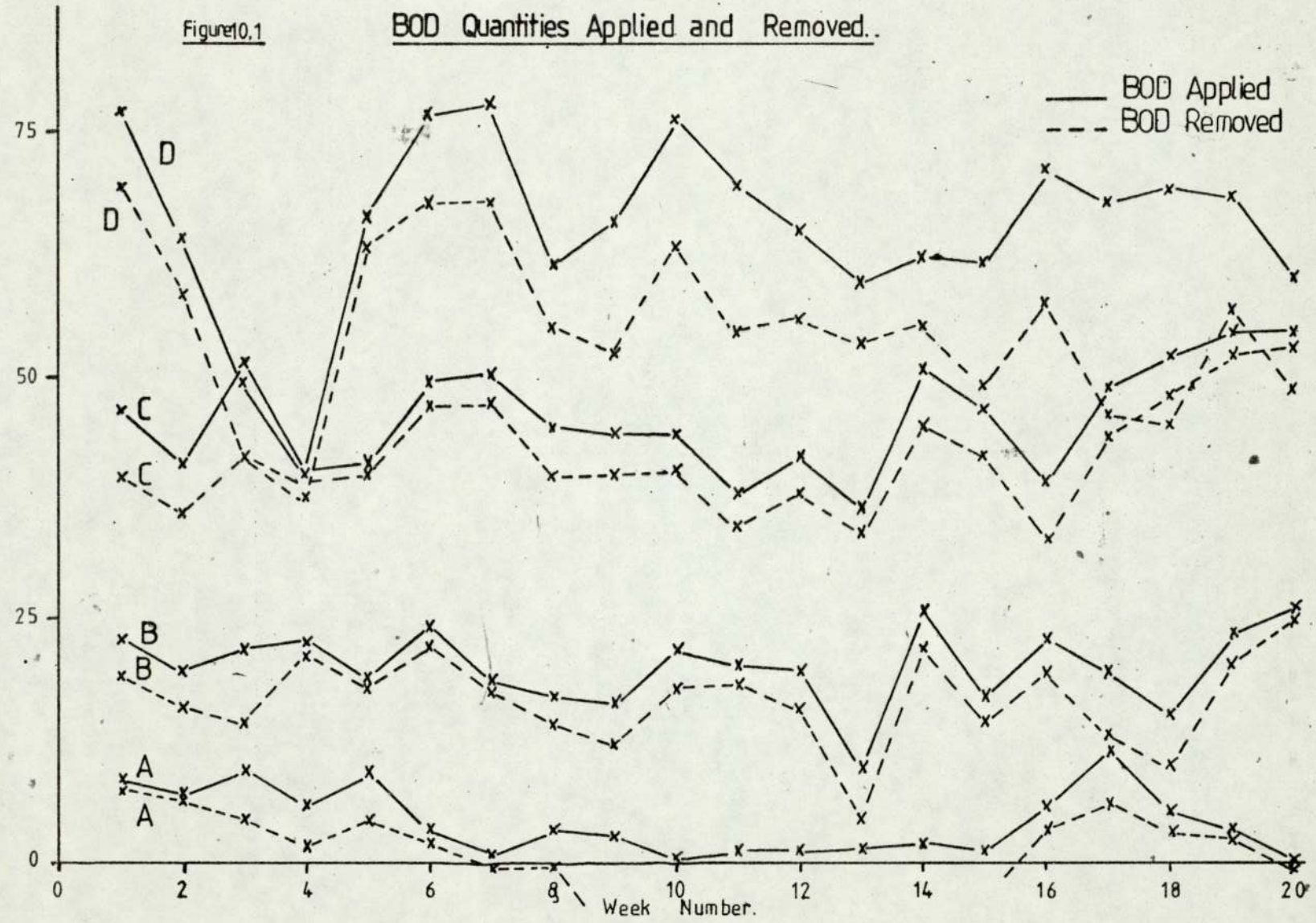
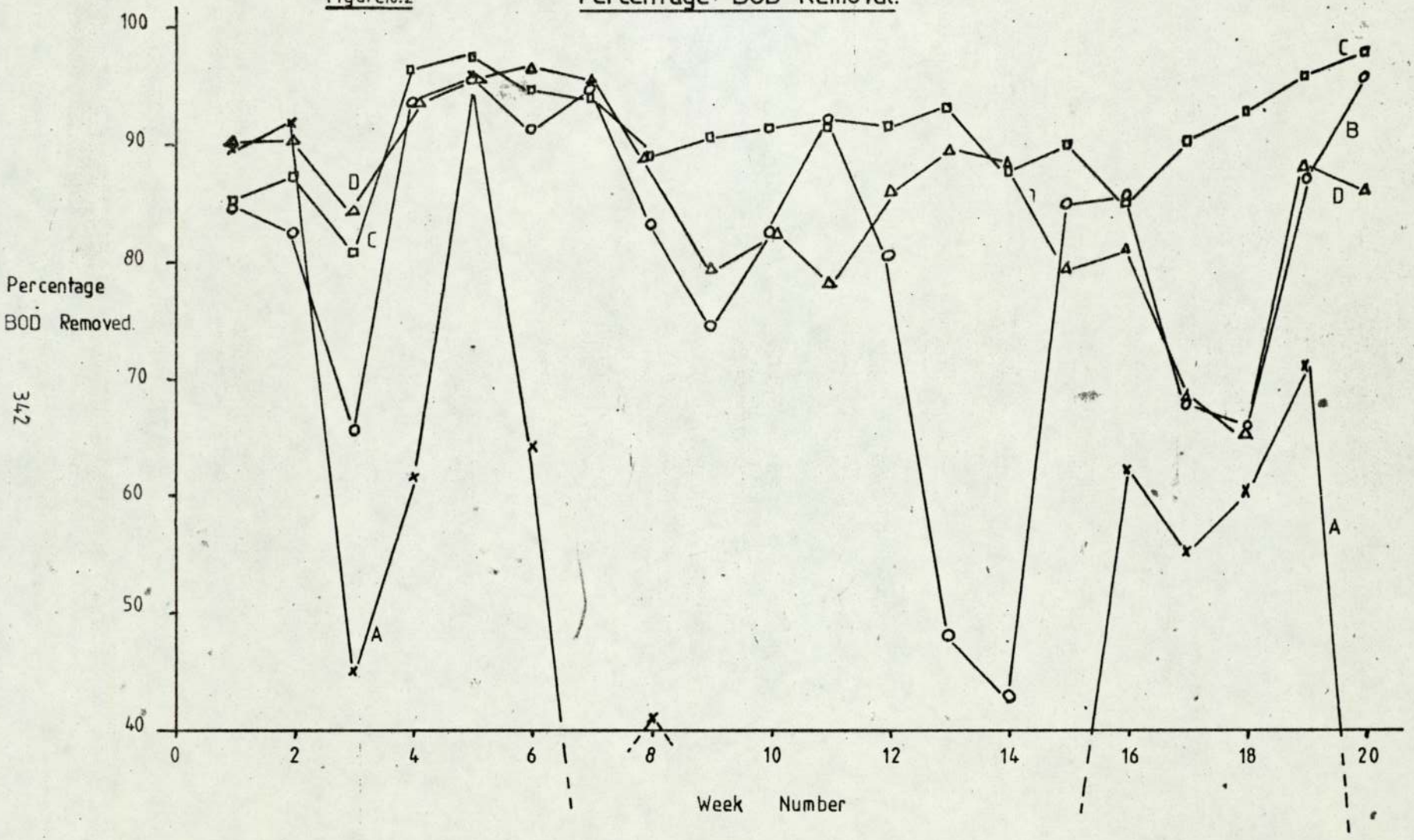


Figure10.2

Percentage BOD Removal.



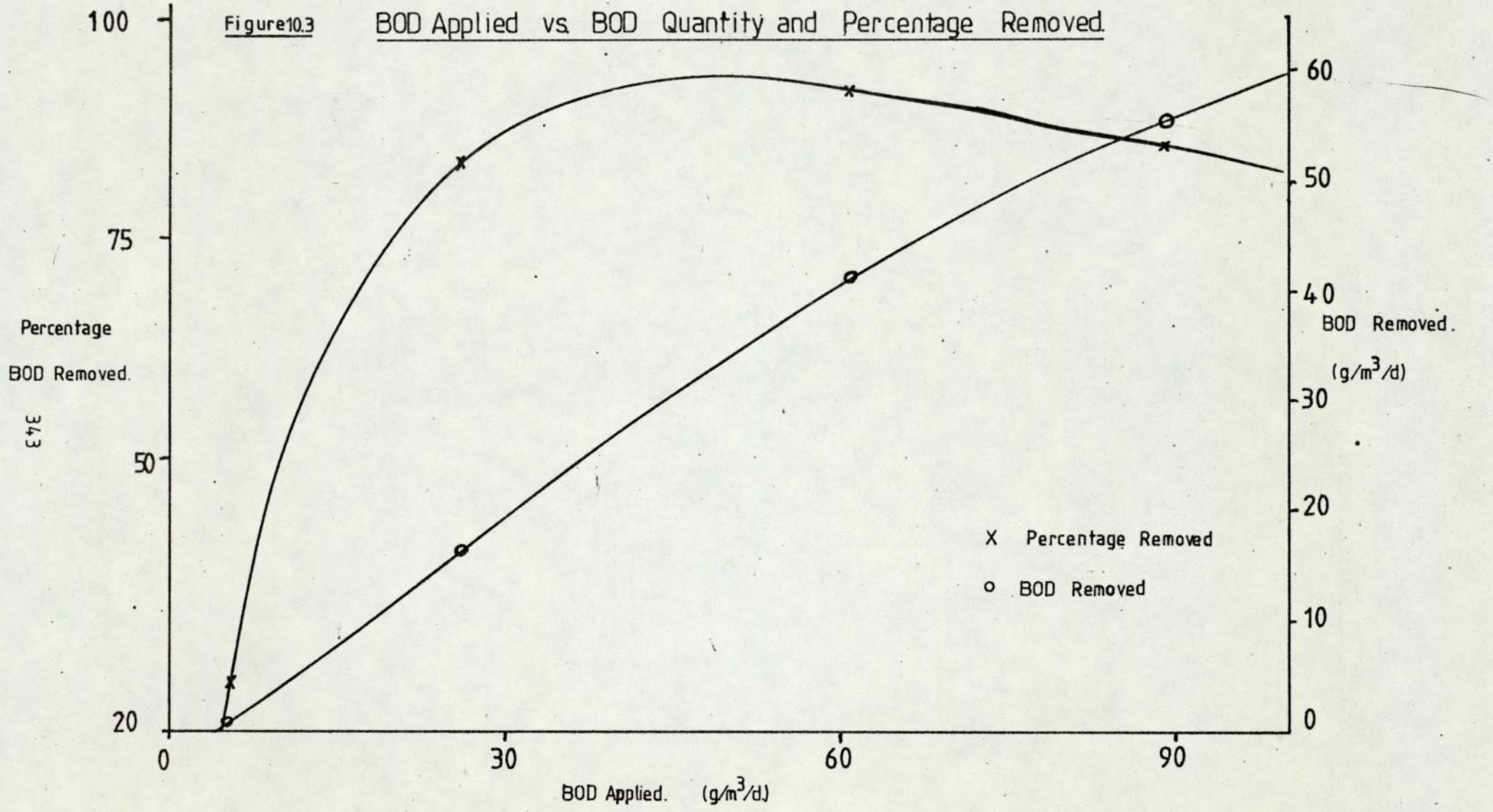
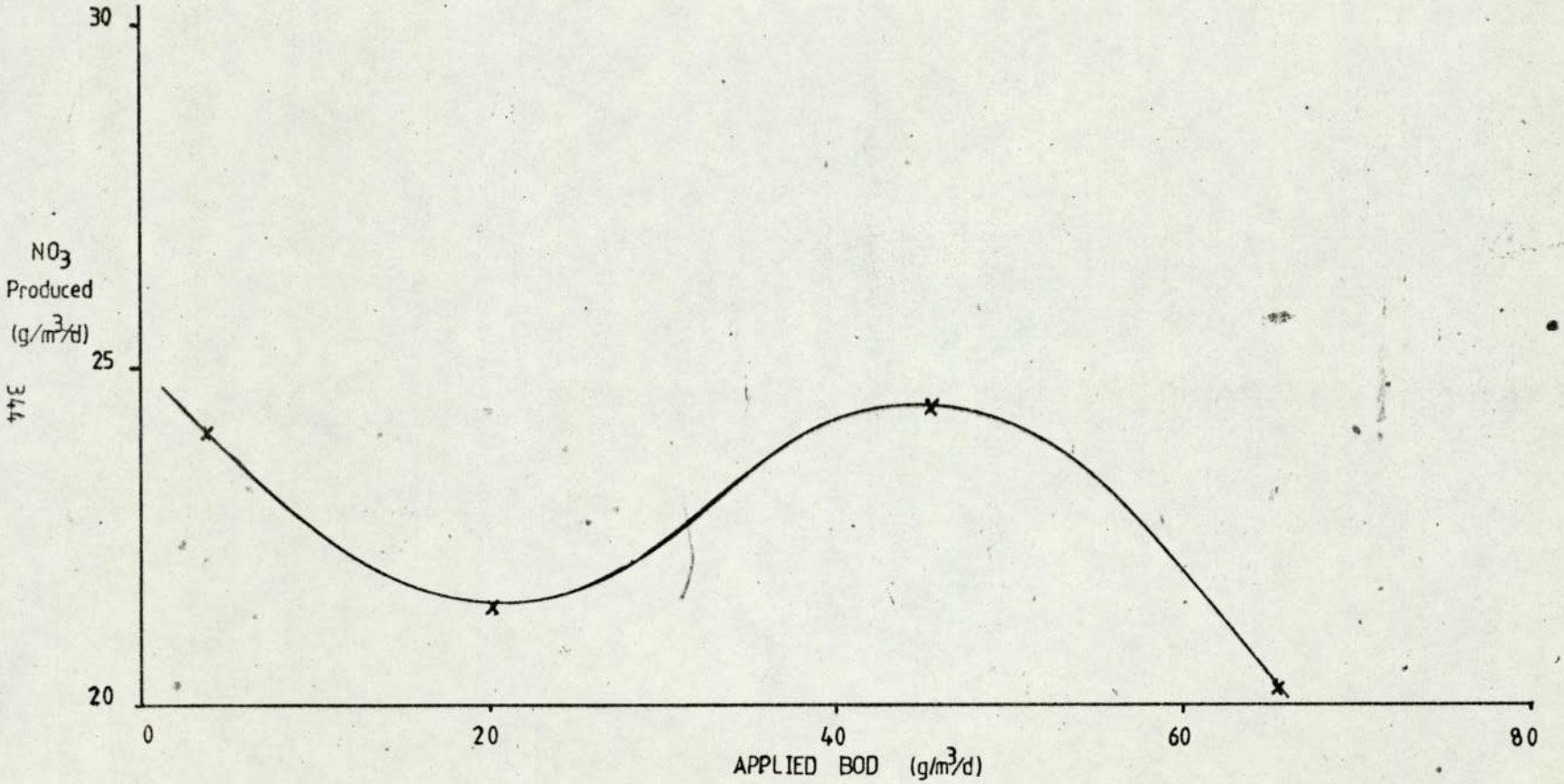


Figure10.3
BOD Applied vs. BOD Quantity and Percentage Removed.
100
75
50
20
Percentage
BOD Removed.
343
60
50
40
30
20
10
0
BOD Removed.
(g/m3/d)
X Percentage Removed
o BOD Removed
0
30
60
90
BOD Applied. (g/m3/d)

Figure10.4 Nitrate Produced vs. BOD Applied, using synthetic sewage.



D. Discussion.

The nominal flow rate was 0.66 $m^3/m^3/d$; however from the results shown in appendix 10.1, it can be seen that this value was commonly exceeded for all eight filters. Although the values obtained were significantly greater than 0.66 $m^3/m^3/d$, in view of the constancy of the results it was considered acceptable to maintain this flow rate. Occasions when the individual flow rates were greater or less than one standard deviation from the mean were generally attributable to damaged or incorrectly tensioned feed pump tubings.

Table 10.2 showing the means of the BOD data shows that apart from the BOD concentrations applied, the gravimetric loads and removals and effluent BOD concentrations varied significantly with time. Since the applied BOD concentrations and the flows did not vary significantly with time, the variations in the gravimetric BOD loads must be the product of the combined variations of the BOD concentrations and the flow rates. No significant variation was found between the loads or removal performances of any of the duplicate filters.

From table 10.2 showing the means of the BOD data, it can be seen that the mean concentrations applied to filters B,C and D were close to the desired concentrations of 30, 60 and 90 mg/l. However, in the case of the feed applied to A filters there should have been no organic matter present capable of exerting a BOD. The BOD observed in practice was due to bacterial contamination of the feed canisters and the supply tubing. The BOD and oxidised nitrogen analyses showed that there was no oxidised nitrogen or BOD present in the feeds at the beginning of each week, but that trace amounts of oxidised nitrogen were present by the end of each week and that

the feed also had a BOD by the end of each week. When renewing the synthetic sewage supply to the filters, the canisters were washed using hypochlorite and then thoroughly rinsed before being refilled; the contamination was therefore introduced by the supply tubings to the pump. Again, considering A filters, the weekly averaged data in appendix 10.1 shows that the BODs of the effluents were frequently greater than the applied BOD. The result could be explained as the consequence of autotrophic nitrifiers in the filters; that is the nitrifying bacteria impart a BOD to the effluent as a result of metabolism and cell lysis.

From figures 10.1 and 10.2 it can be seen that the BOD removals in all cases closely followed the applied BOD loads, and that in the case of D filters the percentage removal was less than that observed in C filters, although the absolute quantity of BOD removed was generally greater than that of C filters.

Observing the BOD removal for D filters in figure 10.2 shows that during the study period the percentage removal declined. This trend began during the sixth week. Visual observation of the filters indicated that by the fifth week a thick light grey-brown fungal film had developed on the surfaces of C1,C2,D1 and D2 filters to a depth of approximately 50 mm; particularly in the case of D filters. Microscopic examination of the surface film indicated that Fusarium aquaeductuum was the dominant fungus present. Sepedonium and Subbaromyces were also tentatively identified from the filter films. The films were all extensively grazed by nematode worms, present in much greater numbers than commonly occurring in full scale filters. This was presumably due to the absence of macro-grazers. By the seventeenth week of the study a thick black fungal

film had developed on D filters; in the case of D2 ponding occurred; the surface only partially draining between each dose of sewage. The black coloration was due to the anoxic zones where anaerobic degradation of the fungal film occurred.

From table 10.2 it may be seen that the effluent BOD concentrations of A and B filters did not differ significantly although the BOD removals differed significantly. In the case of A filters, a greater quantity of synthesised organic matter was produced as a result of autotrophic nitrification giving rise to an oxidizable effluent. From table 10.3 it can be seen that A filters produced a significantly greater quantity of oxidised nitrogen than B filters leading to a greater production of oxidizable organic matter in the effluent. Considering the BOD percentage removal figures shown in table 10.2, the low figure of 25.4% for A filters occurred for the above mentioned reasons. It is of interest to note that D filters showed a lower percentage removal than C filters although the absolute quantity of oxidizable matter removed was greater than for C filters. The trend observed for the percentage removal figures indicated that at low quantities of applied BOD the activity of the autotrophic nitrifiers exerted a significant BOD load on the effluents from the filters, whilst the absolute quantity of BOD removed did increase with increasing applied BOD. The percentage removal figures indicate that at some stage between a BOD concentration of 30 to 90 mg/l, near to 90 mg/l, at the hydraulic load employed, the ability of the filters to accommodate the increasing BOD load declines, suggesting that at a higher BOD loading than 90 mg/l the quantity of BOD removed would reach a maximum value. After that stage, any further BOD load applied to the filters would be present in the filter

effluent, (see figure 10.3).

Appendix 10.1 shows that the applied ammonia concentrations varied significantly with respect to time, but that the applied nitrate concentrations did not do so. This indicates that the production of nitrate in the feed canisters by nitrifying bacteria was not wholly responsible for the variations in the ammonia applied to the filters. Therefore the variations in the applied ammonia concentrations must also be attributable to inconsistencies in the production of synthetic sewages, analytical techniques; and also the oxidation of nitrogenous organic matter in the cases of B, C and D filters.

From table 10.3 it can be seen that the ammonia concentrations applied to the four sets of filters varied. Filters C and D received feeds significantly stronger in ammonia than A filters, although proportional quantities of ammonium salts were used to prepare the synthetic sewages. It can also be seen from table 10.3 and appendix 10.1 that A and B filters generally received a greater concentration of nitrate in the synthetic sewages applied. This pattern indicates that autotrophic nitrification was occurring within the feed canisters of A and B filters in particular, and also that oxidation of organic matter was occurring. The oxidation of organic matter converting organic nitrogenous materials into ammonia can be seen to be occurring at a greater rate than the production of nitrate from ammonia; the net effect being the increasing concentrations of ammonia available for oxidation in the filters receiving sewages containing organic matter.

From table 10.3, the following table can be produced :-

Table 10.4 Nitrate Production and Ammonia Removal in Filters receiving Synthetic Sewage.

	A	B	C	D
Ammonia Quantity in effluents ($g\ N/m^3/d$)	3.67	11.68	11.43	14.98
Nitrate Produced ($g\ N/m^3/d$)	24.02	21.46	24.38	20.23
Ammonia Quantity Removed ($g\ N/m^3/d$)	23.56	17.68	18.81	14.77
"Excess" Nitrate Production ($g\ N/m^3/d$)	0.46	3.78	5.57	5.46

From this table it can be seen that more nitrate was produced than ammonia removed from the synthetic sewage in each set of filters and that the excess nitrate production to ammonia removal is far greater in filters B, C and D than for A filters. Initially, it may seem incongruous that a greater quantity of nitrate may be produced than ammonia removed. However, the synthetic sewages to B, C and D filters also contained organic nitrogenous materials in the form of Oxoid laboratory Lemco and Bacteriological Peptone. Therefore the overall picture is one of nitrogenous organic matter producing ammonia within the filters which may be further oxidised to nitrate. Overall, it can be seen that the amount of nitrate produced in any of the filters was less than the quantity applied, so that in quantitative terms, the organic nitrogen was oxidised only as far as ammonia in the filters. Table 10.4 also shows that in the case of A filters more nitrate was produced than ammonia removed, yet this should not occur since the synthetic sewage applied to A filters contained no nitrogenous organic matter. This difference can only be accounted for as an artefact; that is the analysis for nitrate nitrogen and ammoniacal nitrogen

caused consistent differences to occur, or that the previously matured filter film was being lysed during the period, releasing inorganic nitrogen. This last proposition could be feasible for A filters particularly, since during the maturation period organic sewages were applied to the filters thus developing a film which might not be able to survive under the conditions of the study, due to the application of inorganic salts only. If the first suggestion was the cause of this difference, a consistent error of only 0.9% in the two analyses would account for the mean values shown.

There was no significant trend in the differences between the nitrate being produced and ammonia applied to A filters. For only six widely spread weeks did the mean nitrate production exceed the ammonia removal. It may therefore reasonably be concluded that the overall greater nitrate production in A filters than ammonia removal was in the most part attributable to analytical errors.

Table 10.3 shows that B filters removed significantly less ammonia from the applied sewage than A filters. However, the true ammonia removal in B, C and D filters could be greater than that shown in table 10.3. From the following table (table 10.5), the additional inorganic nitrogen present in the effluents to that applied in the synthetic sewages can be observed; this additional inorganic nitrogen occurred as the result of oxidation of nitrogenous organic matter, as previously explained. Therefore a more accurate value of the ammonia nitrogen removals can be made using the nitrate production data. From table 10.4 it can be seen that D filters produced the least nitrate, although not significantly different from that produced by B filters. A and C filters produced significantly greater quantities of nitrate than either B or D filters. It should be recalled that the BOD load to B, C and D filters increased in the

order B least and D greatest.

Table 10.5 Total Inorganic Nitrogen Balance.

	A	B	C	D
Inorganic Nitrogen Applied (g $N/m^3/d$)	27.27	29.49	30.27	29.82
Inorganic Nitrogen in Effluent (g $N/m^3/d$)	27.81	33.16	35.75	35.01
Additional Inorganic Effluent N (g $N/m^3/d$)	0.54	3.67	5.48	5.19

Previous studies have indicated that increasing BOD load applied to nitrifying filters reduces the nitrifying ability either directly or by an indirect competitive effect exerted by the heterotrophic bacteria, as explained in chapter 3. It might therefore be expected that C filters would produce less nitrate than B filters and that D filters would produce even less. The ammonia concentrations in the effluents in table 10.3 show that the presence of the oxidisable organic matter had a considerable effect in reducing the nitrification in B filters from that shown by A filters. Again, it might be expected that C filter effluents would contain a higher concentration of ammonia than B filters. Figure 10.4 shows the nitrate production which occurred at the various organic loadings.

There are at least two possible explanations for the curve shown. One is that the curve is a consequence of two opposing trends. Increasing the BOD load to nitrifying filters reduces nitrification, either by directly inhibitory activities or the effects of competition. However, increasing the organic loading to a filter may also have the effect of increasing the nitrogenous organic material present, as in the present study. The nitrogenous organic matter has been shown to be oxidised to ammonia, thus increasing the concentration available

for oxidation to nitrate; that is , the greater the organic matter applied to the filters, the greater the concentration of substrate for the autotrophic nitrifiers.

Another explanation for the nitrate production / BOD loading curve observed may be that the nitrogenous oxidation is performed by both autotrophic and heterotrophic nitrifiers. Again two independent trends could explain the curve observed. Autotrophic nitrification is known to be depressed in mixed cultures when the organic loading increases. From the differences in performances of A and B filters, it might be concluded that low concentrations of oxidizable organic matter in the range 0 to 30 mg/l of BOD begin to suppress the autotrophic nitrifying activity. However, the presence of organic matter may enhance the activity of heterotrophic nitrifiers, but that the optimum performance lies somewhere between 30 and 90 mg/l of applied BOD. At higher organic loadings heterotrophic nitrification is depressed perhaps as a direct result or indirect consequence of increased oxidation of the organic matter by other heterotrophic organisms. However, only limited numbers of studies have shown the existence of heterotrophic nitrification.

Eylar and Schmidt (1959) isolated heterotrophic organisms from various soils which displayed a nitrifying ability. Fungus isolates were the most numerous and also the most active nitrite producers. Fifteen fungal isolates produced nitrate as well as nitrite. Quastel, Scholefield and Stevenson (1950) found three species of organisms, isolated from soil, capable of oxidising pyruvic oxime to form nitrite. Jensen and Gundersen (1955) isolated a bacterium Corynebacterium simplex from a soil capable of converting aromatic compounds to nitrite. Marshall and Alexander (1962) showed that Aspergillus flavus could produce nitrate from organic sources of nitrogen in sufficient quantities in culture studies to be of practical significance.

Doxtader and Alexander (1966) found that various heterotrophic soil bacteria, actinomycetes and fungi produced nitrite when grown in media containing various forms of reduced nitrogen; however, none of the organisms formed nitrate from the substrates tested. The majority of studies, as indicated in chapter 3, have suggested that autotrophic oxidation is the most common form of nitrification; therefore this second explanation for the observed nitrate production / BOD loading curve should be viewed with caution.

E. Conclusions.

From the study reported in this chapter it can be seen that nitrification of ammonia is affected by the presence of oxidisable organic matter. However, the precise nature of this suppression has not been elucidated. At a BOD loading of less than 60 $g/m^3/d$ suppression of nitrification occurs. This suppression might begin at a very low BOD loading in the region of 10 $g/m^3/d$.

Further laboratory scale studies using higher concentrations of organic substrates are required to find out to what extent nitrification is suppressed.

Studies using only ammonium salts and organic substrates without organic nitrogen compounds would more accurately indicate the nature of autotrophic nitrification suppression.

More stringent quality controls should have been exercised in the production of the synthetic sewages in order to avoid significant variations in their strengths.

11. HEREFORD PILOT SCALE SECONDARY FILTERS

A. Purpose of the Secondary Filters.

In view of the preliminary findings from the laboratory scale secondary filters at Aston which indicated that the high rate primary effluent could be nitrified at conventional rates on mineral media, it was considered desirable to observe the performance of pilot scale filters at Hereford subject to more realistic environmental conditions and using fresh settled primary effluents.

Also the opportunity arose to examine the performance of two plastic media, namely Flocor RS and Flocor R2S, which were developed with the intention of providing a Royal Commission effluent. A previous study (Wheatley and Williams 1976) had indicated that the Flocor RC (similar to Flocor RS) could produce such an effluent using settled sewage, although the nitrification achieved was poor. Flocor RS and Flocor R2S have specific surface areas of 240 m^2/m^3 and 140 m^2/m^3 respectively, with void capacities of greater than 94%; therefore in order to compare favourably with mineral media the hydraulic loadings would have to be of the order 0.6 $m^3/m^3/d$ and 0.35 $m^3/m^3/d$ respectively.

During the planning of these secondary filters, it was noted that in order to obtain maximum BOD removal from high rate primary filters, hence reducing the capital expenditure on high rate filters, loadings in excess of those which produced a well oxidised effluent are required. However, the pilot high rate studies were indicating that the effluent which would be achieved at high loadings might not be suitable for nitrifying in secondary filters. This led to the thought that three stage filtration of the sewage, in which the tertiary stage was designed to effect nitrification, might overall reduce the volume of media required. Therefore during the design stage of the pilot

secondary filters using the plastics media, consideration was given to providing much higher organic loads than would be conventionally used for nitrifying filters.

The construction of pilot scale nitrifying filters would also provide an opportunity to study the development of maturation, the ecology of nitrifying filters and the film thickness at different depths.

B. Design and Construction Considerations.

At Hereford beside the pilot scale high-rate filters exists a Braithwaite tank of 18 m^3 volume, which had been employed for previous experimental trials. The tank is 3.6 metres long, 2.4 metres wide and an average depth of approximately 2 metres.

The shape of the tank dictated the use of reciprocating distributors of 3.6 m travel. In order to study the effect of frequency of dosing, the speed of the distributor's movement should be variable. The jets on the distributor should also be designed such that the loading and method of distribution could be varied.

In view of the Braithwaite tank shape, it was considered feasible to study two filters each of 1.2 metres by 3.6 metres surface dimensions. Since the media to be studied (Flocor RS and Flocor R2S) were of light weight, the filters could be separated by the construction of a heavy gauge polythene partition fastened into position by a wooden framework which would also prevent the mixing of the effluents at the base of the filters. As can be seen from figure 11.1, the Braithwaite tank has a sloping base which would permit adequate egress of the filter effluents. The loading to each filter could be regulated by varying the number and size of the jets on the distribution arm.

Figure 11.1. Elevation of Secondary Filtration Plant.

Scale 1:50.

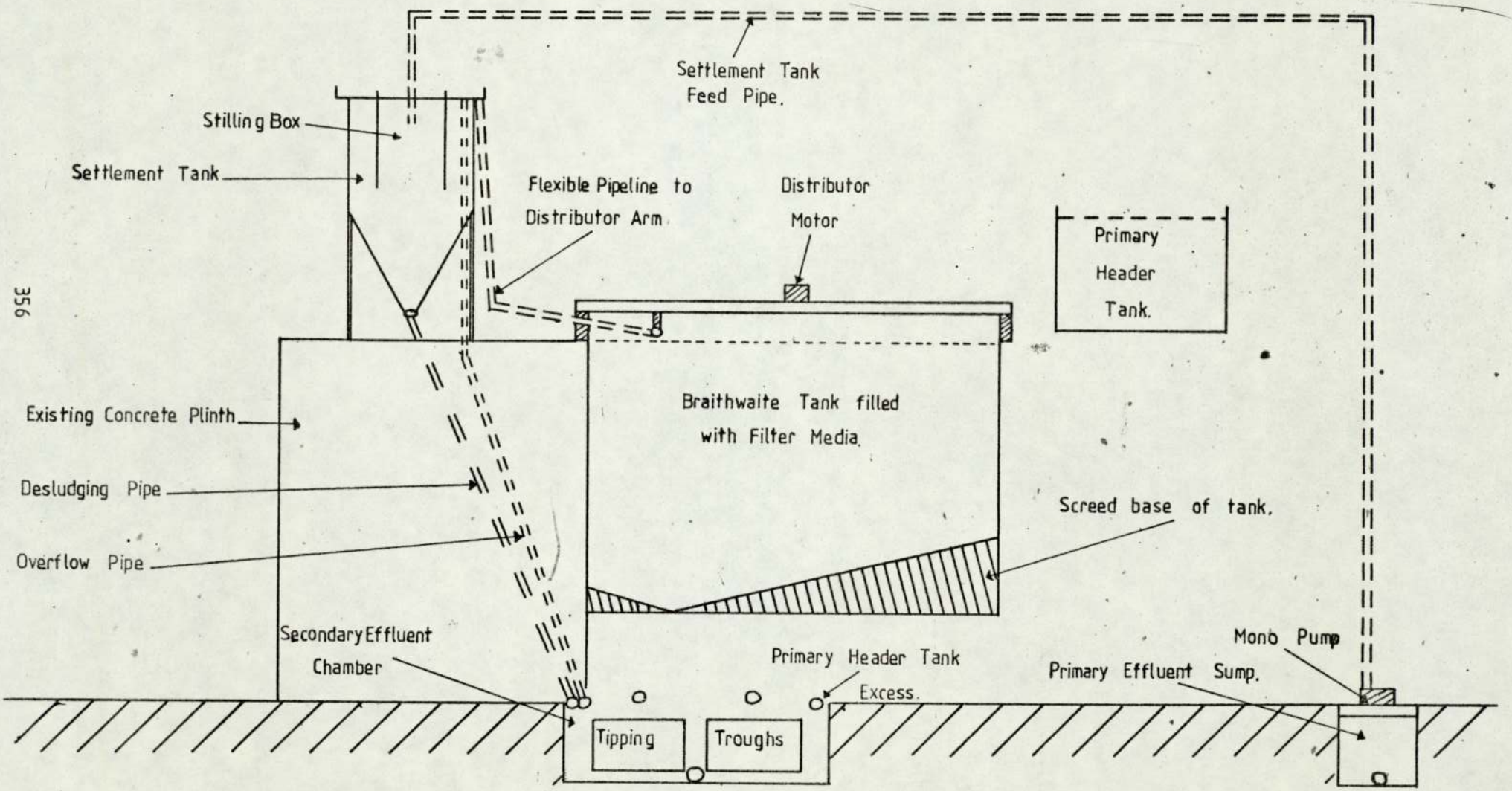
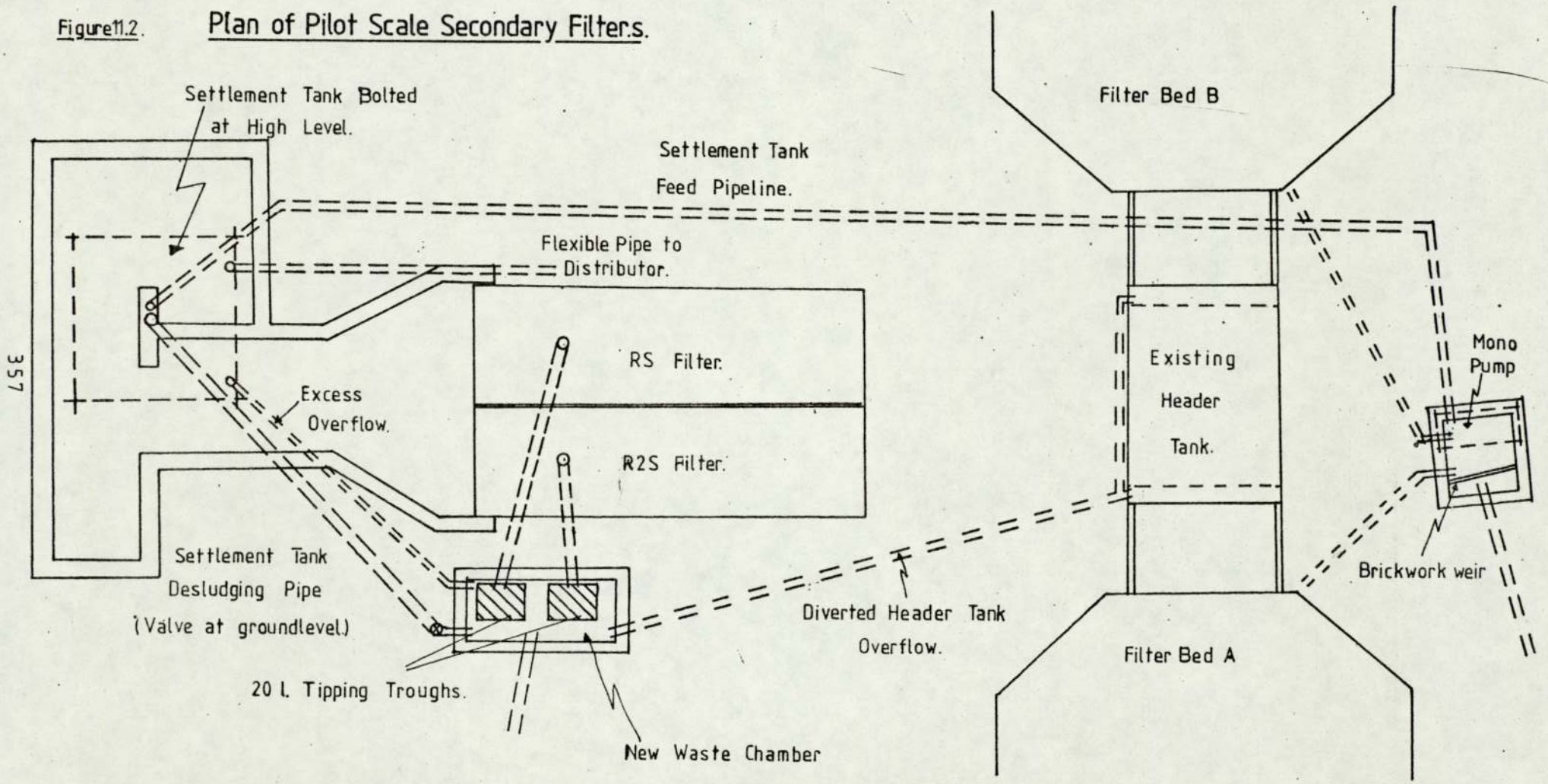


Figure11.2. Plan of Pilot Scale Secondary Filters.



The use of Flocor RS and Flocor R2S dictated the quantity of primary effluent which would require settlement and application to the filters. In order to raise the primary effluents to a settlement tank and the surface of the filters, the wasted settled sewage from the primary filters header tank would require diverting from the effluent channels into a separate chamber so that only the primary filter effluents would enter the existing outlet chamber. This existing chamber would then require modification to form a sump from which the primary effluent could be pumped to a settlement tank. In order to minimise the pumping requirements, the primary effluent settlement tank should be mounted on the raised concrete standing beside the Braithwaite tank so that the settled effluent could be gravity fed into the distribution system. The settled effluent would be most easily conveyed to the distributor by means of flexible piping to accommodate the travel of the distributor arm.

To maintain the required hydraulic loadings to the secondary filters, excess primary effluent would need to be pumped to the settlement tank. In order that the secondary filters could be supplied with effluent having received similar settlement at all hydraulic loadings, the entire quantity pumped up to the settlement tank should receive settlement; the excess being run to waste. To minimise the modifications to the waste system, it would be advantageous for this excess to be directed to the same waste chamber as the primary filters header tank overflow.

In order to desludge the settlement tank, a system should be devised which would enable the operator to observe when desludging should cease. Again, to simplify the modifications, the sludge

should be conveyed to the same waste chamber used for the excess supplies. Preferably, a valve should be installed in the desludging line at ground level, beside the waste chamber, so that the operator could observe the sludge being wasted, and close the valve without having to climb up to the settlement tank for this procedure.

Adequate provisions must also be provided to sample the liquors at each stage of the secondary treatment and to monitor the flows received by each filter. Samples of the sewage at each stage should preferably be obtained at ground level. By providing a free fall into the waste chamber for the excess settled primary effluent, the desludging pipework and the secondary filter effluents, all the samples could be obtained at one position on ground level, apart from the mixed unsettled primary effluents, which could be sampled from the pump wet well. The flows through the two filters could be monitored using tipping troughs in a similar manner to that used for the primary filters, on the effluents from the filters.

Two electric motors would be required for this secondary treatment stage; one driving the primary effluent pump and one for the reciprocating distributor. Three phase motors are to be preferred to single phase, to reduce the likelihood of overloading any single phase during start-up proceedings which could interrupt the supply to any of the other electrical equipment on the pilot plant.

C. Construction Details.

The primary filters header tank excess was diverted to a newly constructed waste chamber beside the Braithwaite tank, so that only

the primary filter effluents entered the existing waste chamber. A brick wall was constructed in this chamber to form a sump of 0.27 cubic metres capacity; the excess primary effluent flowed over the wall into the waste pipe. In order to drain the sump of any accumulated solids over an extended period, a port was built into the base of the sump wall to permit total emptying of the sump. A 240 volt three phase Mono pump was positioned directly above the sump to convey the unsettled effluent to the settlement tank; the pump being capable of providing a flow of 60 $m^3/d.$ against a 7 metre head.

A 2 m^3 steel settlement tank was mounted on the concrete base adjoining the secondary filters. The rectangular tank constructed for ICI Limited for similar experimental purposes is of the 'Dortmund' design with a steep pyramidal base and a stilling box in the centre. The unsettled effluent in this instance is conveyed into the stilling box via the top of the tank. At the maximum theoretical flow, the settlement tank would allow 48 minutes residence time for the primary effluent. A 75 mm diameter uPVC pipe was fitted to the base of the tank to convey the sludge to the newly constructed waste chamber. A valve was fitted into the desludging pipework adjacent to the waste chamber.

The settled effluent is conveyed to the distribution system via 50 mm diameter heliflex tubing from the tank perimeter weir. The excess settled effluent is to be conveyed to the waste chamber by 75 mm diameter uPVC pipework with a valve to control the flow.

The reciprocating arm distribution system, manufactured by W.E. Farrer Limited, specifically for this study, was mounted directly on to the angle iron flange at the ends of the Braithwaite tank. Facilities were incorporated to adjust the horizontal level of the

arm to ensure the surface of the filter would be evenly provided with the settled primary effluent.

A three phase 240 volt motor had been fitted to drive the distributor arm. The speed of the arm can be varied by alteration of a chain drive mechanism. Initially, the drive had been adjusted to move the distributor arm at a speed of 0.5 metres per minute, so that the entire surface of the filters are dosed in 7.2 minutes, providing a pseudo dosing frequency of 14.4 minutes.

The Braithwaite tank was modified to form two rectangular filters separated by a polythene partition. The filter effluents flowed from the base of the filters via 75 mm diameter uPVC pipes to the waste chamber. The filters were filled with Flocor RS and Flocor R2S media. Because the media were supplied in bulky 2 m^3 packages, it was necessary to use a crane to raise the media above the filters, from where they were tipped into the filters.

The flows through each filter could be assessed by the installation of two nominal 20 litre tipping troughs which were under the outlets of the 75 mm diameter uPVC pipes in the waste chamber.

In order to calculate the flow through the settlement tank, the volume of the excess primary effluent wasted could be timed by collection in a vessel of known volume in the waste chamber; knowing the flow through each filter the total settlement tank throughput may be derived.

Unfortunately, due to a 12 month production delay at the manufacturers, it was not possible to use the secondary filters during the study period. It will however by available for use in a continuation of these studies.

12. CONCLUSIONS AND RECOMMENDATIONS.

A. Conclusions.

The results of this investigation were, in some ways, limited by the uncontrollable changes in the nature and quantity of sewage available due to works reconstruction and also by the limited period available for the maturation of the filters. The following conclusions may therefore only be taken as indicative of the likely full scale performance.

1. High-rate filtration at hydraulic loadings of 2.8 $m^3/m^3/d$ on mineral media and 5.6 $m^3/m^3/d$ on plastic media removed a high proportion (65 - 85%) of the organic matter from Hereford sewage, which contained a high organic concentration from cider production and food processing. Nitrification however was not established.
2. Of the media tested, Biopac 50 nominally dosed at 5.6 $m^3/m^3/d$ consistently proved the most effective in removing BOD. The relative performances of the different media was related to their respective specific surface areas. Although the Biopac 50 proved the most effective at 5.6 $m^3/m^3/d$, there was evidence that at increased loadings severe ponding of this media might occur, resulting in decreased efficiency.
3. At constant hydraulic loading, there was a direct relationship between the BOD removal per unit surface area and the BOD applied per unit surface area as determined by the differences in specific surface area of the media. Thus the smaller the specific surface area of the media, the more effective per unit area it was in removing BOD, withinthe range of loadings experienced.
4. Sludge production did not appear to be correlated to organic loading or removal in the various filters. A much greater

proportion of the organic matter within the sewage was converted to sludge than commonly associated with low-rate filters.

5. When the filters were loaded with macerated crude sewage at comparable organic loadings to those employed when settled sewage was applied, effluents of a suitable quality for secondary treatment were produced.

6. The amount of film per unit volume of filter was directly proportional to the specific surface area for the random media - both mineral and plastic; the corresponding amounts on the modular media were appreciably less but were again related to the relative specific surface areas.

7. The high-rate filter films although restricted in diversity, had similar floral and faunal components to films observed in low-rate filters. The abundance and diversity of both the flora and fauna were most restricted in the two Flocor media, which would appear to be an effect of its modular nature, presenting only limited horizontal surfaces on which film might accumulate. Fusarium aquaeductuum was a dominant member of the flora, frequently present in greater masses than the zoogleal bacteria. This fungus freely sporulated within the filters and was frequently the cause of localised ponding on the surface of the smaller graded mineral media and the Biopac 50 filters. It is likely that at higher loadings severe ponding might occur. Psychoda alternata enchytraeid worms were the dominant macrograzers. Eristalis tenax was also present, in limited numbers, at the bases of the filters.

8. The results of tests on the Hereford high-rate pilot plant effluents using laboratory scale filters indicated that under the condition of a full scale plant, the effluent from a high-rate filter could be nitrified on a secondary filter of conventional

medium loaded at 0.2 $m^3/m^3/d$.

9. A laboratory scale study of the nitrification process using synthetic sewages showed that nitrification is affected by the presence of organic matter, although the mechanism of the suppression was not determined. The effects of this suppression were of limited significance below 0.06 kg BOD/m^3/d, but could be detected at organic loadings as low as 0.01 kg BOD/m^3/d.

B. Comments on the Methods Employed.

1. The sodium sulphate soundness test (B.S. 1438 (1971)) proved to be a particularly severe test of media stability. Both types of media withstood ten immersion/ drying cycles after which pieces began to disintegrate. The use of 105°C for 4 hours for drying the media is a harsh test unrelated to conditions experienced by filter media. The substitution of freezing / thawing cycles for physical testing of the media would be worthy of evaluation.
2. The paint dipping method of estimating the specific surface area of the media proved satisfactory, although paint uptake increased with each coat.
3. Retention time determinations proved extremely time consuming and of limited use in assessing filter film condition. It would therefore appear that its use as a means of operational control is very restricted.
4. Neutron scatter determinations proved to be a rapid nondestructive method of obtaining a profile of the filter moisture content, and their results could be related to film accumulation within the filters. This method also indicated that the moisture content might not be directly related to the volatile solids content, but was also dependent upon the nature of the film. The application of neutron scatter techniques to low-rate filters would appear to be of limited usefulness.

C. Recommendations.

1. To prove a viable alternative to single filtration, further studies should be carried out at higher loadings on secondary filters than employed in this investigation to determine whether satisfactory nitrification can be achieved. Results from the present study suggest that nitrification would be satisfactory up to an organic loading of 0.06 kg BOD/m^3/d on secondary filters.
2. In view of the high costs associated with sludge handling, examinations are needed into the nature, quantity, settleability and dewatering of high-rate filter sludges.
3. Maturation of the primary at higher loadings, and operation of the secondary filters for a minimum period of twelve months at loadings of 0.5 m^3/m^3/d or greater could provide further useful information upon which full scale two stage filtration could be developed. The possible beneficial effects of controlled frequency of dosing and recirculation upon film accumulation should also be considered.
4. There were indications that over a limited period of observations (during which there were uncontrollable variations in the sewage supply), maturation had not occurred in the filters. Continued biological observations of the filters under the final loadings and also at higher loadings could provide a greater insight of the ecology of high-rate filters.
5. The possibility of increasing the hydraulic and consequently organic loading to the primary filters should be considered, such that the secondary filters' function would be oxidation of residual organic matter at high hydraulic loadings, to provide an effluent suitable for tertiary filtration where the objective would be almost solely the oxidation of nitrogenous matter.

However, the increased settlement and possible pumping requirements should also be considered.

6. Further studies using synthetic sewage of greater organic strengths and at higher hydraulic loadings are required to ennumerate the degree of nitrification suppression caused by increasing organic loadings. Studies using only ammonium salts and organic substrates excluding organic nitrogen sources could aid the determination of nitrification suppression.
7. Under the range of hydraulic loadings observed, it appears that the ultimate choice of media depends upon the removal performance required, economies of construction, space available and likely loadings encountered.
8. The use of filter media containing a large variety of sizes should be avoided in high-rate filters. A large range of media sizes leads to limited void capacities which could render the filter susceptible to ponding, although due to closer packing, the specific surface area may be enhanced.

Appendix 5.1

B.S. 1438 (1971) Sodium Sulphate Soundness Test.

b) Granite Media. 40 pieces tested.

Original Sample Weight 9375.2 g

Mean Weight 234.38g

Final Sample Weight 1994.3 g

Piece No.	Original Weight(g)	Final Weight(g)	Loss (g)	% Loss	Remarks.
1	397.8	D	D	-	10d, soft,crumbled
2	219.6	D	D	-	8d, crumbled
3	332.0	D	D	-	11d, crumbled
4	63.5	D	D	-	10d, coarse, broken
5	133.1	D	D	-	14d,v soft, crumbled
6	141.9	129.1	12.8	5.5	15d, flaking
7	91.0	D	D	-	10d, soft, v flaky
8	175.0	166.2	8.8	3.8	21d, flaking
9	353.2	D	D	-	10d, f soft,crumbled
10	185.7	D	D	-	10d, f soft, crumbled
11	434.8	426.6	8.2	3.5	19d, flaking
12	266.9	D	D	-	10d, soft, flaky
13	393.5	D	D	-	12d,v soft, crumbled
14	122.1	121.8	0.3	0.1	
15	72.1	D	D	-	7d,v soft,crumbled
16	151.4	149.6	1.8	1.2	21d, cracking
17	187.6	D	D	-	10d, soft,v flaky
18	286.9	259.8	27.1	11.6	16d, cracking
19	270.0	D	D	-	18d, crumbled
20	347.0	D	D	-	18d,v dense,fractured
21	323.1	323.4	0	0	
22	471.0	D	D	-	12d,v soft, crumbled
23	223.7	D	D	-	11d, surface flaked
24	192.3	191.8	0.5	0.2	
25	65.2	D	D	-	10d, soft, crumbled
26	154.8	D	D	-	11d,f soft, crumbled
27	170.5	D	D	-	15d, surface crumbled
28	322.1	D	D	-	14d,f soft,crumbled
29	198.9	D	D	-	12d,f soft, crumbled
30	221.5	D	D	-	12d,f soft, crumbled
31	282.1	D	D	-	15d,f soft, crumbled
32	269.4	D	D	-	11d,v soft, crumbled
33	202.0	D	D	-	10d,f soft, crumbled
34	222.6	D	D	-	8d, soft,crumbled
35	179.9	D	D	-	11d,v soft,crumbled
36	180.5	D	D	-	11d,v soft,crumbled
37	127.0	D	D	-	10d,f soft,fractured
38	398.0	D	D	-	11d,v soft,crumbled
39	229.0	226.0	3.0	1.3	
40	309.3	D	D	-	20d, v crumbly

D - Disintegrated sample.
d - day sample withdrawn.

Appendix 5.1

B.S. 1438 (1971) Sodium Sulphate Soundness Test.

a) Slag Media. 40 pieces tested.

Original Sample Weight 6464.7g

Mean Weight 202.0g

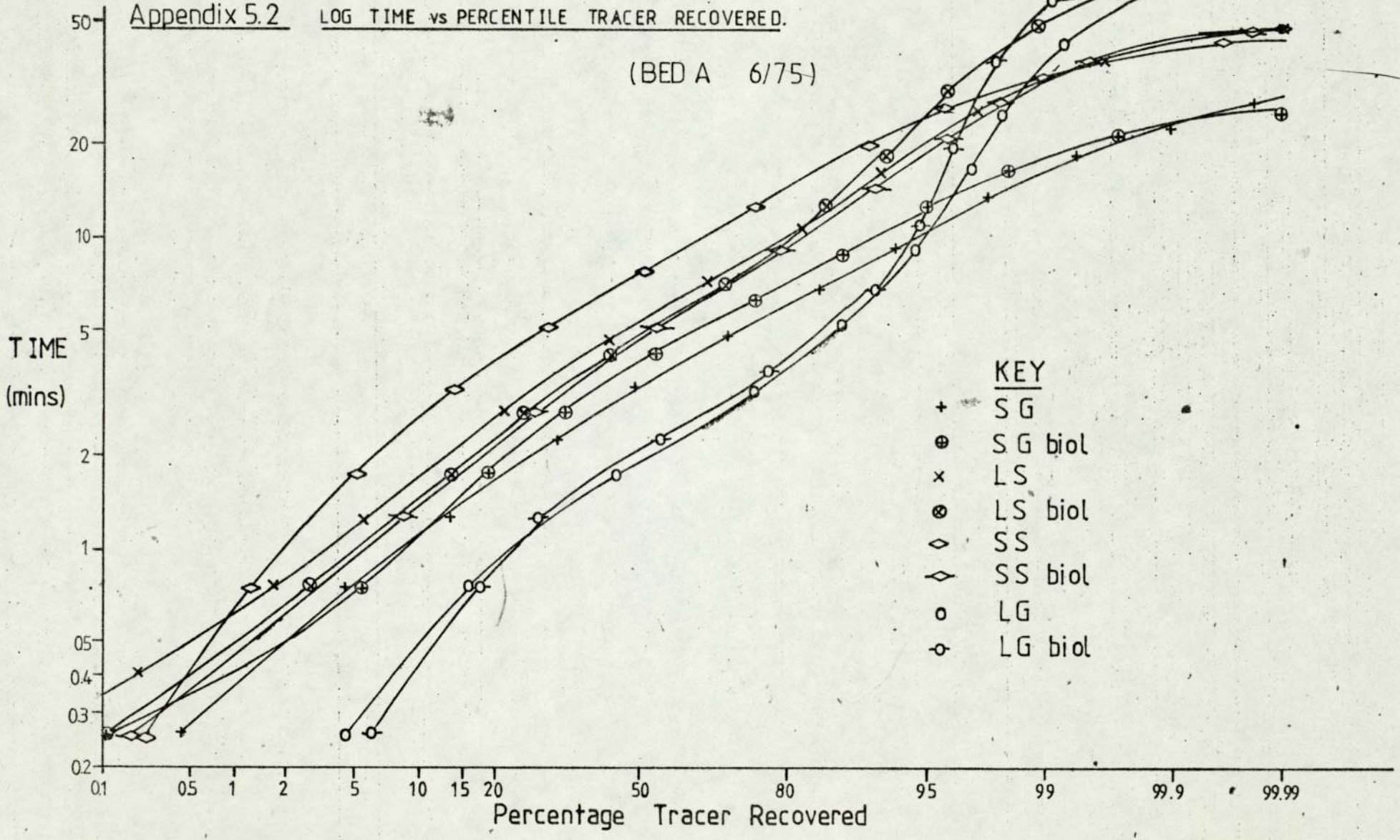
Final Sample Weight 6365.3g

Piece No.	Original Weight(g)	Final Weight(g)	Loss (g)	% Loss	Remarks.
1	307.7	306.8	0.9	0.4	
2	250,7	229.0	21.7	10.7	
3	211.0	209.2	1.8	0.9	
4	103.2	101.0	2.2	1.1	
5	134.1	136.1	0	0	
6	157.9	157.9	0	0	
7	212.8	209.7	3.1	1.5	
8	170.0	167.5	2.5	1.2	
9	226.3	225.1	1.2	0.6	
10	245.3	243.4	1.9	0.9	
11	232.6	230.0	2.6	1.3	
12	183.0	182.9	0.1	0	
13	241.0	239.6	1.4	0.7	
14	283.8	D	D	-	8d,brittle,fractured
15	77.0	76.9	0.1	0	
16	134.3	133.5	0.8	0.4	
17	235.5	234.9	0.6	0.3	
18	248.7	248.0	0.7	0.3	
19	240.7	233.0	7.7	3.8	
20	168.1	145.3	22.8	11.3	soft & crumbly
21	344.3	337.4	6.9	3.4	
22	232.8	231.4	1.4	0.7	
23	323.0	324.2	0	0	
24	86.8	D	D	-	6d,v porous,crumbled
25	243.0	D	D	-	17d,varied density
26	135.1	134.6	0.5	0.2	
27	97.7	D	D	-	18d,cracked
28	223.5	224.5	0	0	
29	190.1	D	D	-	9d,v porous,cracked
30	254.3	256.1	0	0	
31	187.0	186.4	0.6	0.3	
32	320.2	D	D	-	13d,dense, fractured
33	189.0	188.3	0.7	0.3	
34	146.1	145.6	0.5	0.2	
35	155.5	144.9	10.6	5.3	
36	120.0	D	D	-	12d,porous,flaked
37	142.8	138.0	4.8	2.4	
38	227.5	D	D	-	7d,brittle,cracked
39	133.4	133.0	0.4	0.2	
40	218.0	217.1	0.9	0.4	

D - Disintegrated sample.
d - day sample withdrawn.

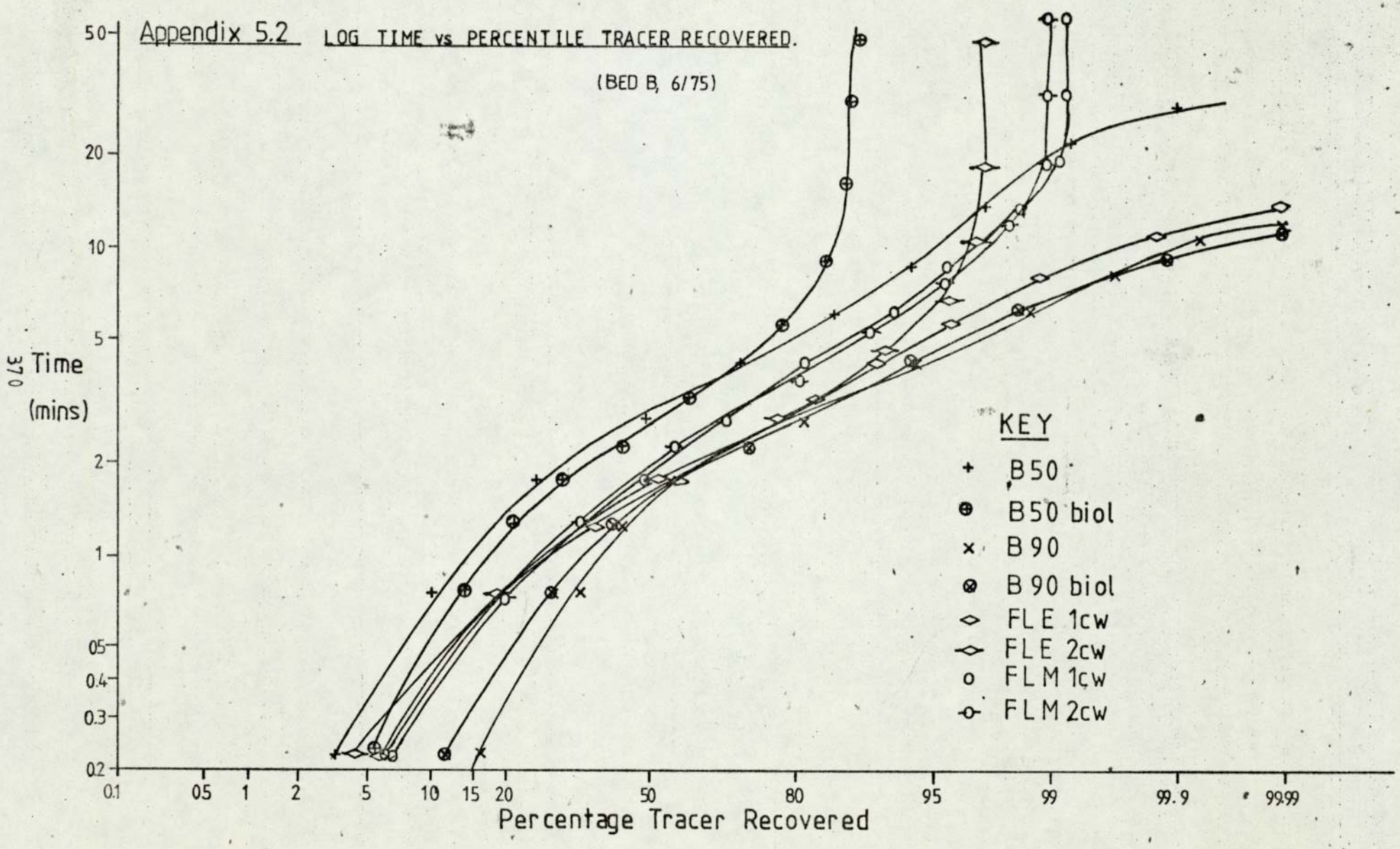
Appendix 5.2 LOG TIME vs PERCENTILE TRACER RECOVERED.

(BED A 6/75)



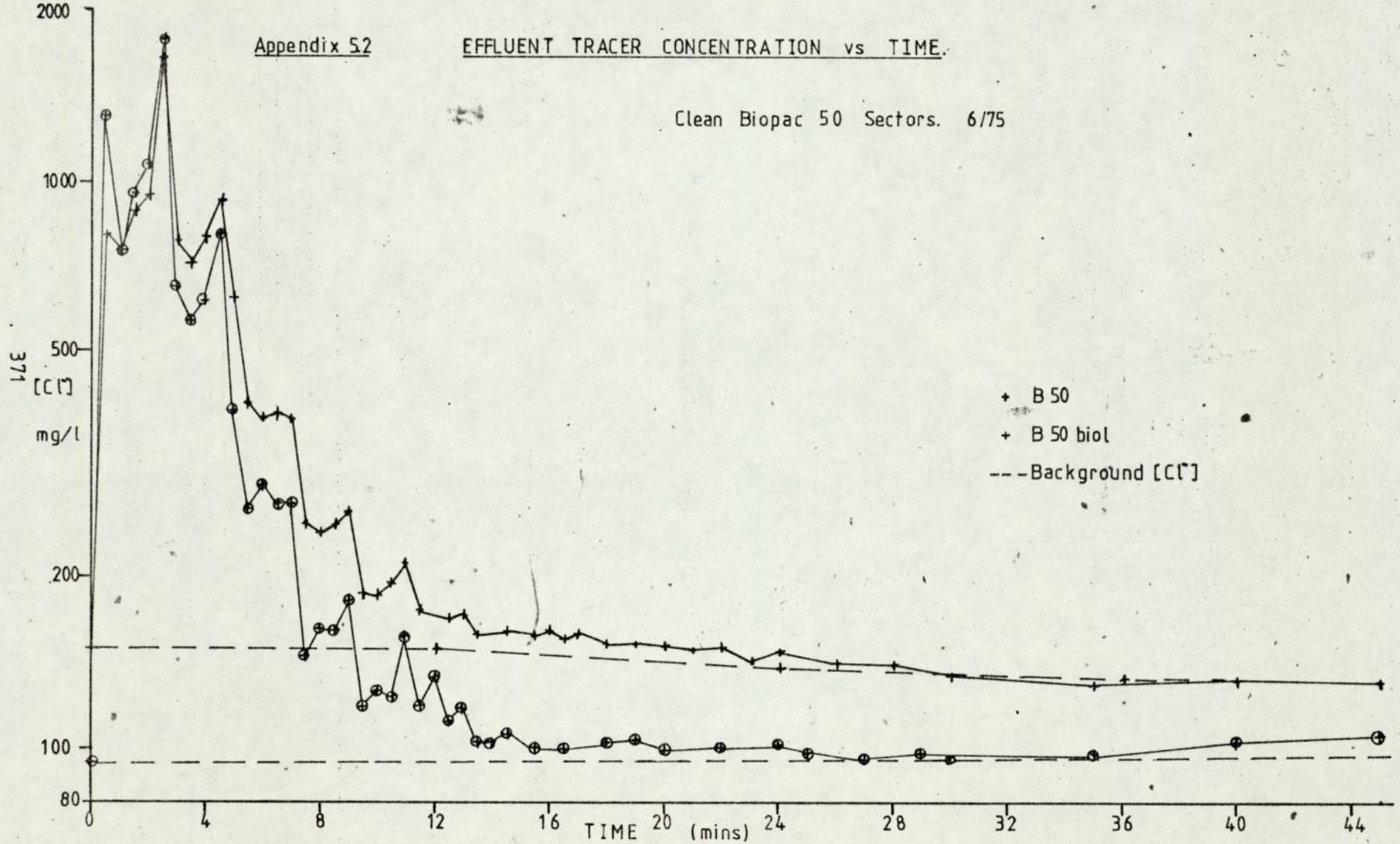
Appendix 5.2 LOG TIME vs PERCENTILE TRACER RECOVERED.

(BED B, 6/75)



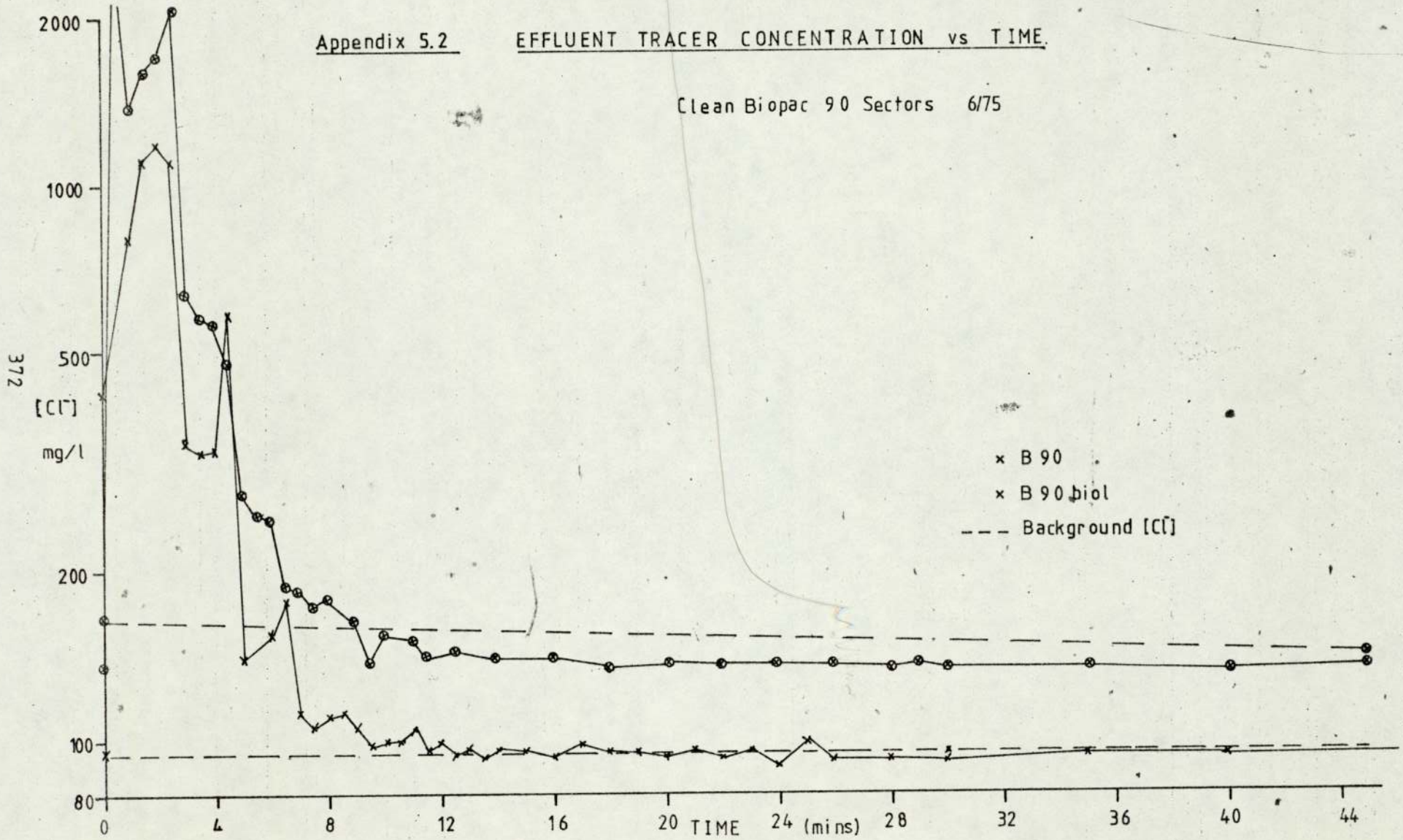
Appendix 5.2 EFFLUENT TRACER CONCENTRATION vs TIME.

Clean Biopac 50 Sectors. 6/75



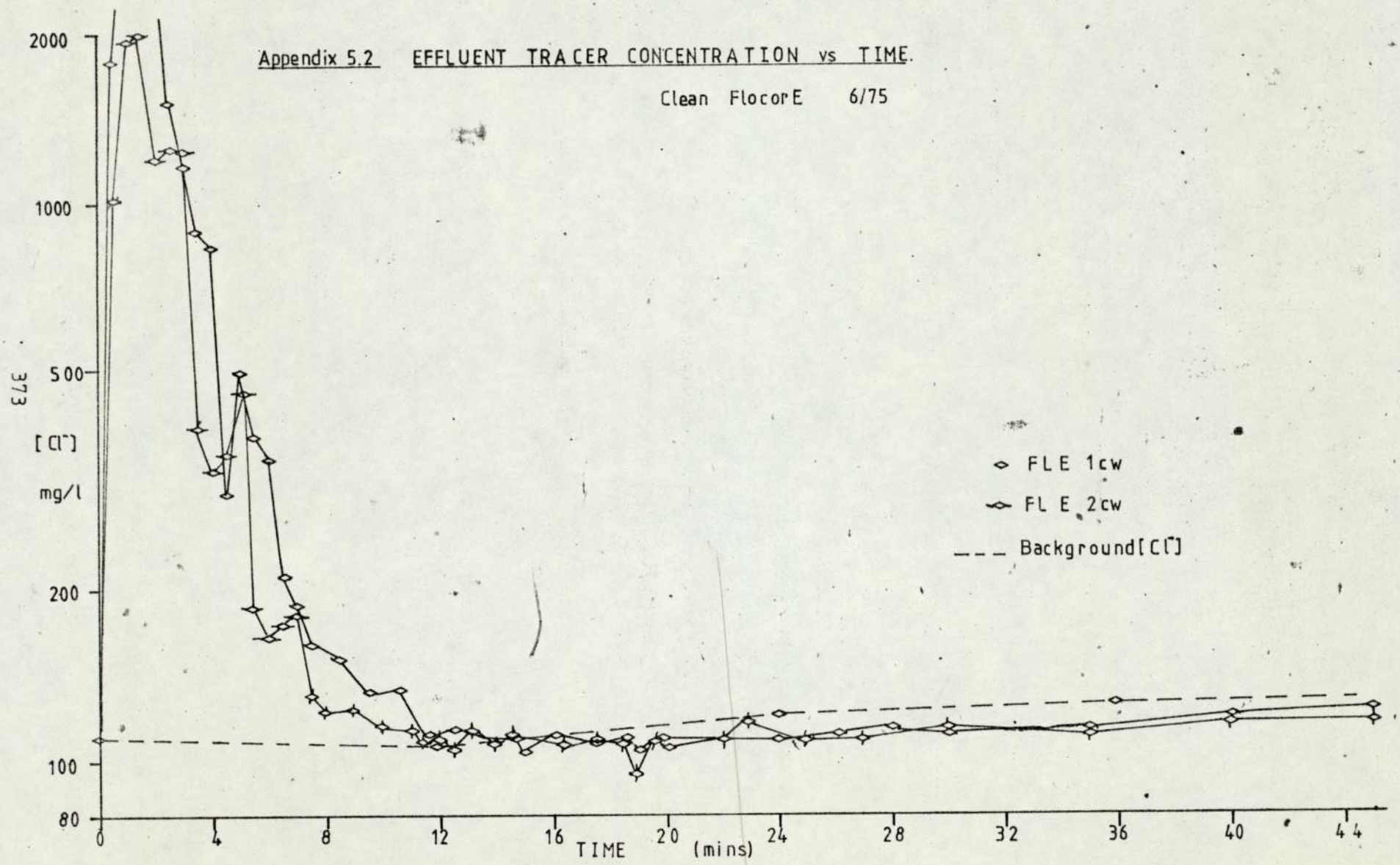
Appendix 5.2 EFFLUENT TRACER CONCENTRATION vs TIME.

Clean Biopac 90 Sectors 6/75



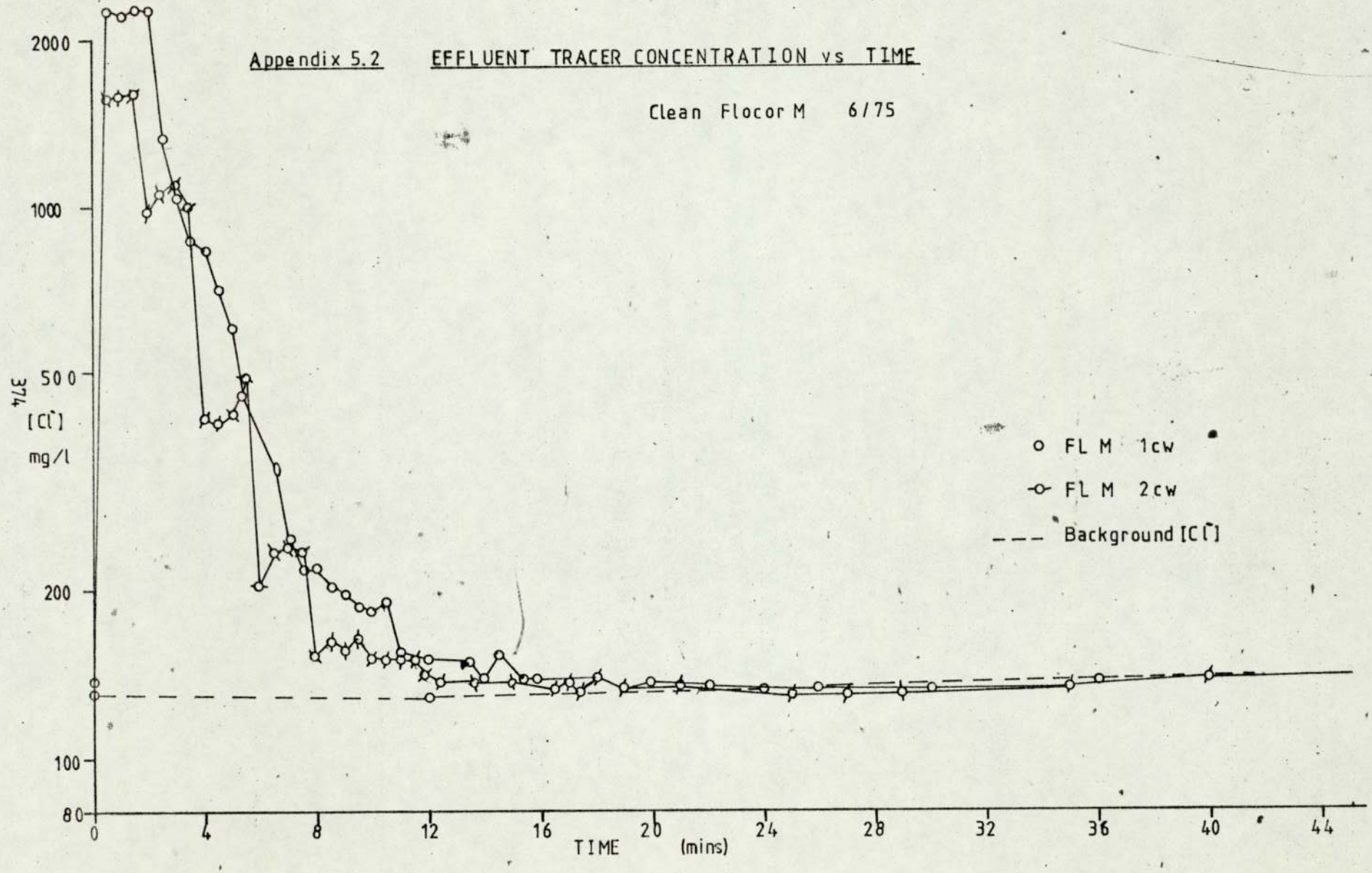
Appendix 5.2 EFFLUENT TRACER CONCENTRATION vs TIME.

Clean FlocorE 6/75



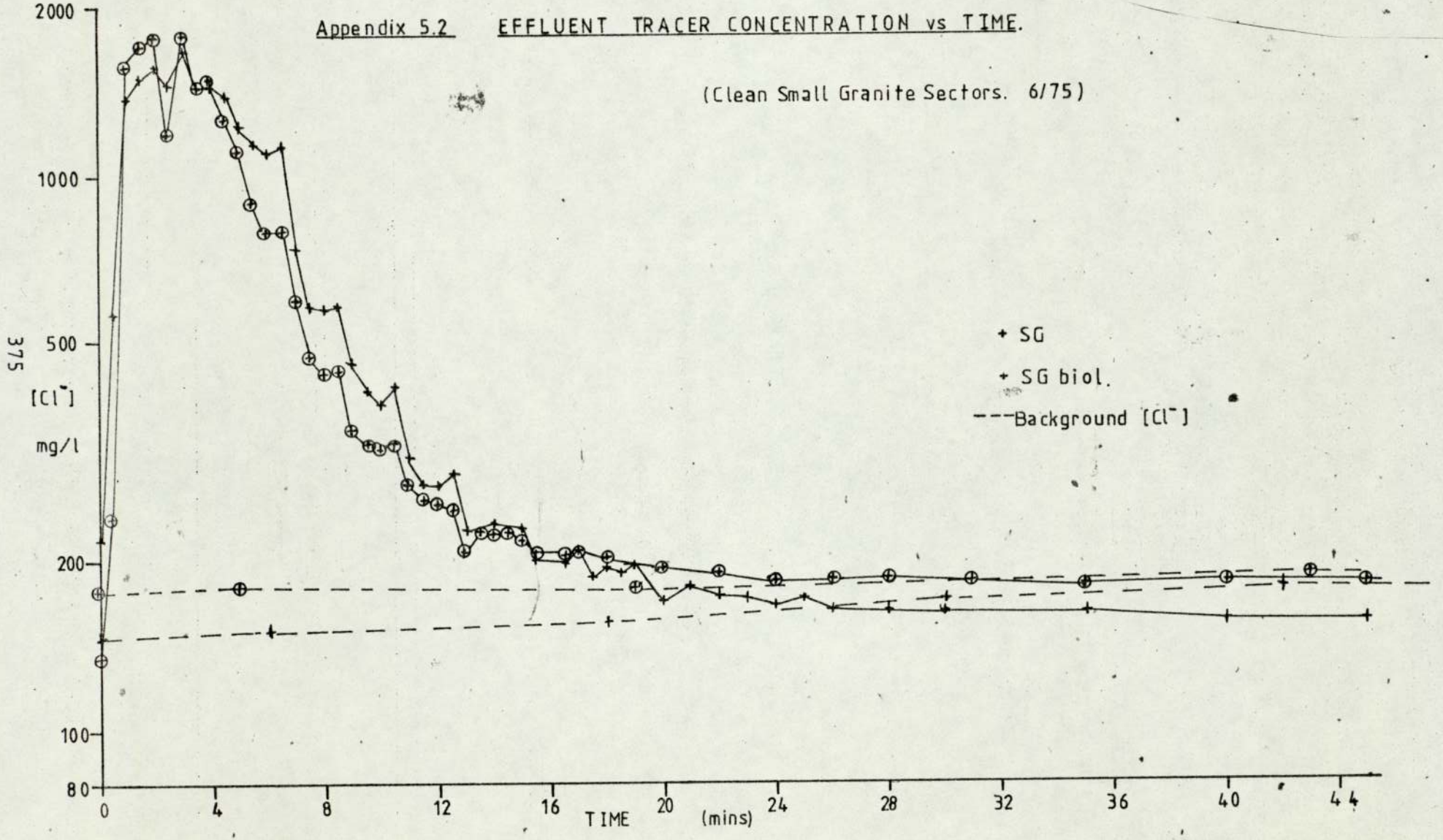
Appendix 5.2 EFFLUENT TRACER CONCENTRATION vs TIME

Clean Flocor M 6/75



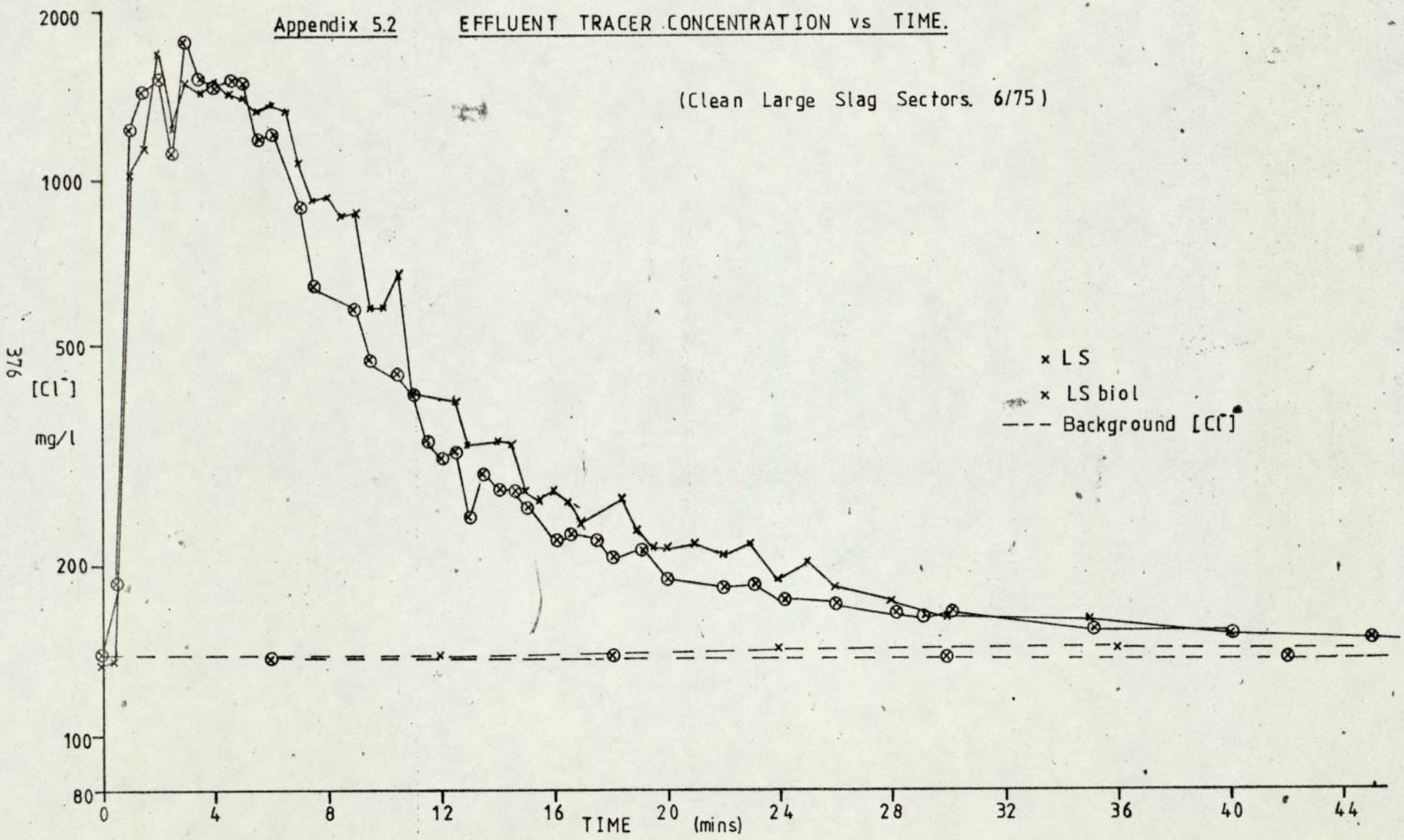
Appendix 5.2 EFFLUENT TRACER CONCENTRATION vs TIME.

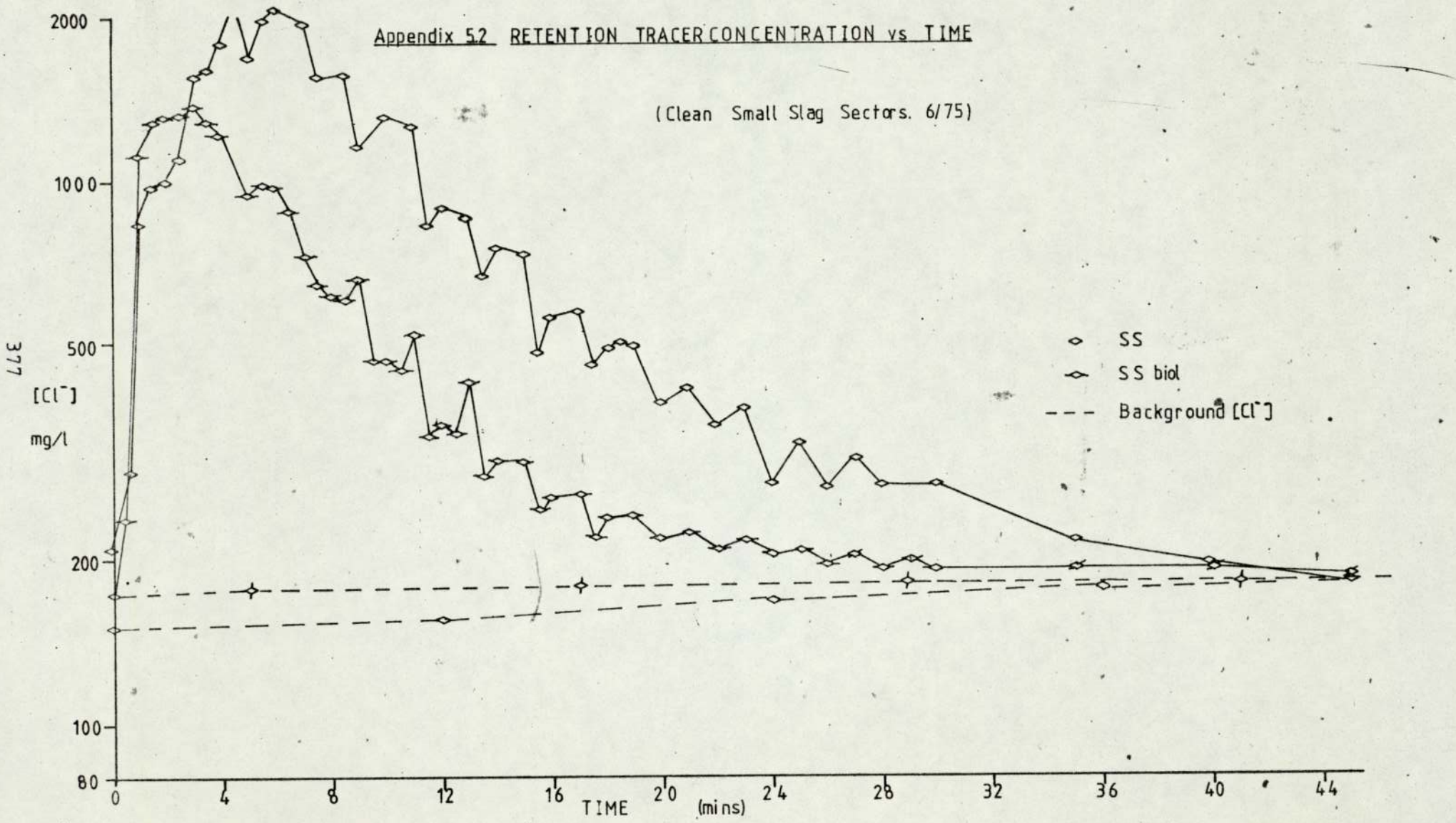
(Clean Small Granite Sectors. 6/75)



Appendix 5.2 EFFLUENT TRACER CONCENTRATION vs TIME.

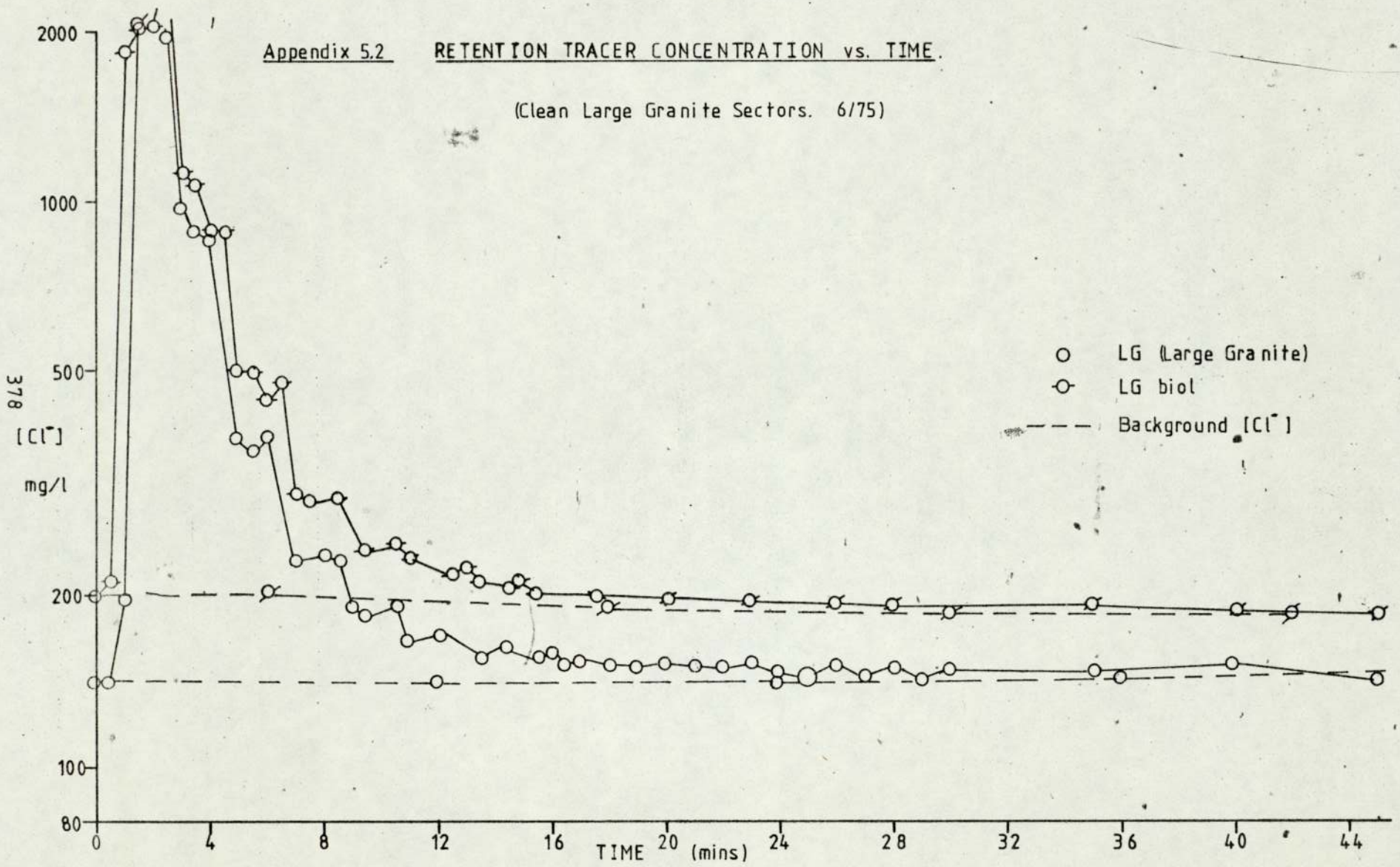
(Clean Large Slag Sectors. 6/75)




Appendix 5.2 RETENTION TRACER CONCENTRATION vs TIME
(Clean Small Slag Sectors. 6/75)
2000
1000
500
200
100
80
[Cl⁻]
mg/l
SS
SS biol
Background [Cl⁻]
0
4
8
12
16
20
24
28
32
36
40
44
TIME (mins)

Appendix 5.2 RETENTION TRACER CONCENTRATION vs. TIME.

(Clean Large Granite Sectors. 6/75)



Appendix 6.1 Suspended Solids Analysis.

1. 100 ml. aliquots of the shaken sample were withdrawn by pipette from the 500 ml stock bottles, at 10 cm. below the top of the bottle.
2. 100 ml.aliquots of the settled sample were similarly withdrawn from the stock bottle after one hour's settlement.
3. The 100 ml samples were transferred to 150 ml beakers used to fill the Hartley funnels; both beakers and funnels being washed down to ensure all the solids were transferred to the filter papers.
4. The 7 cm. Whatman GF/C filter papers were dried at 105°C, cooled to room temperature in a dessicator and weighed before use. After insertion in the funnels, the papers were wetted using distilled water.
5. After filtration with the aid of suction, the filter papers were removed from the funnels, placed on 10 cm. watch glasses and dried at 105°C for one hour.
6. The papers were then transferred on their watch glasses to a dessicator, where they were allowed to cool for an hour before being reweighed.
7. The suspended solids were then obtained by difference in the weight of the papers and expressed in mg/l.

Appendix 6.2 Biochemical Oxygen Demand Analysis.

Apparatus.

Ground glass stoppered 250 ml. bottles.

Grade A 25 ml. automatic levelling and refilling burette, marked in 0.02 ml. divisions.

Grade A pipettes for sample withdrawal.

Electric induction pump for aeration.

10 litre aspirator.

Reagents.

Ferric chloride solution: 0.125g $Fe_3.6H_2O$ in 1 litre distilled water.

Calcium chloride solution:55g $CaCl_2.6H_2O$ in 1 litre distilled water.

Magnesium sulphate solution: 25g $MgSO_4.7H_2O$ in 1 litre distilled water.

Phosphate buffer: 42.5g KH_2PO_4 dissolved in 700 ml H_2O; 8.8g NaOH added, 2g $(NH_4)_2SO_4$ and made up to 1 litre.

1 ml of each above solution added per litre of diluent water.

Manganous sulphate solution: 500g $MnSO_4.5H_2O$ in 1 litre.

Alkaline iodide solution: 500g NaOH and 150g KI per litre of distilled water.

Alkaline iodide/azide solution: 1 litre alkaline iodide mixed with 300 ml of 25g/1 sodium azide solution.

Sulphuric acid: 50% v/v.

Potassium Iodate : N/40 0.892g KIO_3 in 1 litre distilled water.

Sodium thiosulphate: N/80 working solution using BDH convol phials.

Starch Indicator : 10g soluble starch urea/ litre distilled water.

Procedure.

10 litres of diluent water was prepared in a polythene aspirator, previously sterilised and thoroughly washed out with distilled water, adding 10 ml of each nutrient stock solution. The water was then aerated for one hour, using air filtered through cottonwool to minimise contamination. The water was then allowed to stand for a further hour before use.

The samples were withdrawn from the same level in the 500 ml stock bottles as the suspended solids samples, and pipetted directly into the 250 ml ground glass stoppered bottles. Diluent water was then added from the aspirator; carefully poured down the bottle sides to prevent entrainment of air. The bottles were completely filled with diluent water, sharply tapped on their sides and left to stand to allow any excess gaseous oxygen to escape before being stoppered.

One of each duplicate sample was then incubated for five days at 20°C, whilst the other sample was immediately fixed with 2 ml of manganous sulphate solution and 2 ml of alkaline iodide solution. After thorough mixing and settlement of the precipitate, 4ml of 50% (v/v) sulphuric acid was added to the sample bottle which was then restoppered and inverted several times to redissolve the precipitate and mix the bottle contents. Two 50 ml aliquots were then titrated against N/80 sodium thiosulphate using starch solution to indicate the end point. The samples were titrated in conical flasks immediately after being pipetted to minimise the liberation of iodine.

After five days incubation, the second sample was analysed for its oxygen content in the manner described above and the

biochemical oxygen demand of the original sample calculated from:-

$$BOD = \left(x-y-\frac{az}{(a+1)}\right)\frac{(a+1)}{2} \quad mg/l.$$

where

x = Volume N/80 thiosulphate required for 200 ml of the original dilution,(ml.).

y = Volume N/80 thiosulphate required for 200 ml of incubated dilution,(ml).

a = Volume of dilution water to 1 volume of sample (ml).

z = Difference between volumes of N/80 thiosulphate required for 200 ml of dilution water before and after incubation, (ml.). - the blank correction.

Appendix 6.3 Chemical Oxygen Demand Analysis.

Apparatus.

Electric heating mantle.

Reflux condensers.

Reflux flasks.

Grade A 10 ml burette.

Grade A pipettes.

Reagents.

Potassium dichromate, N/8. Dissolve 6.129g potassium dichromate in 1 litre distilled water.

Ferrous sulphate, N/8. Dissolve 34.75g $FeSO_4.7H_2O$ in 100 ml sulphuric acid (25% v/v), diluted to 1 litre with distilled water.

Saturated silver sulphate in 25% sulphuric acid, (v/v).

Sulphuric acid SG 1.84.

Ferrous phenanthroline indicator BDH prepared reagent.

Anti-bumping granules.

Procedure.

To 5 ml of sample in the reflux flask, 0.2g of mercuric sulphate were added, and shaken thoroughly. With the flask immersed in cold water, 5 ml of N/8 potassium dichromate, 10 ml sulphuric acid, 1 ml silver sulphate and a few anti-bump granules were added and the contents mixed well. The flask was then fitted to the reflux condenser and carefully refluxed for 2 hours. To ensure accurate and consistent heating the electric mantle controls were preset and wired through a timer which cut off the electricity supply after 2 hours. 45 ml of distilled water were added through the condenser washing all the condensate into the flask. The flasks were then cooled in a bath of cold water, before being titrated against

N/8 ferrous sulphate using three drops of phenanthroline indicator.

Calculation.

$$COD = \frac{(\text{Blank titre} - \text{Sample titre}) \times 1000}{\text{Sample Volume.}} \quad \text{mg/l.}$$

Appendix 6.4 Total Oxidised and Ammoniacal Nitrogen Analysis.

Apparatus (After Chapman et al. 1967).

Technicon AutoAnalyzer

Technicon Colorimeter

Technicon Chart Recorder

625 mμ colorimeter filter

520 mμ colorimeter filter

i) Ammoniacal Nitrogen.

Reagents

All reagents were Analytical Grade, prepared with distilled water.

Disodium ethylenediaminetetra acetate solution: 2g of E.D.T.A. were dissolved in 1 litre of distilled water; the resulting solution adjusted to pH 11.0 with sodium carbonate solution.

Sodium hypochlorite solution: containing 5% available chlorine, any suspended matter being decanted off.

Phenol solution : 83g of phenol in 100 ml distilled water.

Sodium hydroxide solution: this stock solution was prepared by dissolving 200g NaOH in 1 litre of distilled water.

Sodium phenate solution: 180 ml of stock sodium hydroxide added to the phenol solution and diluted to 1 litre with distilled water.

Standard ammonia solution : 0.191g of NH_4Cl dissolved in 1 litre of distilled water to provide a standard solution containing 50 mg/l of ammoniacal nitrogen.

Procedure.

The AutoAnalyzer was set up as shown in figure A 6.4.1., first running a set of standards; their optical densities at 625 mμ being read from the chart recorder. From a calibration curve of ammoniacal nitrogen concentration vs. optical density,

the ammonia content of the samples could be determined. After every eight samples a blank of distilled water was run in order to ascertain whether the conditions were stable without significant base line drift. Six standards were used in the range 0 - 20 mg/l ammoniacal N to establish the calibration curve. The 20 mg/l standard corresponded to approximately 90% of full scale deflection on the chart recorder.

ii) Oxidised Nitrogen.

Reagents

Sodium hydroxide solution : 20g NaOH dissolved in 1 litre of distilled water.

Sulphanilic acid solution : 6g sulphanilic acid were dissolved in 700 ml of hot distilled water. After cooling, 200 ml concentrated HCl were added and the resulting solution made up to 1 litre with distilled water.

Acetone/Water : 125 ml of acetone in 1 litre distilled water.

Hydrazine sulphate solution : 1g of hydrazine sulphate dissolved in 1 litre of distilled water.

Copper sulphate solution : 0.8g $CuSO_4.5H_2O$ dissolved in 1 litre distilled water.

N(1-naphthyl)ethylenediamine dihydrochloride solution : 0.4g of N(1-naphthyl)ethylenediamine dihydrochloride dissolved in 1 litre distilled water.

Standard oxidised nitrogen solution: 0.361g anhydrous KNO_3 dissolved in 1 litre distilled water. This solution contained 50 mg/l oxidised nitrogen. 1 ml of chloroform added to the solution inhibited biological activity.

Procedure.

The AutoAnalyzer was set up as shown in figure A 6.4.2. with a set of standards (6 in the range 0 to 15 mg N /l)

being initially run, from which the calibration curve could be established. The top standard of 15.0 mg/l of nitrogen corresponded to approximately 90% of the chart recorder full scale deflection. A blank of distilled water was also run after every eight samples. The optical densities of the samples were determined at a wavelength of 520 mμ.

Figure A.6.4.1 Flow Diagram of AutoAnalyser Ammoniacal Nitrogen. Analysis.

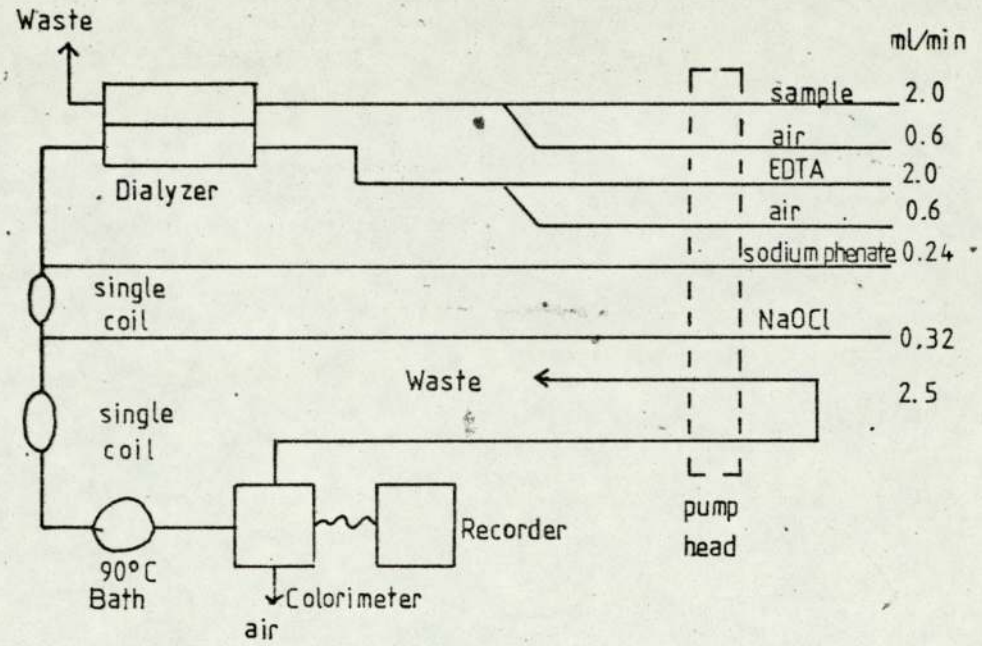
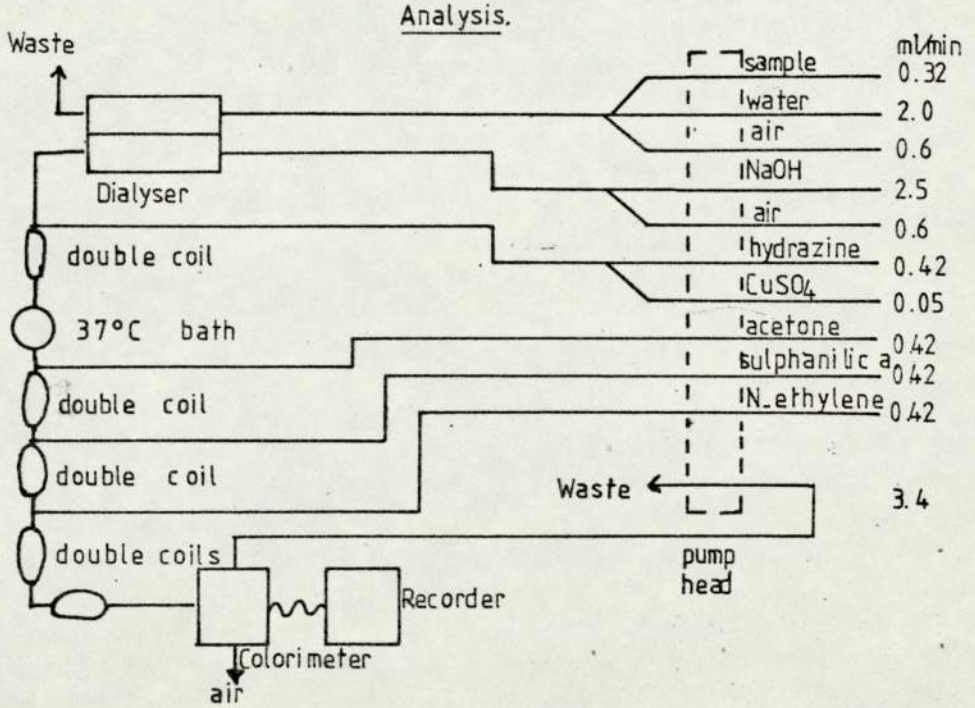


Figure A.6.4.2. Flow Diagram of AutoAnalyzer Oxidised Nitrogen Analysis.



Appendix 6.5 Total Inorganic Phosphate Analysis.

Apparatus.

Technicon AutoAnalyzer

Technicon Chart Recorder

Technicon Colorimeter

Technicon 660 mu filter.

Reagents.

All reagents were Analytical Grade, prepared with distilled water.

Aminonaphtholsulphonic acid solution(ANSA): 120g $NaHSO_3$ and 4g Na_2SO_3 were dissolved in 800 ml warm distilled water. 2g of ANSA were added, dissolved and the reagent made up to 1 litre with distilled water. From this stock solution, a one in ten dilution working solution was made up daily.

Ammonium molybdate solution: 10g of $(NH_4)_6Mo_7O_{24}.4H_2O$ was dissolved in 1 litre 1.2N H_2SO_4.

Sulphuric acid : 10N

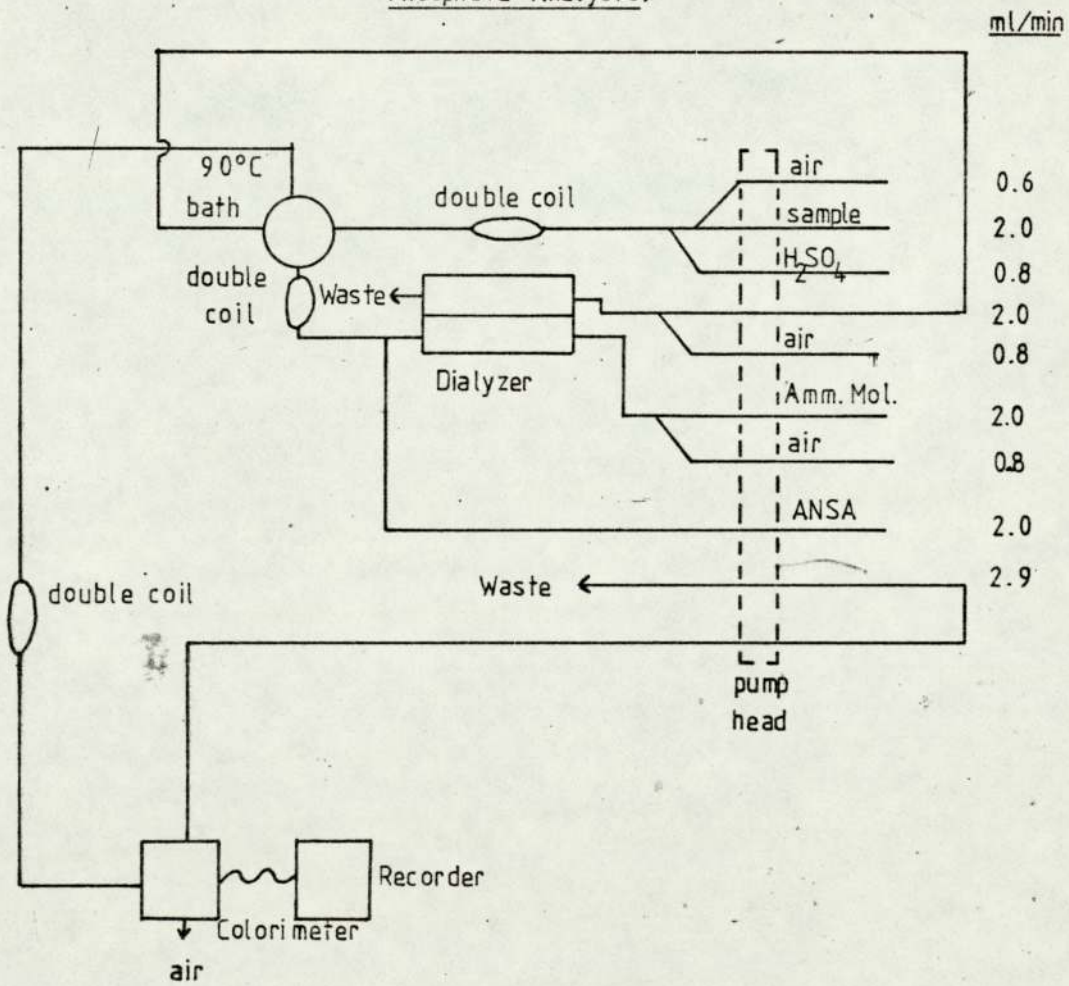
Phosphate stock solution: 1.433g of anhydrous KH_2PO_4 dissolved in approximately 500 ml distilled water, 1 ml concentrated H_2SO_4 added and the resultant solution made up to 1 litre with distilled water.

Procedure.

The AutoAnalyzer was set up as shown in figure A 6.5.1., first running a set of standards; their optical densities being read at 660 mu from the chart recorder. A calibration curve could then be established in the range 0 - 10 mg/l total inorganic phosphate (TIP) from which the concentration of TIP in the samples could be determined. The 10 mg/l TIP standard corresponded to approximately 40% of full scale deflection. Only 40% of the optical range was used due to

the nonlinear response of the solution optical density as the phosphate concentration increased. As in the case of the nitrogen analyses, a blank was run after every eight samples to check on the stability of the system.

Appendix A.6.5.1 Flow Diagram of AutoAnalyzer Total Inorganic Phosphate Analysis.



Appendix 7.A.1. Hereford High Rate Filtration Project Sampling Programme.

Frequency :- 3 days per week (2 weekdays, 1 weekend day.).

Weekday Sampling Periods:-

Daytime 8 hrs.	10.00 - 16.00
Night-time 16 hrs.	17.00 - 09.00

Weekend day sampling :-

Daytime 8 hrs.	10.00 - 16.00

Sample days and analysis :-

Sample	Process	Final DO (BOD).
Sunday	Monday	Saturday
Tuesday	Wednesday	Monday
Thursday	Friday	Wednesday

Samples generated per 24 hrs. :-

Double period: (8 + 8 + 1) x 2 = 34

Single period: (8 + 8 + 1) x 1 = 17

Routine Analysis :-

	Shaken sample	Settled sample
Suspended solids	"	"
BOD	-	"
COD*	-	"

(CODs to be carried out on 1 of each duplicate only.)

Occasional filtered samples to be used for analysis.

In addition to the above, daily samples of the sewage feed to measure the overall loading of the filters, and a weekly 24 hr. analysis of the feed to monitor hourly variations in sewage strength.

Weekly ammoniacal and oxidised nitrogen analysis of the samples to be carried out at Aston University.

Appendix 7.A.2. List of Filter Codes and Symbols employed.

Filter Type	Filter Code	Figure Symbol.
89/50 mm Slag	SS	◇
89/50 mm Slag biol	SSbiol	◈
89/50 mm Granite	SG	+
89/50 mm Granite biol	SGbiol	⊕
125/75 mm Slag	LS	×
125/75 mm Slag biol	LSbiol	⊗
125/75 mm Granite	LG	○
125/75 mm Granite biol	LGbiol	⊙
Biopac 50	B50	+
Biopac 50 biol	B50biol	⊕
Biopac 90	B90	×
Biopac 90 biol	B90biol	⊗
Flocor E 1cw	FLE1cw	◇
Flocor E 2cw	FLE2cw	◈
Flocor M 1cw	FLM1cw	○
Flocor M 2cw	FLM2cw	⊙

biol refers to the sector containing the three perforated steel shafts used for biological analysis.

1cw refers to the first sector clockwise when viewed from above.

2cw refers to the second sector clockwise viewed from above.

Appendix 7.A.3. Timetable of study periods at Hereford.

Period.	Dates.	Source of Sewage.
1	16/6/75 - 16/11/75	Old works settled sewage
2	19/11/75- 27/ 1/76	Crude sewage (Restricted supply)
3	29/ 1/76- 29/7 /76	Pilot plant settled sewage
4	29/7/76 - 17/7/77	New works settled sewage

Appendix 7.B.1 Weekly Mean Flows to the Filters from 16.6.75 to 16.11.75.

Date W/E	Tank A (Mineral Media) Trough 1	Trough 2	$\bar{x}$	Tank B (Plastic Media) Trough 1	Trough 2	$\bar{x}$	Flocor M
22/6/75	2.14	-	2.14	5.22	-	5.22	5.80
29/6/75	2.50	3.51	3.01	4.98	4.07	4.53	5.03
6/7/75	1.82	2.10	1.96	5.56	5.32	5.44	6.04
13/7/75	2.73	6.47	4.60	5.49	5.37	5.43	6.03
20/7/75	4.50	5.26	4.88	5.51	5.46	5.49	6.10
27/7/75	2.46	2.51	2.49	6.10	6.04	6.07	6.74
3/8/75	1.38	1.48	1.43	4.14	3.95	4.05	4.50
10/8/75	2.64	2.56	2.60	5.54	5.40	5.47	6.08
17/8/75	2.32	2.56	2.44	5.62	5.44	5.53	6.14
24/8/75	2.93	2.67	2.80	4.62	4.20	4.41	4.90
31/8/75	5.10	4.29	4.70	4.72	4.50	4.61	5.12
7/9/75	2.67	2.74	2.71	5.35	5.07	5.21	5.79
14/9/75	2.35	3.05	2.70	5.22	5.02	5.12	5.69
21/9/75	1.73	2.79	2.26	4.84	5.33	5.09	5.66
28/9/75	2.40	2.41	2.41	3.94	4.37	4.16	6.62
5/10/75	1.90	2.06	1.98	4.85	4.59	4.72	5.24
12/10/75	1.84	3.28	2.56	4.46	4.26	4.36	4.84
19/10/75	2.15	2.58	2.37	6.06	5.28	5.67	6.30
26/10/75	3.41	3.73	3.35	5.83	5.84	5.84	6.49
2/11/75	-	2.40	2.40	5.01	4.69	4.85	5.39
9/11/75	-	2.92	2.92	3.80	5.24	4.52	5.02
16/11/75	-	3.01	3.01	4.80	5.28	5.04	5.60
Mean			2.83			5.03	5.59

Flows expressed in $m^3/m^3/d$.

Appendix 7.B.2. Weekly Average Maximum and Minimum Temperatures 16/6/75 - 16/11/75 (°C)

	22/6	29/6	6/7	13/7	20/7	27/7	3/8	10/8	17/8	24/8	31/8	7/9	14/9	21/9	28/9	5/10	12/10	19/10	26/10	2/11	9/11	16/11
FEED																						
Max.	19.5	20.5	20.8	20.7	20.9	20.7	18.8	15.7	14.2	13.9	16.4	17.0	-	-	-	13.4	13.3	11.3	10.5	10.3	8.9	7.4
Min.	18.0	18.9	19.6	19.1	19.4	19.3	17.1	14.2	13.4	12.5	14.9	15.1	-	-	-	11.7	12.5	10.2	9.6	9.1	8.0	6.7
B90 (FLM 2cw)																						
Max.	18.4	19.1	18.7	19.6	20.0	19.9	19.8	14.2	13.3	12.7	16.1	16.8	-	-	-	12.7	12.9	10.4	10.1	9.5	8.0	5.3
Min.	16.8	16.2	16.3	17.5	19.0	18.4	16.8	11.9	10.9	11.4	14.4	15.0	-	-	-	11.2	11.8	9.3	8.9	8.1	7.1	3.8
LG (SS biol)																						
Max.	18.7	19.4	19.7	19.3	18.7	18.7	19.6	15.0	13.4	12.4	16.0	15.3	-	-	-	11.0	11.4	8.8	9.4	9.5	8.5	3.6
Min.	16.9	17.6	17.7	17.7	17.4	17.3	16.8	13.3	10.6	11.0	14.2	14.2	-	-	-	9.1	9.1	6.8	8.5	8.2	6.8	1.9

Appendix 7.B.3. Weekly Mean of the 12.00 hrs. Comparative Temperature Data (16.6.75 - 16.11.75) (°C)

	22/6	29/6	6/7	13/7	20/7	27/7	3/8	10/8	17/8	24/8	31/8	7/9	14/9	21/9	28/9	5/10	12/10	19/10	26/10	2/11	9/11	16/11
SG Biol	-	19.4	18.3	18.7	15.6	18.8	20.8°	14.6	12.8	11.5	16.4	15.1	-	-	11.9	11.4°	-	-	9.6	8.7	7.7°	6.2
LS Biol	-	19.3	18.0	19.2°	16.5	17.8	19.9×	14.4	12.5	11.2	16.3	15.1	-	-	11.8	11.0	-	-	9.6	8.7	7.5	6.2
SS	-	19.5	18.4	19.1	18.2°	17.8	20.5	14.4	12.4	11.2	16.5	15.5°	-	-	12.1°	11.1	-	-	9.8	8.8	7.4	5.7×
LG	-	19.0	17.8×	18.9	16.9	16.2×	20.6	14.0×	12.0×	10.8×	16.2×	14.8×	-	-	11.0×	9.7×	-	-	9.5×	9.0°	7.6	6.0
SG	-	19.6	18.5	18.1×	17.2	17.5	20.8°	14.2	12.6	11.2	16.3	15.1	-	-	11.6	10.4	-	-	9.6	8.7	7.0×	5.9
LS	-	19.8	18.6	18.1×	17.2	18.4	20.8°	14.3	12.8	11.4	16.3	15.5°	-	-	11.8	10.9	-	-	9.9°	8.6×	7.4	6.4°
SS Biol	-	19.9°	18.7°	17.7	15.5×	19.2°	20.8°	14.5	13.0°	11.5	16.6°	15.5°	-	-	11.9	11.2	-	-	9.8	8.6×	7.6	6.1
LG Biol	-	18.7×	18.6	18.2	15.9	19.1	20.3	14.6°	13.0°	11.6°	16.6°	15.5°	-	-	11.9	11.3	-	-	9.8	8.7	7.6	6.2
B50Biol	-	19.7×	18.9	19.5	19.8	19.2	21.2	14.8°	13.1	11.2	16.8×	16.4	-	-	12.2	11.9	-	-	9.8	9.2	8.0	6.7
B90Biol	-	19.9	18.5×	18.5	18.0×	18.3×	21.0	14.8°	12.9×	10.7×	16.9	15.5	-	-	12.1	11.9	-	-	10.4	7.7×	7.8×·	6.4
FLE2cw	-	19.7×	19.0	18.1×	18.8	18.7	20.6×	14.7	13.2	10.9	17.2	15.4×	-	-	11.9×	11.8×	-	-	10.2	8.6	7.9	5.7×
FLE1cw	-	20.1	19.1	18.8	19.9	19.3	21.0	14.7	13.3	11.5	17.3°	16.3	-	-	12.2	12.1	-	-	9.8	9.6°	8.1	6.7
B50	-	20.1	19.4°	19.1	20.4°	19.6	21.5°	14.7	13.4°	11.6	17.1	15.7	-	-	12.5	12.4°	-	-	10.5°	9.5	8.1	6.4
B90	-	19.9	19.1	19.0	20.2	19.7°	20.9	14.6×	13.3	11.8°	16.9	16.2	-	-	12.6°	12.1	-	-	10.3	9.4	8.1	6.4
FLM2cw	-	20.2°	19.4°	19.6°	20.0	19.4	20.9	14.6×	13.2	11.7	17.2	16.5°	-	-	12.2	12.3	-	-	10.4	9.3	8.2°	6.7
FLM1cw	-	20.0	19.2	19.4	20.0	19.5	21.1	14.7	13.4°	11.8°	17.1	16.3	-	-	12.4	12.3	-	-	9.7×	9.3	8.1	6.8°

× Lowest Temperature in bed.

° Highest temperature in bed

Appendix 7.B.4. Weekly Averaged BOD data (16/6/75 - 16/11/75) (mg/l)

	22/6	29/6	6/7	13/7	20/7	27/7	3/8	10/8	17/8	24/8	31/8	7/9	14/9	21/9	28/9	5/10	12/10	19/10	26/10	2/11	9/11	16/11
FEED	301	161	186	242·5	-	240	237·8	267·3	239	240	500	313·3	389	370	-	212	-	-	553	472	302	458
SG biol	214	56·5	37·5	38·4	-	25	65·5	72	54·8	8·5	137	41·4	151·5	104·2	-	9	-	-	137·7	115	138	99
LS biol	224	43	50	61·4	-	53	60·5	68·7	51·3	17·3	144	67	97·3	110	-	44	-	-	165	78	123	83
SS	244	49	30·3	47·4	-	34	65·8	58·3	45·3	21·3	143	50·7	193	89·5	-	29·5	-	-	177·2	75	127	107
LG	31	71	53·5	73·2	-	81	77·0	57·7	37·8	31·8	146	70·5	100·8	105·7	-	82	-	-	220	154	176	142
SG	51	52	34·5	58·9	-	64	66·0	72·3	13·3	42·8	150	65·2	96	97·8	-	48	-	-	148·2	145	153	110
LS	84	60·5	43·5	62·4	-	74	72·0	63	33·8	35·5	153	65·7	99	97·2	-	67·5	-	-	162·5	126	185	117
SS biol	286	50·5	37	57·9	-	71	59	57·7	35·3	35·3	168	72·4	98	102·8	-	32	-	-	207	130	153	100
LG biol	284	58·0	52·5	65·7	-	78	72	68	37·8	37·3	188	81·2	118·5	125·5	-	57	-	-	210·5	141	169	148
B50 biol	314	57	26·5	48·9	-	49	70·5	103·7	78·1	62	95	51·9	82·5	62·7	-	43	-	-	156	86·8	106	83·3
B90 biol	306	63·5	62·5	79·4	-	60	70	111·7	61·1	44·8	104	65·9	113	84·5	-	31	-	-	168·5	67·8	131	108
FLE 2cw	314	62·5	52	55·4	-	91	83·8	112·3	87·8	63	95	71	112·3	84·5	-	77·5	-	-	201	126	158	142
FLE 1cw	304	59·5	61·5	58·9	-	87	78·8	109·3	102·6	60·3	73	72·7	106·3	87·5	-	69·5	-	-	206	142	175	150
B 50	139	75	61	47·2	-	55	71	96·3	79·1	69·3	105	78·5	93·5	71·7	-	69	-	-	195·5	135	166	123
B 90	186	66·5	58·8	82·9	-	84	74	106·3	79·6	66·8	104	63·5	113·3	75·8	-	71·5	-	-	175	97	145	114
FLM 2cw	71	75	41·5	61·2	-	95	88·5	122	120·8	74	103	69	110·8	85·2	-	68·5	-	-	214	127	166	144
FLM 1cw	111	62·5	42·8	65·7	-	94	78·3	111·3	117·8	87	83	68·2	109	89	-	67	-	-	199·5	123	168	149

Appendix 7.B.5. Weekly Averaged COD data (16.6.75 - 16.11.75) (mg/l)

	22/6	29/6	6/7	13/7	20/7	27/7	3/8	10/8	17/8	24/8	31/8	7/9	14/9	21/9	28/9	5/10	12/10	19/10	26/10	2/11	9/11	16/11
Feed	392.7	341.3	354	397	-	339.3	-	371.5	449.3	436.7	426.7	422.5	457.3	528.5	338	330	-	-	542	424	312	368
SG Biol	164	150.7	116	185	-	124.6	-	162.5	154	125.3	183.3	134.5	165.3	158.5	120	107	-	-	200	136	252	162
LS Biol	149.3	150.7	120	177	-	127.3	-	162.5	162	118.7	166.7	153	169.3	154.5	105	117	-	-	262	134	202	164
SS	176.7	152.7	118.5	174.5	-	132.7	-	140.5	155.3	130.7	172	142	153.3	143	89	106	-	-	237	120	180	126
LG	159.3	180.7	136.5	191	-	135.3	-	152	159.3	138	170.7	140	168	166	147	163	-	-	290	210	270	204
SG	162.7	172.7	139.5	173	-	150	-	157	150	121.3	182.7	144.5	166	146.5	123	129	-	-	245	174	210	150
LS	183.3	164.7	122	174	-	146	-	138.5	128.7	112.7	172	130.5	134.7	121	93	231	-	-	221	86	210	166
SS Biol	146.7	153.3	115	157.5	-	144	-	129.5	152	121.3	163.3	117	132	133.5	97	102	-	-	237	134	186	132
LG Biol	154	166	121	177.5	-	132.7	-	153	147.3	148	196.7	124	142	154.5	107	124	-	-	245	140	216	188
B50Biol	198.7	184	103.5	156.5	-	91	-	196	154	156	76	118.5	124	95.5	87	104	-	-	190	98	154	108
B90Biol	198.7	201.3	123	186	-	112	-	228.5	213.3	134.7	130	116	166	119	89	114	-	-	195	82	176	138
FLE2cw	204.7	191.3	135	186	-	124	-	205	198	144	100	124	129	112	128	131	-	-	-	136	-	162
FLE1cw	198	172	144	139	-	109.3	-	239.5	200	152.7	64	105	151.3	129.5	100	157	-	-	248	170	206	172
B 5 0	195.3	144.7	132	157.5	-	112	-	201.5	175.3	162	172	106.5	126	100	98	126	-	-	231	116	220	162
B 9 0	205.3	176.7	139	193.5	-	112	-	208	201.3	136	103	108.5	158.7	121.5	102	100	-	-	207	82	190	134
FLM2cw	141	165.3	132	178.5	-	111	-	236	166	108	128	127	150	116.7	119	138	-	-	250	-	226	140
FLM1cw	194	165.3	126	236	-	125	-	206	208	166	116	105	136.7	113	100	119	-	-	247	124	230	168

Appendix 7.B.6. Weekly Averaged Shaken Solids data (16.6.75 - 16.11.75) (mg/l)

	22/6	29/6	6/7	13/7	20/7	27/7	3/8	10/8	17/8	24/8	31/8	7/9	14/9	21/9	28/9	5/10	12/10	19/10	26/10	2/11	9/11	16/11
Feed	146	204·3	295	171·3	-	107·3	107·3	109·5	133·7	183·3	123	148	168·3	212	179·5	224	-	-	188·5	166	260	186
SG Biol	68	106	139·3	132·5	-	170·3	650·8	140·3	78	133·7	113·5	162	148·7	151·5	117·5	246	-	-	122·5	79	171	210
LS Biol	79·7	105	131·3	139·5	-	182·3	360	159·8	77	113·3	105·5	349·3	237·7	304·5	125·5	306	-	-	215·5	93	133	142
SS	67·7	104	109·5	140	-	222·7	389	93·3	94·7	119·7	88	206	109·3	110	97	604	-	-	139	72	119	102
LG	68	118·7	152·5	172·8	-	202·7	236·3	91·8	63·7	107·3	93·5	158·3	117·7	121·3	106·5	303·5	-	-	166	116	142	189
SG	103·3	125·3	157·5	139·3	-	239·3	207·8	87·3	74·3	116·3	90	132·8	104·7	129	112	172	-	-	202	105	151	146
LS	77·7	117	119·5	136·3	-	262·3	231·8	79·8	90	104·3	94·5	135·3	111	123·8	120·5	105·5	-	-	165·5	88	133	120
SS Biol	95·7	100	129·3	135	-	221·3	215·8	69·5	77·7	99·3	102·5	146·8	102	112·3	143	262·5	-	-	144·5	96	146	111
LG Biol	90·0	110	131·8	143·8	-	200·3	221·5	87·5	73·3	109	728	149·3	245·7	157	135	541	-	-	134·5	93	136	192
B50Biol	109·3	111	112·8	133·3	-	101	177·8	192	162	115·7	73	91·8	150	137·3	100·5	192·5	-	-	129	128	143	116
B90Biol	85·0	113·3	141·3	143·8	-	93·7	266	241·3	149·7	69·7	57·5	95·5	211·3	180·5	100	187·5	-	-	136	104	170	122
FLE2cw	113·3	127·3	131·3	124·5	-	87·3	136·5	231·5	235·7	88·7	80	63	143·3	152·3	131	201	-	-	130	169	142	119
FLE1cw	110·7	112·3	138·3	130·8	-	87	146·8	213·3	238·7	103·3	64·5	70·5	187	180·5	122·5	260	-	-	161·5	190	150	190
B50	90·3	117	96·5	88·8	-	70	165·3	220	141·3	100·3	61·5	70	139·3	173·5	120	246	-	-	142	115	111	119
B90	96·3	123	111·3	105·8	-	69·3	119·8	217·8	255·3	82	55	70	146·7	190·3	119	159·5	-	-	142	106	147	144
FLM2cw	106·3	127	115·5	89·8	-	73·3	113·8	183·8	303·3	87	60	112·8	142·3	163·5	143·5	231	-	-	131	171	136	130
FLM1cw	88·0	118·3	114·5	105·5	-	86·7	111·5	199·3	292	111·7	47	92	153·7	158·3	110·5	209	-	-	155·5	102	167	176

Appendix 7.B.7. Weekly Averaged Settled Solids Data (16/6/75 - 16/11/75) (mg/l)

	22/6	29/6	6/7	13/7	20/7	27/7	3/8	10/8	17/8	24/8	31/8	7/9	14/9	21/9	28/9	5/10	12/10	19/10	26/10	2/11	9/11	16/11
FEED	58	84	88·5	98·5	-	55·3	62·8	82·3	88·3	123·3	78	106·3	115·7	118·5	96·5	95	-	-	113·5	149	164	148
SG biol	45	60	45·5	57·3	-	41·7	58·3	54	47·3	38	41·5	36·8	44·7	61·3	42	42·5	-	-	66·5	60	98	83
LS biol	57	60·7	49·0	43·5	-	60	47·5	86·5	45·3	38	33·5	32·5	47·3	63·5	43	51·5	-	-	86	42	74	59
SS	27·7	51·7	43·5	39·3	-	35·3	66·5	38·8	45·0	35·7	30	58·0	36·7	45	42·5	57·5	-	-	78·5	38	59	46
LG	50·7	64·0	55·0	55·5	-	35·7	55·5	43·3	42·3	38	31	25	40·0	60·3	45·5	66·5	-	-	109·5	64	93	55
SG	40·7	63·3	45·3	46·5	-	46·3	48·5	37·0	45	38·7	33	28	39·7	57·8	33	43	-	-	73·5	61	76	53
LS	46	65·3	49·5	45·5	-	52·7	49·3	34·0	41·7	44	30	26·3	41·0	48·3	28·5	49	-	-	82·5	55	83	53
SS biol	42·7	46·3	51·8	47·8	-	52·3	60·8	32·0	37·3	34	36·5	28·3	38	51·5	41·5	38·5	-	-	87	56	73	49
LG biol	39·0	64·7	45·5	71·0	-	34·7	45·3	43·8	36·3	42	52	37·8	46·3	51	46	58·5	-	-	88·5	54	99	49
B50biol	55	69·3	34·3	72·3	-	23·3	50·8	61·8	46·0	68·3	31·5	28·8	36·7	56·5	34·5	41	-	-	65	138	73	42
B90biol	54	64	51·5	82	-	18·3	38·3	77·3	62	45·7	24·5	22·3	48·7	47·3	34	45·5	-	-	68·5	52	84	43
FLE2cw	51·3	71·7	55·0	78·8	-	23	38·8	58·5	41·7	55·3	32·5	41	44	43·5	46	53·5	-	-	88	82	94	67
FLE1cw	60	59·3	48·5	78·8	-	23·7	34·0	55·5	63·3	63·7	34·0	34·5	47·3	51·5	47·5	65	-	-	86·5	56	99	70
B50	57·7	71·7	40·5	69·8	-	20·7	28·8	64·5	46	73·3	31·5	99·5	40	44	42	53	-	-	77	64	88	53
B90	65	71	65·3	74·3	-	23·3	27·8	64·8	59·7	55·7	31·5	34·3	47·7	47	42·5	38	-	-	57	49	83	50
FLM2cw	65	57·3	50·3	51·8	-	22·3	34	56·3	97·7	67·3	34·0	48·5	43·3	43	40·5	54·5	-	-	95·5	70	100	62
FLM1cw	56·3	76·7	55·0	81·3	-	20·7	28·5	55	94	74	29·5	34·8	42·3	42	40·5	55·5	-	-	77	63	90	63

Appendix 7.B.8. Weekly Averaged Ammoniacal Nitrogen data (16.6.75 - 16.11.75) (mg N/l)

	22/6	29/6	6/7	13/7	20/7	27/7	3/8	10/8	17/8	24/8	31/8	7/9	14/9	21/9	28/9	5/10	12/10	19/10	26/10	2/11	9/11	16/11
Feed												13.0	18.8	13.3	10.5	-	-	-	12.5	13.4	-	8.2
SG Biol												39.3	14.6	10.3	10.9	-	-	-	14.6	9.4	-	10.2
LS Biol												11.7	15.6	10.8	11.5	-	-	-	18.8	10.4	-	10.4
SS												11.2	15.4	10.9	11.8	-	-	-	11.3	11.6	-	10.5
LG												11.7	15.6	10.6	10.5	-	-	-	12.6	10.6	-	9.0
SG												12.0	15.6	10.8	11.5	-	-	-	18.6	-	-	10.5
LS												9.8	15.6	11.2	11.4	-	-	-	18.6	-	-	10.8
SS Biol												12.5	15.6	11.0	11.6	-	-	-	12.1	-	-	11.0
LG Biol												11.8	15.6	11.4	11.4	-	-	-	17.6	-	-	10.0
B50Biol												12.5	21.6	8.8	11.8	-	-	-	9.6	9.9	-	8.5
B90Biol												11.8	17.6	9.3	11.5	-	-	-	9.7	10.7	-	8.6
FLE2cw												11.6	19.0	9.9	12.0	-	-	-	8.6	10.3	-	7.6
FLE1cw												12.5	18.6	9.9	11.9	-	-	-	7.9	-	-	7.7
B50												12.9	19.6	10.5	12.5	-	-	-	9.5	9.9	-	8.6
B90												10.0	19.6	9.8	12.4	-	-	-	10.2	-	-	8.2
FLM2cw												6.1	19.0	11.1	11.8	-	-	-	9.4	10.2	-	7.8
FLM1cw												11.8	18.4	10.6	12.1	-	-	-	9.6	-	-	8.4

Appendix 7.B.9. Weekly Averaged Oxidized Nitrogren data (16.6.75 - 16.11.75) (mg N/l)

	22/6	29/6	6/7	13/7	20/7	27/7	3/8	10/8	17/8	24/8	31/8	7/9	14/9	21/9	28/9	5/10	12/10	19/10	26/10	2/11	9/11	16/11
Feed												1.0	<0.5	<0.5	6.0	-	-	-	< 0.5	<0.5	-	<0.5
SG Biol												1.9	<0.5	<0.5	<1.0	-	-	-	<0.5	<0.5	-	<0.5
LS Biol												1.7	<0.5	<0.5	<1.0	-	-	-	<0.5	<0.5	-	<0.5
SS												1.9	<0.5	<0.5	<1.0	-	-	-	<0.5	<0.5	-	<0.5
LG												2.1	<0.5	<0.5	<1.0	-	-	-	<0.5	<0.5	-	<0.5
SG												2.2	<0.5	<0.5	<1.0	-	-	-	<0.5	<0.5	-	<0.5
LS												3.3	<0.5	<0.5	<1.0	-	-	-	<0.5	<0.5	-	<0.5
SS Biol												3.2	<0.5	<0.5	<1.0	-	-	-	<0.5	<0.5	-	<0.5
LG Biol												0.7	<0.5	<0.5	<1.0	-	-	-	<0.5	<0.5	-	<0.5
B50Biol												2.8	<0.5	<0.5	<1.0	-	-	-	<0.5	<0.5	-	<0.5
B90Biol												3.8	<0.5	<0.5	<1.0	-	-	-	<0.5	<0.5	-	<0.5
FLE2cw												3.7	<0.5	<0.5	<1.0	-	-	-	<0.5	<0.5	-	<0.5
FLE1cw												3.2	<0.5	<0.5	<1.0	-	-	-	<0.5	<0.5	-	<0.5
B50												1.7	<0.5	<0.5	<1.0	-	-	-	<0.5	<0.5	-	<0.5
B90												1.9	<0.5	<0.5	<1.0	-	-	-	<0.5	<0.5	-	<0.5
FLM2cw												2.1	<0.5	<0.5	<1.0	-	-	-	<0.5	<0.5	-	<0.5
FLM1cw												<0.5	<0.5	<0.5	<1.0	-	-	-	<0.5	<0.5	-	<0.5

Appendix 7.C.1. Weekly Mean Flows to the Filters from 19.11.75 to 27.1.76.

Date W/E	Tank A (Mineral Media)			Tank B (Plastic Media)			
	Trough 1	Trough 2	$\bar{x}$	Trough 1	Trough 2	$\bar{x}$	Flocor M
23.11.75	-	0.59	0.59	-	-	-	-
30.11.75	-	1.28	1.28	2.04	1.98	2.01	2.23
7.12.75	-	2.37	2.37	1.96	1.33	1.65	1.83
14.12.75	1.00	-	1.00	1.14	0.90	1.02	1.13
21.12.75	1.07	-	1.07	1.53	-	1.53	1.70
28.12.75	0.49	-	0.49	2.08	-	2.08	2.31
4.1.76	0.49	-	0.49	2.08	-	2.08	2.31
11.1.76	1.33	-	1.33	2.28	-	2.28	2.53
18.1.76	1.47	-	1.47	2.04	-	2.04	2.27
Mean			1.12			1.84	2.04

(Flows expressed in $m^3/m^3/d.$)

Appendix 7.C.2. Weekly Averaged Daily Maximum and Minimum Temperatures 19/11/75 - 27/1/76 (°C)

	23/11	30/11	7/12	14/12	21/12	28/12	4/1	11/1	18/1	25/1	1/2	8/2	15/2	22/2	29/2	7/3
FEED																
Max.	7.3	-	-	-	-	13.5	12.0	15.7	-							
Min.	4.7	-	-	-	-	12.3	11.1	12.9	-							
FLM2cw																
Max.	6.7	-	-	-	-	12.9	11.1	15.1	13.5							
Min.	2.9	-	-	-	-	11.4	9.6	12.6	10.8							
SSbiol																
Max.	4.9	-	-	-	-	12.6	10.0	14.7	15.3							
Min.	0.3	-	-	-	-	11.4	8.2	12.1	14.4							

Appendix 7.C.3. Weekly mean of the MIDDAY Comparative Temperature Data (19/11/75 - 27/1/76) (°C)

	23/11	30/11	7/12	14/12	21/12	28/12	4/1	11/1	18/1
SGbiol	5.7	8.3	-	-	-	-	-	14.0	15.1
LSbiol	5.3	8.1	-	-	-	-	-	13.1	14.3
SS	5.1	8.1	-	-	-	-	-	13.7	14.7
LG	4.9	7.9	-	-	-	-	-	12.9	13.3
SG	4.7	6.5	-	-	-	-	-	13.8	14.7
LS	5.6	7.8	-	-	-	-	-	14.0	15.0
SSbiol	6.0	7.6	-	-	-	-	-	14.4	15.2
LGbiol	5.7	8.0	-	-	-	-	-	14.1	15.1
B50biol	5.3	10.3	-	-	-	-	-	13.9	14.3
B90biol	5.6	9.0	-	-	-	-	-	10.7	13.8
FLE2cw	6.3	10.4	-	-	-	-	-	11.1	12.5
FLE1cw	6.1	10.3	-	-	-	-	-	13.1	12.2
B50	6.5	10.5	-	-	-	-	-	13.9	10.1
B90	6.5	11.8	-	-	-	-	-	14.6	10.7
FLM2cw	6.3	11.2	-	-	-	-	-	14.6	12.6
FLM1cw	6.0	11.6	-	-	-	-	-	13.4	13.2

Appendix 7.C.4. Weekly Averaged BOD Data (mg/l) (19.11.75 - 27.1.76)

	23/11	30/11	7/12	14/12	21/12	28/12	4/1	11/1	18/1
Feed	-	400	890	1075	-	-	-	-	467
SG Biol	-	98	68	178	-	-	-	-	32.5
LS Biol	-	18	65	170	-	-	-	-	30
SS	-	20	85	190	-	-	-	-	22.5
LG	-	18	108	155	-	-	-	-	57.5
SG	-	28	85	158	-	-	-	-	40
LS	-	8	108	160	-	-	-	-	30
SS Biol	-	21	78	135	-	-	-	-	57.5
LG Biol	-	43	103	83	-	-	-	-	50
B50Biol	-	53	95	198	-	-	-	-	42.5
B90Biol	-	60	103	305	-	-	-	-	22.5
FLE2cw	-	33	118	938	-	-	-	-	42.5
FLE1cw	-	63	140	505	-	-	-	-	37.5
B50	-	58	113	623	-	-	-	-	47.5
B90	-	43	118	318	-	-	-	-	65
FLM2cw	-	50	175	380	-	-	-	-	70
FLM1cw	-	88	180	335	-	-	-	-	72.5

Appendix 7.C.5. Weekly Averaged COD Data(mg/l) (19.11.75 - 27.1.76)

	23/11	30/11	7/12	14/12	21/12	28/12	4/1	11/1	18/1
Feed	-	544	1540	-	2320	-	-	1190	1320
SG Biol	-	124	130	148	180	-	-	92	128
LS Biol	-	108	124	152	176	-	-	78	198
SS	-	104	124	126	146	-	-	72	132
LG	-	160	172	150	168	-	-	90	160
SG	-	132	132	154	160	-	-	80	136
LS	-	134	136	152	142	-	-	100	140
SS Biol	-	112	124	180	168	-	-	84	142
LG Biol	-	108	152	144	190	-	-	88	132
B50Biol	-	152	124	416	162	-	-	96	134
B90Biol	-	136	130	544	180	-	-	116	156
FLE2cw	-	128	220	756	192	-	-	88	162
FLE1cw	-	132	232	684	224	-	-	204	140
B50	-	124	186	760	190	-	-	140	144
B90	-	140	192	510	184	-	-	136	148
FLM2cw	-	172	208	-	180	-	-	110	152
FLM1cw	-	184	254	512	204	-	-	128	150

Appendix 7.C.6. Weekly Averaged Shaken Solids Data(mg/l) (19.11.75 - 27.1.76)

	23/11	30/11	7/12	14/12	21/12	28/12	4/1	11/1	18/1
Feed	-	650	299	928	376	-	-	353	332
SG Biol	-	1131	342	1666	587	-	-	274	1197
LS Biol	-	274	155	177	746	-	-	324	3054
SS	-	747	381	139	265	-	-	200	247
LG	-	497	225	169	188	-	-	223	570
SG	-	263	283	138	164	-	-	191	201
LS	-	217	229	149	144	-	-	269	188
SS Biol	-	266	218	189	169	-	-	166	183
LG Biol	-	218	231	137	594	-	-	194	348
B50Biol	-	608	342	799	183	-	-	302	412
B90Biol	-	518	225	2216	157	-	-	305	377
FLE2cw	-	574	628	4593	173	-	-	528	195
FLE1cw	-	536	744	3432	186	-	-	520	261
B50	-	519	398	4876	199	-	-	338	111
B90	-	404	438	3166	153	-	-	444	187
FLM2cw	-	553	322	1648	169	-	-	254	331
FLM1cw	-	535	979	1272	302	-	-	401	289

Appendix 7.C.7. Weekly Averaged Settled Solids Data (mg/l) (19.11.75 - 27.1.76)

	23/11	30/11	7/12	14/12	21/12	28/12	4/1	11/1	18/1
Feed	-	650	299	928	376	-	-	353	332
SG Biol	-	90	29	66	69	-	-	38	58
LS Biol	-	62	35	50	72	-	-	40	117
SS	-	66	35	63	38	-	-	31	55
LG	-	97	52	63	44	-	-	55	61
SG	-	73	31	50	46	-	-	44	51
LS	-	65	45	47	47	-	-	44	37
SS Biol	-	52	48	40	38	-	-	36	48
LG Biol	-	68	52	45	71	-	-	27	58
B50Biol	-	81	67	196	35	-	-	41	51
B90Biol	-	86	56	251	53	-	-	59	50
FLE2cw	-	106	93	500	48	-	-	82	57
FLE1cw	-	87	96	452	52	-	-	69	56
B50	-	79	79	466	44	-	-	60	46
B90	-	78	66	284	33	-	-	59	59
FLM2cw	-	98	93	286	44	-	-	57	61
FLM1cw	-	97	94	210	51	-	-	66	57

Appendix 7.C.8. Weekly Averaged Ammoniacal Nitrogen Data (mgN/l) (19.11.75 - 27.1.76)

	23/11	30/11	7/12	14/12	21/12	28/12	4/1	11/1	18/1
Feed	-	15.4	-	13.8	-	-	-	13.5	17.0
SG Biol	-	16.5	-	4.3	-	-	-	10.8	12.2
LS Biol	-	16.0	-	6.3	-	-	-	11.4	13.4
SS	-	16.8	-	5.4	-	-	-	12.0	8.3
LG	-	15.0	-	8.2	-	-	-	9.0	10.8
SG	-	15.8	-	7.8	-	-	-	11.2	12.8
LS	-	16.0	-	8.0	-	-	-	11.5	13.3
SS Biol	-	16.5	-	6.8	-	-	-	11.1	14.0
LG Biol	-	15.8	-	6.6	-	-	-	11.1	13.0
B50Biol	-	12.8	-	15.6	-	-	-	9.0	14.1
B90Biol	-	13.6	-	17.0	-	-	-	10.5	16.2
FLE2cw	-	13.8	-	18.8	-	-	-	11.5	15.9
FLE1cw	-	13.8	-	18.8	-	-	-	11.4	14.6
B50	-	13.8	-	24.0	-	-	-	11.2	18.4
B90	-	12.9	-	20.8	-	-	-	12.2	18.5
FLM2cw	-	14.5	-	20.6	-	-	-	10.8	10.7
FLM1cw	-	16.7	-	20.6	-	-	-	10.5	17.2

Appendix 7.C.9. Weekly Averaged Oxidized Nitrogen Data(mgN/l) (19.11.75 - 27.1.76)

	23/11	30/11	7/12	14/12	21/12	28/12	4/1	11/1	18/1
Feed	-	1.0	-	<0.5	-	-	-	5.4	2.2
SG Biol	-	<0.5	-	<0.5	-	-	-	3.6	<0.5
LS Biol	-	<0.5	-	0.9	-	-	-	3.1	<0.5
SS	-	<0.5	-	0.8	-	-	-	3.6	<0.5
LG	-	<0.5	-	1.0	-	-	-	3.9	<0.5
SG	-	<0.5	-	<0.5	-	-	-	3.4	<0.5
LS	-	<0.5	-	<0.5	-	-	-	3.1	<0.5
SS Biol	-	<0.5	-	<0.5	-	-	-	3.9	<0.5
LG Biol	-	<0.5	-	1.8	-	-	-	3.7	<0.5
B50Biol	-	<0.5	-	<0.5	-	-	-	2.9	<0.5
B90Biol	-	<0.5	-	<0.5	-	-	-	1.5	<0.5
FLE2cw	-	<0.5	-	<0.5	-	-	-	2.7	<0.5
FLE1cw	-	<0.5	-	<0.5	-	-	-	2.8	<0.5
B50	-	<0.5	-	<0.5	-	-	-	3.1	<0.5
B90	-	<0.5	-	<0.5	-	-	-	3.3	<0.5
FLM2cw	-	<0.5	-	<0.5	-	-	-	4.4	<0.5
FLM1cw	-	<0.5	-	<0.5	-	-	-	4.0	<0.5

Appendix 7.D.1. Weekly Meaned Daily Flow Results. (29.1.76 to 29.7.76)

Date W/E	Tank A (Mineral Media)			Tank B (Plastic Media)			
	Trough 1	Trough 2	Mean	Trough 1	Trough 2	Mean	Flocor M.
1.2.76	1.70	-	1.70	1.70	-	1.70	1.89
8.2.76	1.05	-	1.05	1.70	-	1.70	1.89
15.2.76	1.89	-	1.89	2.57	-	2.57	2.86
22.2.76	2.91	-	2.91	5.37	6.09	5.73	6.37
29.2.76	3.10	-	3.10	5.72	5.30	5.51	6.12
7.3.76	2.80	2.64	2.72	5.50	5.06	5.28	5.87
14.3.76	2.56	2.75	2.65	5.09	4.68	4.89	5.43
21.3.76	3.09	3.24	3.17	6.10	5.39	5.75	6.39
28.3.76	3.00	3.21	3.10	5.98	5.41	5.70	6.33
4.4.76	3.33	3.58	3.45	5.78	5.04	5.41	6.01
11.4.76	3.28	3.37	3.32	4.85	4.43	4.64	5.16
18.4.76	2.86	2.42	2.64	4.83	4.35	4.59	5.10
25.4.76	1.24	1.27	1.25	3.10	3.02	3.06	3.40
2.5.76	2.42	2.64	2.52	-	5.47	5.47	6.08
9.5.76	2.76	2.78	2.77	6.51	5.17	5.84	6.49
16.5.76	2.68	2.48	2.58	6.01	5.01	5.51	6.12
23.5.76	2.21	2.08	2.15	5.73	5.34	5.54	6.16
30.5.76	2.47	2.78	2.63	5.17	5.03	5.10	5.67
6.6.76	2.78	2.75	2.77	4.92	4.94	4.93	5.48
13.6.76	2.58	3.11	2.84	5.63	5.61	5.62	6.24
20.6.76	-	2.77	2.77	4.83	4.83	4.83	5.37
27.6.76	2.90	3.20	3.05	4.98	5.03	5.01	5.57
4.7.76	-	2.80	2.80	4.83	-	4.83	5.37
11.7.76	2.94	2.93	2.93	5.50	4.86	5.18	5.76
18.7.76	2.58	2.98	2.78	5.14	6.09	5.62	6.24
25.7.76	2.42	2.56	2.49	-	5.18	5.18	5.76
29.7.76	2.90	2.90	2.90	-	5.92	5.92	6.58
$\bar{x}$	2.58	2.78	2.63	4.90	5.10	4.86	5.40
S.D.	0.58	0.48	0.54	1.31	0.64	1.03	1.15

$(m^3/m^3/d)$

Appendix 7.D.2. Weekly Meaned Daily Maximum & Minimum Temperature (°C) 29.1.76 - 29.7.76)

	1/2	8/2	15/2	22/2	29/2	7/3	14/3	21/3	28/3	4/4	11/4	18/4	25/4	2/5	
Feed Max.	14.2	-	13.8	14.4	16.1	16.2	15.3	15.0	13.7	16.0	16.4	15.9	17.2	17.6	
Feed Min.	10.7	-	12.8	13.9	15.1	15.1	13.9	13.6	12.2	15.3	15.8	14.8	16.3	16.8	
FLM2cw Max.	11.5	11.7	13.0	13.4	15.3	15.0	13.9	13.8	13.0	14.8	15.6	14.6	16.2	16.4	
FLM2cw Min.	9.4	9.9	11.8	12.8	14.2	14.0	12.8	12.1	11.4	14.2	14.9	13.6	15.2	15.8	
SS Biol Max.	11.7	11.1	12.4	13.3	15.2	14.6	13.7	13.5	13.2	14.9	15.9	14.9	16.2	16.3	
SS Biol Min.	10.9	10.0	11.4	12.7	14.3	13.9	12.5	12.8	11.7	14.3	14.9	14.1	15.6	15.6	

	9/5	16/5	23/5	30/5	6/6	13/6	20/6	27/6	4/7	11/7	18/7	25/7	29/7	$\bar{x}$	S.D.
Feed Max.	17.7	18.7	18.4	18.4	19.1	20.7	21.1	22.4	23.7	24.1	23.4	23.1	22.6	18.28	3.35
Feed Min.	17.2	18.0	17.6	16.7	18.1	20.3	20.3	21.7	23.1	23.2	22.4	21.5	21.7	17.23	3.58
FLM2cw Max.	17.8	18.3	18.4	17.8	18.6	20.3	20.5	22.1	23.5	24.2	23.5	23.0	22.5	17.36	3.92
FLM2cw Min.	15.5	17.2	17.0	16.1	17.3	19.5	19.5	20.7	22.5	23.1	22.0	21.4	21.3	16.12	3.97
SS Biol Max.	17.4	18.0	17.5	17.8	18.6	20.9	20.5	22.4	23.0	23.6	22.9	22.5	22.3	16.53	4.67
SS Biol Min,	16.4	17.0	16.4	16.6	17.3	19.6	19.2	20.1	21.5	22.4	21.4	21.3	21.0	23.21	38.09

Appendix 7.D.3. Weekly Averaged Midday Comparative Bed Temperatures (°C) (29.1.76 - 2.5.76)

	1/2	8/2	15/2	22/2	29/2	7/3	14/3	21/3	28/3	4/4	11/4	18/4	25/4	2/5
SG Biol	11.0	9.9	11.9	13.0	15.0	15.0	13.6	13.1	11.1	-	15.1	-	15.4	-
LS Biol	9.1	8.2	11.2	12.7	14.8	14.7	13.6	12.6	10.7	-	14.9	-	15.3	-
SS	11.5	10.9	11.8	13.2	15.1	15.1	13.9	13.8	11.2	-	14.8	-	15.2	-
LG	10.2	12.1	10.6	12.9	14.5	14.6	13.5	13.4	10.5	-	14.5	-	15.2	-
SG	12.2	11.4	11.2	13.1	14.7	14.7	13.5	13.6	10.9	-	14.9	-	15.6	-
LS	12.0	10.6	11.9	13.0	14.9	14.9	13.5	13.6	11.2	-	14.7	-	15.6	-
SS Biol	11.5	10.6	11.9	13.0	14.9	14.9	13.4	13.4	11.3	-	15.1	-	15.6	-
LG Biol	10.8	11.7	12.0	12.9	14.9	14.9	13.0	11.9	11.3	-	15.2	-	15.7	-
B50Biol	8.0	7.3	12.0	12.4	15.3	15.3	14.5	14.3	11.4	-	15.7	-	17.0	-
B90Biol	9.9	9.4	12.3	13.1	14.8	14.9	13.2	14.0	11.0	-	14.9	-	15.9	-
FLE2cw	9.5	8.0	11.2	12.9	15.1	15.0	12.5	12.7	10.7	-	14.2	-	14.7	-
FLE1cw	10.1	9.3	10.6	13.3	14.6	15.4	13.2	13.3	11.6	-	15.5	-	15.4	-
B50	8.5	6.8	9.5	12.8	14.4	15.0	14.1	14.1	11.2	-	16.1	-	15.4	-
B90	7.6	5.8	10.0	11.6	14.3	13.8	13.5	13.5	11.8	-	15.3	-	15.7	-
FLM2cw	8.9	8.2	11.6	12.6	14.5	15.0	13.8	13.0	11.6	-	15.1	-	15.5	-
FLM1cw	8.0	7.8	12.0	13.3	15.2	15.7	13.7	13.4	11.1	-	15.1	-	15.4	-

Appendix 7.D.3. cont. Weekly Averaged Midday Comparative Bed Temperatures (^{o}C) (9.5.76- 29.7.76)

	9/5	16/5	23/5	30/5	6/6	13/6	20/6	27/6	4/7	11/7	18/7	25/7	29/7	$\bar{x}$	S.D.
SG Biol	16.7	18.1	16.7	18.5	18.0	20.7	20.3	21.5	23.5	23.5	22.9	22.1	21.9	17.02	4.29
LS Biol	16.4	17.7	16.7	18.7	18.0	20.2	20.0	21.4	22.5	23.2	23.0	21.8	21.2	16.61	4.50
SS	16.1	18.6	16.6	18.7	17.7	20.6	20.2	21.7	23.6	23.8	23.1	22.8	22.0	17.17	4.25
LG	16.2	17.8	16.5	17.8	17.2	19.9	19.6	21.2	22.9	23.6	22.3	21.2	20.7	16.62	4.10
SG	16.5	17.0	16.5	18.5	17.3	20.1	20.1	21.9	23.9	23.4	23.0	21.0	21.6	16.94	4.11
LS	16.2	18.0	16.6	18.1	17.8	19.8	20.0	21.3	23.4	23.3	22.5	22.5	22.8	17.01	4.15
SS Biol	16.7	18.0	16.7	18.4	17.8	20.5	20.0	21.6	23.4	23.2	22.7	22.7	21.9	17.05	4.17
LG Biol	15.6	17.0	17.1	18.6	18.0	19.9	20.1	21.3	22.4	23.0	22.7	21.9	21.1	16.79	4.04
B50 Biol	18.8	16.6	16.8	18.1	18.4	20.3	20.4	21.9	23.5	24.0	23.5	22.4	22.1	17.08	4.73
B90 Biol	16.3	15.5	16.5	17.9	18.0	19.4	19.9	21.4	22.9	23.7	21.4	20.2	21.2	16.57	4.07
FLE2cw	16.0	16.7	16.4	18.1	18.3	19.9	19.9	21.6	23.2	23.4	21.7	20.8	20.6	16.38	4.42
FLE1cw	16.5	17.6	17.1	18.6	18.4	20.1	20.1	21.6	23.6	23.6	22.6	21.8	22.4	16.93	4.41
B50	16.7	18.0	17.2	19.0	18.6	20.4	20.6	22.0	23.5	24.1	23.9	22.8	22.1	16.95	4.99
B90	16.6	19.3	17.3	18.8	18.5	20.4	20.3	21.9	23.1	23.4	23.1	22.5	22.2	16.68	5.08
FLM2cw	16.5	17.7	17.6	19.1	18.2	20.1	20.1	21.6	23.3	24.0	23.6	22.7	22.6	16.95	4.69
FLM1cw	16.2	17.4	16.8	18.6	18.3	20.1	20.1	21.7	23.1	23.8	22.8	21.9	22.1	16.82	4.60

Appendix 7.D.4. Weekly Averaged BOD Data (mg/l) (29.1.76 - 25.4.76)

	1/2	8/2	15/2	22/2	29/2	7/3	14/3	21/3	28/3	4/4	11/4	18/4	25/4
Feed	243	328	467.5	403	378	314	417.5	433	265	264	323	-	300
SG Biol	78.5	83	157	88	79.5	60.5	87.5	74.5	97.5	78.5	121.5	-	133
LS Biol	75.0	98	214	89	80.0	66	111	85.0	105.5	79	110	-	133
SS	67.0	103	151	96	76.5	61	91.5	73.5	94	84.25	133	-	126
LG	88.0	124	191.5	168	129.5	80	124	100	117.25	85.25	133.5	-	126
SG	72.0	100	177.5	122	81	70.5	118.5	79.5	108	82.75	131	-	135
LS	76.0	100	178.5	126	101.5	78.5	124.5	87.5	106.5	88.75	130.5	-	137
SS Biol	67.5	114	161.5	128	89	64.5	106	75.0	102.5	81	116	-	126
LG Biol	71.5	133	179.5	133	135.5	93	115.5	83.5	116	86.75	127.5	-	111
B50 Biol	66.0	79	138	121	66.5	62	88.5	86.5	86.75	85.0	68.5	-	78
B90 Biol	79.0	103	136.5	123	93	74.5	84	96	72.75	75.5	52.5	-	74
FLE2cw	77	147	154.5	195	167	120	135.5	111.5	84.75	75.5	71.5	-	96
FLE1cw	78	148	147	202	159.5	126	139.5	130.5	90.5	86.75	65.5	-	109
B50	69.5	83	119	103	67.5	63.5	96	98.0	71.5	78	48.5	-	65
B90	75.5	79	124	132	89	66	96	106	86.75	88	58	-	110
FLM2cw	80	110	153	184	142.5	124.5	108.5	130.5	105.75	84.5	99.5	-	105
FLM1cw	76	119	137.5	168	146	111.5	146	121.5	87	84.75	78.5	-	115

Appendix 7.D.4. cont. Weekly Averaged BOD Data (mg/l) (2.5.76 - 29.7.76)

	2/5	9/5	16/5	23/5	30/5	6/6	13/6	20/6	27/6	4/7	11/7	18/7	25/7	1/8
Feed	-	-	385	286.5	356.5	512.5	358.5	419.5	360	297.5	419.5	508	360	-
SG Biol	-	-	38.5	76	102.5	83	90.5	114	62.75	111	106.5	113.5	41	-
LS Biol	-	-	46	86	95.5	89.5	92	123.5	93	62.5	87	117.5	42	-
SS	-	-	54	87	136.5	100.5	115	138	84.25	68	67	115	31	-
LG	-	-	47.5	69	113.5	99	98	130.5	92	123	89.5	130.5	52	-
SG	-	-	55	87	135	92	112	130	77	126.5	97.5	131.5	32	-
LS	-	-	59.5	99.5	120.5	131	118	144	89.25	85	98.5	133	39	-
SS Biol	-	-	40.5	73.5	115	106	108	152.5	76.5	61	66.5	119.5	32	-
LG Biol	-	-	34	69.5	110.5	107.5	101	141.5	75	101	92	141	42	-
B50 Biol	-	-	37	25.5	28	29	33	83	45.5	11.5	32.5	104	20	-
B90 Biol	-	-	35	36	62	83	79.5	117	62.75	44	70.5	125	46	-
FLE2cw	-	-	25.5	33	61.5	104	40	111	67	32.5	69.5	140	34	-
FLE1cw	-	-	32.5	28.5	66	69.5	59	101.5	68.75	29.5	56.5	117	36	-
B50	-	-	21	16.5	23.	23.5	87	69.5	32.75	6	44.5	88.5	29	-
B90	-	-	41	35.5	61	73.5	59.5	109.5	44.75	36.5	52.5	135.5	44	-
FLM2cw	-	-	43.5	30.0	76.5	93	118	152.5	95.5	47.5	68	132	58	-
FLM1cw	-	-	32.5	25.75	69	95.5	102	145	91.75	35.5	58	132	45	-

Appendix 7.D.5. Weekly Averaged COD Data (29.1.76 - 25.4.76) (mg/l)

	1/2	8/2	15/2	22/2	29/2	7/3	14/3	21/3	28/3	4/4	11/4	18/4	25/4
Feed	940	680	1585	800	930	745	860	810	670	615	865	1110	670
SG Biol	277	248	320	184	204	165	179	182	213	165	224	176	156
LS Biol	294	260	370	276	222	189	210	209	215	170	237	202	190
SS	269	252	303	260	203	161	177	175	193	177	246	204	204
LG	275	256	339	304	267	207	191	215	232	189	258	202	232
SG	258	246	322	196	216	170	185	188	207	171	231	190	202
LS	248	256	332	296	233	228	217	187	223	181	267	188	232
SS Biol	229	250	294	306	200	151	180	187	200	174	228	174	188
LG Biol	253	268	298	220	238	194	205	197	234	176	245	184	224
B50 Biol	156	244	269	206	163	146	180	173	175	165	168	168	174
B90 Biol	145	226	259	238	216	187	198	189	176	164	173	152	204
FLE2cw	135	276	287	372	286	230	217	212	178	157	194	156	180
FLE1cw	147	288	268	296	294	182	224	221	174	176	198	150	202
B50	137	196	236	150	183	143	169	197	158	149	167	140	192
B90	151	202	233	208	225	143	176	193	181	186	180	152	210
FLM2cw	157	260	274	260	246	196	238	219	186	180	221	174	160
FLM1cw	136	232	268	264	258	176	229	213	179	172	199	180	184

Appendix 7.D.5. cont. Weekly Averaged COD Data (2.5.76 - 29.7.76) (mg/l)

	2/5	9/5	16/5	23/5	30/5	6/6	13/6	20/6	27/6	4/7	11/7	18/7	25/7	1/8
Feed	-	-	520	415	780	1030	615	550	875	450	595	1065	140	-
SG Biol	-	-	181	151	235	190	229	222	248	435	208	190	154	-
LS Biol	-	-	170	149	201	196	209	215	269	303	202	212	144	-
SS	-	-	190	172	235	197	233	228	288	324	177	184	130	-
LG	-	-	199	158	228	201	216	218	251	389	237	262	168	-
SG	-	-	173	160	265	171	225	220	258	427	201	200	140	-
LS	-	-	172	170	242	199	240	233	266	322	204	239	166	-
SS Biol	-	-	163	150	219	188	229	219	282	302	171	200	132	-
LG Biol	-	-	168	150	261	195	208	223	240	380	209	234	150	-
B50 Biol	-	-	188	105	121	107	123	137	207	119	134	197	126	-
B90 Biol	-	-	165	123	174	160	166	184	216	169	194	224	148	-
FLE2cw	-	-	143	148	173	148	176	184	198	145	184	214	144	-
FLE1cw	-	-	146	124	163	151	168	164	224	116	163	183	122	-
B50	-	-	166	120	110	102	135	140	176	100	119	173	112	-
B90	-	-	165	122	180	152	199	193	194	157	169	199	118	-
FLM2cw	-	-	143	139	163	166	201	210	247	143	188	208	164	-
FLM1cw	-	-	125	104	171	164	221	209	233	137	152	211	166	-

Appendix 7.D.6. Weekly Averaged Shaken Solids Data (mg/l) (29.1.76 - 25.4.76)

	1/2	8/2	15/2	22/2	29/2	7/3	14/3	21/3	28/3	4/4	11/4	18/4	25/4
Feed	298	196	250	276	267.5	196.5	243.5	202.5	109	120	196.5	421	173
SG Biol	248.5	225	324	164	216.5	139.5	124.5	131.5	143.5	107.5	109.5	151	159
LS Biol	289	221	497	186	199.5	110	128.5	119	119.5	106.5	100	115	193
SS	222	207	240.5	169	182.5	107.5	112.5	121.5	123	128.5	98.5	153	182
LG	202	198	217	167	200	200	129	121.5	129.5	119	103.5	106	194
SG	166	194	256.5	191	183.5	123	124.5	125	120.5	104.5	78.5	143	191
LS	169.5	227	203.5	154	223	142	123.5	124	124	101	117.5	126	178
SS Biol	152	202	193.5	200	204	160	116	135	131.5	113.5	92	119	200
LG Biol	218	238	361.5	154	186.5	133.5	134.5	128	125	120	110	127	190
B50 Biol	233	144	196	227	170.5	139	120.5	110.5	75.5	95.5	78	123	263
B90 Biol	290	214	218	258	182.5	128	161	140	91.5	98	87.5	128	259
FLE2cw	243.5	203	252.5	241	192	182.5	161.5	183	115	119.5	149	200	204
FLE1cw	294	208	409.5	229	206	260.5	215	159.5	104.5	123	140.5	202	200
B50	230.5	185	239.5	140	128	142.5	183	158	92	108.5	114	147	276
B90	254.5	229	226.5	193	156	130.5	142.5	137.5	94	88.5	97	118	223
FLM2cw	272	227	248	254	209	198.5	200.5	164.5	116	144.5	145.5	234	168
FLM1cw	264.5	218	224.5	206	216.5	141.5	199	163	109	108	149	298	187

Appendix 7.D.6. cont. Weekly Averaged Shaken Solids Data (mg/l) (29.1.76 - 29.7.76)

	2/5	9/5	16/5	23/5	30/5	6/6	13/6	20/6	27/6	4/7	11/7	18/7	25/7	1/8
Feed	-	-	171·5	223	317	449	198·5	195·5	240	146	216·5	178·5	206	-
SG Biol	-	-	88	86	249	258	184	168·5	349·5	446·5	165·5	94	87	-
LS Biol	-	-	133	92.5	217	287·5	142·5	133·5	304·5	258	146	75.5	65	-
SS	-	-	140·5	129	294	216	186	216	335·5	351	164	113	83	-
LG	-	-	114	88	245	232	103·5	103	272	477	170	72	97	-
SG	-	-	116·5	112	244	266·5	248·5	163·5	236	306	132	96.5	79	-
LS	-	-	136·5	108	269	254	189·5	146·5	249·5	305	194·5	79	72	-
SS Biol	-	-	128	97.5	214·5	348·5	213	190	252	255·5	146	103·5	64	-
LG Biol	-	-	83.5	88	218·5	263·5	111·5	130·5	244·5	371·5	192	111·5	105	-
B50 Biol	-	-	276·5	83.5	144	153·5	121	193·5	409	193	146	111·5	137	-
B90 Biol	-	-	113·5	77.5	154·5	225	233	149	364	229	201	62.5	138	-
FLE2cw	-	-	96.5	77	144	430·5	229	124	245	155	299	137	126	-
FLE1cw	-	-	91.5	77	169·5	290·5	253·5	146·5	259·5	173·5	207·5	126·5	107	-
B50	-	-	166·5	63	121·5	153	217	153	341·5	175·5	149·5	141·5	132	-
B90	-	-	94.5	99	171	254·5	214	158·5	251	209	149	135·5	136	-
FLM2cw	-	-	120·5	77.5	147	216·5	180	169·5	385	163	364	132·5	139	-
FLM1cw	-	-	90	69	175	219·5	223·5	173·5	340·5	182·5	159·5	127	129	-

Appendix 7.D.7. Weekly Averaged Settled Solids Data (mg/l) (29.1.76 - 25.4.76)

	1/2	8/2	15/2	22/2	29/2	7/3	14/3	21/3	28/3	4/4	11/4	18/4	25/4
Feed	298	196	250	276	267.5	196.5	243.5	202.5	109	120	196.5	421	173
SG Biol	89.5	88	90	60	71	55	50.5	61	46	37	50.5	54	86
LS Biol	105	109	177	97	78.5	54	58.5	65.5	50.5	44.5	49	52	120
SS	89.5	103	93.5	92	61	37	46	53.5	47	45.5	46.5	83	101
LG	87	105	109.5	108	84	61	68.5	71	52	50	52.5	62	123
SG	69.5	98	96	102	64	41.5	53	58	42	40.5	41	67	97
LS	67.5	108	99.5	104	81.5	45	59	67.5	53	46.5	62.5	68	97
SS Biol	64.5	92	86	68	74	40.5	54	47	40.5	52	48.5	53	97
LG Biol	77	109	108	72	73.5	55.5	64	51	53	54.5	61.5	63	109
B50 Biol	60	81	89.5	82	55.5	40	69.5	53.5	47.5	38.5	51	51	103
B90 Biol	72.5	85	94	88	66	52.5	58.5	63	42.5	47	51.5	41	130
FLE2cw	50.5	101	107.5	129	95	72	80.5	71.5	49	42	63	54	102
FLE1cw	57.5	83	89	121	88.5	66.5	76.5	71.5	54.5	50	62	55	104
B50	54.5	73	89	78	52	40.5	56	56	47.5	40.5	59	39	130
B90	55.5	76	75.5	87	68	49.5	61.5	60.5	44.5	45	51	43	111
FLM2cw	81.5	77	97.5	98	81.5	62	78	71	52.5	45	65.5	87	91
FLM1cw	61.5	85	90	102	81.5	57.5	70.5	72.5	47	51	61.5	81	105

Appendix 7.D.7. cont. Weekly Averaged Settled Solids Data (2.5.76 - 29.7.76) (mg/l)

	2/5	9/5	16/5	23/5	30/5	6/6	13/6	20/6	27/6	4/7	11/7	18/7	25/7	1/8
Feed	-	-	171.5	223	317	449	198.5	195.5	240	146	216.5	178.5	206	-
SG Biol	-	-	45.5	48.5	81	77	66	64	144	176.5	60.5	29.5	37	-
LS Biol	-	-	53	46.5	68.5	70.5	56.5	61.5	121.5	141.5	64.5	29.5	40	-
SS	-	-	60	58	88.5	80	66.5	75	153.5	149	74	34	37	-
LG	-	-	54.5	46.5	85.5	73	56.5	56.5	127	187	72	32	41	-
SG	-	-	55.5	61	90.5	71.5	86	68	119.5	144.5	69.5	35.5	39	-
LS	-	-	60	64	87	74.5	66	69.5	119	130	77	34	34	-
SS Biol	-	-	53	51.5	62.5	88.5	69.5	60	123	128	74.5	29	35	-
LG Biol	-	-	37.5	55	65	58.5	56	59	111.5	162.5	74.5	32	35	-
B50 Biol	-	-	83	36.5	35	36	35	42	98	44.5	47	39.5	38	-
B90 Biol	-	-	60.5	43	52	51	72	55	106	62.5	46	53.5	51	-
FLE2cw	-	-	43	38	47.5	63	55	50.5	99	48	74	43	54	-
FLE1cw	-	-	42.5	36.5	49	54	89	47.5	85.5	49.5	56	39	31	-
B50	-	-	69	29	31.5	33.5	37.5	39.5	64	43.5	39	41	50	-
B90	-	-	55	45.5	52	61	58	56	82.5	69.5	62	42.5	35	-
FLM2cw	-	-	51	36.5	47.5	48.5	60.5	59.5	112	62	58.5	43	40	-
FLM1cw	-	-	37	35.5	47	50.5	54.5	60.5	106.5	56.5	80	34	45	-

Appendix 7.D.8. Weekly Averaged Ammoniacal Nitrogen Data(mgN/l) (29.1.76 - 25.4.76)

	1/2	8/2	15/2	22/2	29/2	7/3	14/3	21/3	28/3	4/4	11/4	18/4	25/4
Feed	-	9.8	10.4	27.5	10.0	11.2	17.8	17.6	12.0	12.6	12.1	13.8	17.2
SG Biol	-	14.3	6.2	21.8	7.8	11.4	17.4	22.8	12.6	13.4	15.2	18.2	19.8
LS Biol	-	13.7	9.0	22.8	8.2	11.8	17.9	17.4	15.2	13.8	15.2	18.8	22.3
SS	-	14.5	6.8	24.8	8.4	11.8	18.5	17.0	15.3	15.0	17.0	19.3	21.3
LG	-	13.2	6.7	23.8	8.8	12.4	18.0	16.4	15.0	13.8	15.9	19.4	22.0
SG	-	14.4	8.4	24.2	9.2	12.4	18.4	16.4	14.8	14.8	15.9	18.6	22.3
LS	-	13.6	8.2	24.3	9.4	9.4	18.8	17.0	15.4	15.2	14.4	19.1	21.8
SS Biol	-	13.5	7.8	26.8	9.4	11.4	18.0	16.2	15.0	15.2	14.4	19.6	21.7
LG Biol	-	11.9	8.0	22.5	9.0	12.4	17.8	15.8	15.0	14.8	15.8	18.9	16.8
B50 Biol	-	11.4	7.0	17.6	7.8	11.2	18.0	21.4	13.8	15.5	15.4	19.4	18.6
B90 Biol	-	11.2	7.8	23.5	9.2	11.8	19.1	16.3	14.2	15.8	17.4	20.7	22.6
FLE2cw	-	9.4	9.2	24.0	9.0	11.0	17.6	13.6	11.2	11.6	13.2	16.6	17.9
FLE1cw	-	9.3	8.6	23.8	8.6	9.4	16.8	13.2	10.6	11.4	12.2	17.3	18.6
B50	-	12.0	7.6	19.6	8.4	11.4	18.5	15.3	15.2	14.8	16.0	21.4	20.2
B90	-	11.9	7.6	23.8	10.2	11.4	19.0	16.1	14.8	16.2	17.5	20.7	23.2
FLM2cw	-	9.8	6.7	23.5	8.8	10.0	17.4	13.4	11.8	12.6	13.4	19.6	18.0
FLM1cw	-	10.1	7.1	23.5	8.8	9.8	16.9	11.8	11.0	11.8	13.1	20.4	18.4

Appendix 7.D.8. cont. Weekly Averaged Ammoniacal Nitrogen Data (2.5.76 - 29.7.76) (mg N/l)

	2/5	9/5	16/5	23/5	30/5	6/6	13/6	20/6	27/6	4/7	11/7	18/7	25/7
Feed	-	-	12.8	18.4	16.2	12.6	17.6	14.6	16.6	14.1	28.6	15.6	-
SG Biol	-	-	12.0	25.6	18.9	12.9	13.2	15.0	16.4	8.4	15.7	13.4	-
LS Biol	-	-	24.2	25.8	16.7	13.4	16.6	16.6	15.9	11.8	18.0	16.2	-
SS	-	-	10.8	27.5	19.1	14.1	16.4	17.8	17.4	11.8	18.0	16.6	-
LG	-	-	12.1	23.2	16.8	11.7	15.2	16.6	15.6	11.0	16.6	16.4	-
SG	-	-	14.3	26.1	18.8	14.2	16.4	17.6	16.7	11.4	17.8	17.5	-
LS	-	-	13.8	26.4	19.2	13.6	16.4	17.8	16.5	12.4	16.7	17.3	-
SS Biol	-	-	13.4	25.3	18.7	11.8	16.0	17.4	17.0	12.2	16.5	17.0	-
LG Biol	-	-	13.4	25.3	18.7	12.4	15.8	16.8	15.2	11.2	17.6	17.0	-
B50 Biol	-	-	11.7	23.9	21.2	12.2	16.0	15.6	17.5	14.0	14.3	10.6	-
B90 Biol	-	-	27.0	24.2	21.6	14.7	18.4	17.1	17.2	15.2	16.6	14.3	-
FLE2cw	-	-	11.3	21.4	18.7	12.4	13.9	14.6	15.2	11.0	17.8	13.1	-
FLE1cw	-	-	12.6	20.4	18.4	12.2	12.6	14.0	14.8	15.2	16.6	11.6	-
B50	-	-	13.5	24.9	20.7	10.3	19.4	14.0	17.0	14.9	19.2	12.0	-
B90	-	-	15.6	25.2	20.6	15.8	17.6	17.6	18.9	15.1	18.7	15.0	-
FLM2cw	-	-	13.1	21.7	19.2	12.6	16.8	15.6	15.9	13.6	18.0	15.0	-
FLM1cw	-	-	13.3	22.8	19.5	13.7	17.2	15.4	15.1	13.4	17.0	13.7	-

Appendix 7.D.9. Weekly Averaged Oxidised Nitrogen Data(mgN/l) (29.1.76 - 25.4.76)

	1/2	8/2	15/2	22/2	29/2	7/3	14/3	21/3	28/3	4/4	11/4	18/4	25/4
Feed	-	< 0.5	-	< 0.5	-	-	-	2.4	-	-	-	-	< 0.1
SG Biol	-	< 0.5	-	< 0.5	-	-	-	< 0.1	-	-	-	-	< 0.1
LS Biol	-	< 0.5	-	< 0.5	-	-	-	< 0.1	-	-	-	-	< 0.1
SS	-	< 0.5	-	< 0.5	-	-	-	< 0.1	-	-	-	-	< 0.1
LG	-	< 0.5	-	< 0.5	-	-	-	< 0.1	-	-	-	-	< 0.1
SG	-	< 0.5	-	< 0.5	-	-	-	< 0.1	-	-	-	-	< 0.1
LS	-	< 0.5	-	< 0.5	-	-	-	< 0.1	-	-	-	-	< 0.1
SS Biol	-	< 0.5	-	< 0.5	-	-	-	< 0.1	-	-	-	-	< 0.1
LG Biol	-	< 0.5	-	< 0.5	-	-	-	< 0.1	-	-	-	-	< 0.1
B50 Biol	-	< 0.5	-	< 0.5	-	-	-	< 0.1	-	-	-	-	< 0.1
B90 Biol	-	< 0.5	-	< 0.5	-	-	-	< 0.1	-	-	-	-	< 0.1
FLE2cw	-	< 0.5	-	< 0.5	-	-	-	< 0.5	-	-	-	-	< 0.1
FLE1cw	-	< 0.5	-	< 0.5	-	-	-	< 0.5	-	-	-	-	< 0.1
B50	-	< 0.5	-	< 0.5	-	-	-	< 0.1	-	-	-	-	< 0.1
B90	-	< 0.5	-	< 0.5	-	-	-	< 0.1	-	-	-	-	< 0.1
FLM2cw	-	< 0.5	-	< 0.5	-	-	-	< 0.5	-	-	-	-	< 0.1
FLM1cw	-	< 0.5	-	< 0.5	-	-	-	< 0.5	-	-	-	-	< 0.1

Appendix 7.D.9. cont. Weekly Averaged Oxidised Nitrogen Data (mgN/l) (2.5.76 - 29.7.76)

	2/5	9/5	16/5	23/5	30/5	6/6	13/6	20/6	27/6	4/7	11/7	18/7	25/7
Feed	-	-	-	< 0.1	-	-	-	-	< 0.1	-	0	0	-
SG Biol	-	-	-	< 0.1	-	-	-	-	< 0.1	-	0.3	0	-
LS Biol	-	-	-	< 0.1	-	-	-	-	< 0.1	-	0.3	0	-
SS	-	-	-	< 0.1	-	-	-	-	< 0.1	-	0.3	0	-
LG	-	-	-	< 0.1	-	-	-	-	< 0.1	-	0.3	0	-
SG	-	-	-	< 0.1	-	-	-	-	< 0.1	-	0.3	0	-
LS	-	-	-	< 0.1	-	-	-	-	< 0.1	-	0.3	0	-
SS Biol	-	-	-	< 0.1	-	-	-	-	< 0.1	-	0.3	0	-
LG Biol	-	-	-	< 0.1	-	-	-	-	< 0.1	-	0.3	0	-
B50 Biol	-	-	-	< 0.1	-	-	-	-	< 0.1	-	0.3	0	-
B90 Biol	-	-	-	< 0.1	-	-	-	-	< 0.1	-	0	0	-
FLE2cw	-	-	-	< 0.1	-	-	-	-	< 0.1	-	0	0	-
FLE1cw	-	-	-	< 0.1	-	-	-	-	< 0.1	-	0	0	-
B50	-	-	-	< 0.1	-	-	-	-	< 0.1	-	0.4	0	-
B90	-	-	-	< 0.1	-	-	-	-	< 0.1	-	0	0	-
FLM2cw	-	-	-	< 0.1	-	-	-	-	< 0.1	-	0	0	-
FLM1cw	-	-	-	< 0.1	-	-	-	-	< 0.1	-	0	0	-

Weekly Meaned Daily Flow Data

29/July, 1976 - 17/July, 1977 ($m^3/m^3/d$)

Appendix 7.E.1.

Date W/E	Trough 1	Trough 2	Mean	Trough 1	Trough 2	Mean	Flocor M
8/8	2.03	2.06	2.05	5.12	5.10	5.11	5.68
15/8	1.58	1.68	1.63	4.24	4.17	4.21	4.68
22/8	2.17	2.29	2.23	4.57	4.76	4.67	5.19
29/8	2.65	2.78	2.72	5.37	5.63	5.50	6.11
5/9	2.75	2.84	2.80	5.84	6.17	6.01	6.68
12/9	2.63	2.73	2.68	4.76	5.12	4.94	5.49
19/9	2.74	2.71	2.73	4.66	4.93	4.80	5.33
26/9	2.85	2.88	2.86	5.09	5.46	5.28	5.87
3/10	2.64	2.67	2.66	4.14	5.00	4.57	5.08
10/10	2.99	3.12	3.06	4.83	5.78	5.31	5.90
17/10	2.89	2.93	2.91	5.06	5.86	5.46	6.07
24/10	2.87	2.95	2.91	4.68	5.37	5.03	5.59
31/10	2.99	2.93	2.96	4.95	5.65	5.30	5.89
7/11	2.77	2.92	2.85	4.87	5.21	5.04	5.60
14/11	-	2.65	2.65	-	4.82	4.82	5.36
21/11	-	3.01	3.01	-	5.97	5.97	6.63
28/11	2.73	-	2.73	-	5.95	5.95	6.61
5/12	2.87	-	2.87	-	5.40	5.40	6.00
12/12	3.08	-	3.08	-	5.23	5.23	5.81
19/12	2.79	-	2.79	-	5.21	5.21	5.79
26/12	2.04	-	2.04	-	5.20	5.20	5.78
2/1	1.97	-	1.97	-	4.98	4.98	5.53
9/1	2.80	-	2.80	-	4.98	4.98	5.53
16/1	2.87	-	2.87	-	4.57	4.57	5.08
23/1	3.19	-	3.19	-	5.38	5.38	5.98
30/1	3.17	-	3.17	6.17	-	6.17	6.86
6/2	2.76	-	2.76	6.20	-	6.20	6.89
13/2	2.99	-	2.99	5.90		5.90	6.56
20/2	2.17	-	2.17	2.90	3.33	3.12	3.47
27/2	-	-	-	-	-	-	-
6/3	1.16	-	1.16	3.37	2.71	3.04	3.38
13/3	2.69	2.16	2.43	4.51	3.81	4.16	4.62
20/3	2.44	-	2.44	4.32	3.70	4.01	4.46
27/3	2.33	-	2.33	4.44	3.93	4.19	4.66

Weekly Meaned Daily Flow Data

29/July, 1976 - 17/July, 1977 ($m^3/m^3/d$)

Appendix 7.E.1.

Date W/E	Trough 1	Trough 2	Mean	Trough 1	Trough 2	Mean	Flocor M
3/4	1.49	-	1.49	2.54	2.25	2.40	2.67
10/4	0.41	-	0.41	0.68	0.58	0.63	0.70
17/4	-	-	-	-	-	-	-
24/4	3.33	2.93	3.13	4.98	4.19	4.59	5.10
1/5	2.82	3.70	3.26	5.61	5.17	5.39	5.99
8/5	3.12	3.45	3.29	5.39	5.17	5.28	5.87
15/5	3.58	3.45	3.52	4.82	4.76	4.79	5.32
22/5	3.28	3.53	3.40	6.32	6.08	6.20	6.89
29/5	3.23	3.34	3.29	-	5.13	5.13	5.70
5/6	-	3.64	3.64	4.36	4.30	4.33	4.81
12/6	2.24	2.39	2.32	-	3.41	3.41	3.79
19/6	3.63	-	3.63	-	6.00	6.00	6.67
26/6	3.72	3.79	3.76	5.52	5.97	5.75	6.39
3/7	3.21	3.24	3.23	5.40	5.25	5.33	5.92
10/7	-	3.21	3.21	5.40	5.42	5.41	6.01
17/7	-	3.23	3.23	6.14	5.85	6.00	6.67
$\bar{x}$	2.67	2.94	2.74	4.80	4.86	4.92	5.48
SD	0.65	0.50	0.65	1.13	1.10	1.05	1.17

Appendix 7.E.2. Weekly Meaned Maximum and Minimum Temperatures (°C) (29.7.76 - 13.2.76)

	8/8	15/8	22/8	29/8	5/9	12/9	19/9	26/9	3/10	10/10	17/10	24/10	31/10	7/11
Feed Max.	22.5	22.7	24.3	22.9	21.6	21.7	20.9	20.9	19.5	19.5	18.3	18.0	17.6	17.3
Min.	21.7	21.9	23.4	21.5	20.4	20.9	20.0	18.9	17.7	17.9	16.8	16.7	16.6	16.2
FLM Max.	22.5	22.7	24.3	23.0	21.3	20.9	20.5	20.3	19.0	18.7	17.6	17.4	16.8	16.3
2cw Min.	21.1	21.6	23.2	21.1	19.7	17.8	18.0	18.3	16.9	17.0	15.9	16.0	15.5	15.0
SS Max.	22.1	22.0	24.1	22.3	20.8	20.8	20.5	19.9	18.7	18.8	17.4	18.1	16.9	16.5
Biol Min.	20.2	21.2	22.5	20.7	19.3	18.5	18.0	18.1	16.9	17.2	15.5	16.3	15.8	15.0

	14/11	21/11	28/11	5/12	12/12	19/12	26/12	2/1	9/1	16/1	23/1	30/1	6/2	13/2
Feed Max.	17.2	17.2	17.0	15.5	14.1	14.5	13.2	10.6	13.1	12.4	12.6	12.0	12.4	12.4
Min.	16.5	15.9	16.0	13.8	12.5	13.2	12.1	9.9	12.1	11.3	11.7	10.9	11.3	11.3
FLM Max.	16.5	16.7	16.1	14.3	13.2	13.5	12.2	9.4	12.3	11.3	11.6	11.1	11.5	11.5
2cw Min.	15.3	15.0	15.2	12.8	11.6	12.3	11.1	8.6	11.0	10.2	10.5	9.8	10.4	10.4
SS Max.	16.1	16.2	16.1	13.3	12.8	13.2	12.1	8.8	11.8	11.3	11.3	10.8	10.9	11.4
Biol Min.	14.4	13.5	14.6	11.8	11.1	12.1	10.9	8.0	10.6	10.2	10.5	9.9	10.1	10.4

Appendix 7.E.2. cont. Weekly Meaned Maximum and Minimum Temperatures (°C) (20.2.76 - 17.7.76)

	20/2	27/2	6/3	13/3	20/3	27/3	3/4	10/4	17/4	24/4	1/5	8/5	15/5	22/5
Feed Max.	-	-	-	-	13.5	13.7	-	-	-	15.1	15.3	15.3	15.9	16.6
Min.	-	-	-	-	12.2	12.7	-	-	-	13.9	14.1	14.0	14.9	15.5
FLM Max.	9.5	7.3	10.3	12.6	12.1	12.9	10.1	11.1	9.0	13.8	14.8	15.0	15.5	15.9
2cw Min.	8.0	6.0	7.8	10.7	10.0	10.7	8.0	8.2	5.6	10.7	13.1	13.2	14.3	14.7
SS Max.	10.1	7.0	9.8	12.5	11.6	12.4	10.5	10.7	7.8	13.8	14.4	14.7	15.2	16.2
Biol Min.	8.7	6.0	7.3	11.0	9.4	10.2	8.4	8.1	6.0	11.5	12.9	13.1	14.0	14.8

	29/5	5/6	12/6	19/6	26/6	3/7	10/7	17/7	$\bar{x}$	S.D.
Feed Max.	17.3	17.8	16.0	16.4	17.7	18.4	19.7	19.4	16.98	3.41
Min.	16.0	16.5	14.8	15.6	16.6	17.5	18.8	18.7	15.83	3.41
FLM Max.	16.8	17.4	15.5	15.9	17.3	18.1	19.2	18.6	16.31	3.67
2cw Min.	15.2	15.7	13.9	14.8	15.9	16.8	18.1	17.6	14.79	3.60
SS Max.	17.0	17.5	15.3	15.6	17.4	18.1	19.5	19.3	16.12	3.73
Biol Min.	14.9	15.2	13.6	14.7	16.0	16.8	18.4	18.0	14.58	3.60

Appendix 7.E.3 Weekly Meaned Comparative Daily Bed Temperatures at Midday (°C) 29/7/76-7/11/76

W/E	8/8	15/8	22/8	29/8	5/9	12/9	19/9	26/9	3/10	10/10	17/10	24/10	31/10	7/11
SG biol	21.6	21.4	22.7	23.4	20.8	20.3	19.0	20.0	17.5	17.5	16.0	16.1	16.3	15.4
LS biol	20.7	21.1	22.2	24.8	19.7	20.0	19.0	20.1	17.9	17.8	16.6	16.8	16.6	15.8
SS	21.3	21.7	22.5	23.3	20.9	20.5	19.2	20.6	18.3	18.6	16.5	16.8	17.1	15.8
LG	19.2	21.1	21.7	22.6	18.8	18.3	17.9	20.3	17.8	17.8	15.8	16.7	16.6	15.3
SG	20.7	22.0	22.8	25.0	21.0	19.6	19.6	20.4	19.1	18.0	16.4	16.6	17.1	16.6
LS	21.6	21.7	24.0	24.9	21.2	21.5	20.0	20.5	17.6	18.2	16.4	16.5	17.4	15.9
SS biol	21.6	21.5	22.9	23.3	20.7	20.9	19.4	20.3	17.6	18.1	16.0	16.4	16.4	15.8
LG biol	21.5	21.9	23.2	23.4	21.9	20.7	19.2	19.9	17.5	17.9	15.8	16.3	16.8	15.4
B50 biol	21.5	22.0	23.1	23.9	21.2	20.7	19.4	20.2	17.4	17.8	16.3	17.0	17.1	16.0
B90 biol	20.3	21.8	22.5	23.3	20.6	19.4	18.4	21.2	17.2	18.0	15.6	17.0	16.3	14.9
FLE 2cw	19.9	21.2	22.7	21.6	19.9	18.8	18.2	20.6	17.9	17.5	15.1	15.8	14.6	15.1
FLE 1cw	20.9	22.1	23.3	23.6	21.1	18.8	19.3	20.2	17.4	17.4	16.4	16.7	15.4	15.6
B50	21.8	22.1	23.2	24.0	21.2	21.1	20.0	20.5	17.6	18.3	16.6	17.2	16.8	16.4
B90	22.0	22.0	22.7	22.8	21.0	19.7	19.1	19.7	17.5	17.4	16.3	16.7	16.1	15.4
FLM 2cw	21.9	22.5	23.5	24.3	21.5	21.0	19.4	20.3	17.9	18.3	16.5	17.0	16.5	15.9
FLM 1cw	21.0	22.3	23.3	24.1	21.2	20.0	19.3	20.2	17.8	17.8	16.2	17.0	16.3	15.4

Appendix 7.E.3 (cont) Weekly Meaned Comparative Daily Bed Temperature at Midday (°C) 14/11/76-6/2/77

W/E	14/11	21/11	28/11	5/12	12/12	19/12	26/12	2/1	9/1	16/1	23/1	30/1	6/2
SG biol	15.7	14.7	15.8	12.9	11.2	13.3	12.0	-	11.1	11.0	11.1	-	-
LS biol	16.3	13.2	14.6	11.7	11.0	13.1	11.8	-	10.9	10.7	11.2	-	-
SS	16.3	15.7	16.1	13.5	11.4	13.6	12.2	-	11.5	11.4	11.7	-	-
LG	16.0	13.8	13.7	11.3	10.6	13.4	11.3	-	10.6	10.7	11.3	-	-
SG	16.6	15.3	15.4	12.7	11.1	13.6	11.6	-	10.9	11.0	11.1	-	-
LS	16.6	14.7	15.2	12.4	11.1	13.4	11.7	-	10.8	10.9	10.9	-	-
SS biol	15.9	15.0	16.0	12.9	11.1	13.4	12.0	-	11.0	11.0	11.0	-	-
LG biol	15.7	14.0	16.0	12.9	11.1	13.3	12.1	-	11.1	10.8	10.9	-	-
B50 biol	17.0	16.2	16.0	13.3	11.7	13.8	12.3	-	11.3	11.6	11.4	-	-
B90 biol	15.0	15.7	15.3	12.7	10.7	13.3	12.1	-	10.8	10.2	11.1	-	-
FLW 2cw	15.2	14.1	14.0	11.8	9.6	11.4	11.0	-	9.7	8.6	9.8	-	-
FLE 1cw	16.2	15.6	15.5	13.4	11.4	13.6	12.2	-	10.8	10.5	10.9	-	-
B50	16.7	16.3	16.6	13.5	11.7	13.9	13.0	-	11.5	11.8	11.8	-	-
B90	15.2	15.8	16.6	13.8	11.9	13.8	12.6	-	11.3	11.0	11.2	-	-
FLM 2cw	15.6	15.8	16.3	13.5	11.9	13.7	12.2	-	11.4	11.2	11.3	-	-
FLM 1cw	15.3	15.7	15.6	13.2	11.5	13.6	12.2	-	10.7	10.4	10.9	-	-

Appendix 7.E.3. (cont) Weekly Meaned Comparative Daily Bed Temperatures at Midday (°C) 13/2/77-15/5/77

W/E	13/2	20/2	27/2	6/3	13/3	20/3	27/3	3/4	10/4	17/4	24/4	1/5	8/5	15/5
SG biol	-	11.4	-	11.2	12.4	11.7	11.7	10.1	7.9	5.5	10.7	13.7	14.1	14.8
LS biol	-	11.3	-	11.1	12.1	11.5	11.6	9.9	8.9	7.1	10.7	13.4	13.8	14.7
SS	-	11.5	-	11.1	12.5	11.6	12.0	11.0	9.8	9.2	10.9	13.6	14.0	15.0
LG	-	11.5	-	10.4	11.9	10.9	11.7	10.7	9.3	8.6	10.9	13.0	13.5	14.6
SG	-	11.4	-	11.3	11.7	10.5	11.9	9.9	8.1	7.7	10.4	12.7	13.7	14.5
LS	-	11.2	-	11.0	11.6	10.6	12.1	9.5	8.1	7.0	10.2	13.5	13.9	14.6
SS biol	-	11.3	-	11.0	12.0	11.3	12.1	9.7	7.2	4.9	10.2	13.6	14.0	14.6
LG biol	-	11.3	-	11.0	12.2	11.6	11.9	9.9	7.6	4.8	10.4	13.8	14.1	14.8
B50 biol	-	11.8	-	11.3	12.6	12.1	12.4	10.0	7.2	4.6	10.2	12.0	13.9	14.8
B90 biol	-	11.8	-	10.6	12.2	11.4	12.3	9.7	6.6	4.5	10.2	10.7	12.5	13.2
FLE 2cw	-	11.0	-	10.9	11.9	11.9	11.7	9.0	6.8	3.6	10.1	11.9	13.8	13.8
FLE 1cw	-	11.4	-	11.7	12.1	11.9	12.6	10.1	7.5	4.0	10.3	13.0	14.4	14.4
B50	-	11.6	-	11.3	12.4	12.0	12.2	9.8	8.0	4.1	10.0	13.0	14.2	14.2
B90	-	12.0	-	11.8	12.6	12.3	12.1	9.4	7.7	4.7	10.1	13.9	14.9	14.9
FLM 2cw	-	11.5	-	11.8	12.8	12.4	12.5	10.1	8.2	5.5	10.9	14.0	14.7	15.0
FLM 1cw	-	11.3	-	11.5	12.2	11.9	12.5	9.7	7.6	4.5	11.0	12.4	14.0	14.0

Appendix 7.E.3 (cont) Weekly Meaned Comparative Daily Bed Temperatures at Midday (°C) 22/5/77-17/7/77

W/E	22/5	29/5	5/6	12/6	19/6	26/6	3/7	10/7	17/7	$\bar{x}$	SD
SG biol	15.2	15.5	16.5	13.6	15.1	16.3	17.2	18.8	18.0	15.07	3.95
LS biol	14.4	15.3	16.2	13.1	15.0	16.1	17.1	18.7	17.9	14.97	3.90
SS	15.3	15.4	16.8	13.8	15.1	16.3	17.2	18.7	18.4	15.46	3.69
LG	14.9	15.4	16.6	13.9	14.9	16.2	16.8	18.7	18.0	14.78	3.57
SG	15.1	15.4	16.6	14.3	14.8	16.2	16.9	18.8	18.2	15.21	4.06
LS	15.2	15.6	16.6	14.0	15.2	16.2	17.0	18.7	18.0	15.22	4.23
SS biol	15.3	15.7	16.8	14.1	15.3	16.3	17.2	18.7	18.1	15.10	3.89
LG biol	15.2	15.6	16.6	13.8	15.3	16.3	17.2	18.8	17.9	15.10	4.14
B50 biol	15.5	15.8	16.7	14.2	15.1	16.6	17.2	18.9	18.3	15.32	4.13
B90 biol	15.0	15.5	15.4	13.8	15.0	16.5	16.2	18.9	18.0	14.74	4.15
FLE 2cw	14.5	14.6	14.6	13.3	14.7	16.3	16.8	18.7	17.0	14.24	4.16
FLE 1cw	15.6	16.0	16.8	14.5	15.3	16.5	17.3	18.8	18.3	15.13	4.09
B50	15.4	15.9	16.6	14.3	15.3	16.7	17.6	19.0	18.4	15.46	4.18
B90	15.0	15.6	16.0	13.8	14.9	16.2	17.6	18.8	18.0	15.20	3.95
FLM 2cw	15.7	15.9	16.8	14.5	15.4	16.6	17.5	18.8	18.0	15.51	4.06
FLM 1cw	15.7	16.0	16.6	14.6	15.4	16.6	17.3	18.8	18.2	15.17	4.15

Appendix 7.E.4. Weekly Averaged BOD Data (mg/l) (29.7.76 - 7.11.76)

	8/8	15/8	22/8	29/8	5/9	12/9	19/9	26/9	3/10	10/10	17/10	24/10	31/10	7/11
Feed	-	375	416.5	377.5	530	461.5	349	413	198	276.5	196	225	-	390.5
SG Biol	-	26	169	135	218	141	71	95	25	35	11	6	-	36
LS Biol	-	40	128	106	208	139	77	85	17	30	15	-	-	46
SS	-	25	108	106	194	119	74	62	27	27	9	6	-	43
LG	-	27	147	131	226	146	97	93	21	46	17	1	-	65
SG	-	21	129	90	158	116	53	64	17	34	91	2	-	44
LS	-	16	138	89	171	122	56	69	16	35	11	5	-	52
SS Biol	-	15	106	117	185	101	71	71	27	25	8	4	-	48
LG Biol	-	27	142	128	214	161	91	101	29	47	14	5	-	63
B50 Biol	-	12	41	30	129	59	44	68	17	27	15	10	-	39
B90 Biol	-	38	75	45	162	70	65	81	16	28	21	-	-	51
FLE2cw	-	40	75	49	228	109	76	80	27	36	28	13	-	87
FLE1cw	-	27	83	48	222	110	75	89	22	38	32	10	-	77
B50	-	28	40	28	100	46	35	59	27	26	19	11	-	44
B90	-	36	65	51	160	72	50	60	15	26	18	5	-	59
FLM2cw	-	42	75	64	201	108	77	95	23	37	21	3	-	73
FLM1cw	-	41	86	55	204	101	67	72	26	34	21	14	-	75

Appendix 7.E.4. cont. Weekly Averaged BOD Data (mg/l) (14.11.76 - 6.2.77)

	14/11	21/11	28/11	5/12	12/12	19/12	26/12	2/1	9/1	16/1	23/1	30/1	6/2
Feed	508·5	484	401·5	261·5	261	427	-	-	319·5	341·5	230	-	-
SG Biol	80	102	123	34	40	126	-	-	27	53	31	-	-
LS Biol	96	128	113	33	38	132	-	-	28	43	27	-	-
SS	87	102	113	35	44	132	-	-	37	48	46	-	-
LG	116	167	155	43	53	140	-	-	44	52	36	-	-
SG	81	118	133	39	40	121	-	-	32	50	41	-	-
LS	89	140	141	36	39	135	-	-	31	45	40	-	-
SS Biol	89	123	112	32	39	124	-	-	46	45	34	-	-
LG Biol	111	155	148	40	50	140	-	-	41	48	30	-	-
B50 Biol	61	69	98	29	13	87	-	-	35	55	36	-	-
B90 Biol	74	83	104	20	12	102	-	-	32	54	45	-	-
FLE2cw	91	112	149	33	23	114	-	-	34	44	29	-	-
FLE1cw	91	119	148	38	36	108	-	-	36	39	23	-	-
B50	78	45	66	22	9	82	-	-	30	55	25	-	-
B90	109	72	111	25	14	100	-	-	35	51	35	-	-
FLM2cw	96	122	160	51	36	126	-	-	51	47	38	-	-
FLM1cw	95	108	159	48	39	130	-	-	49	43	33	-	-

Appendix 7.E.4. cont. Weekly Averaged BOD Data (mg/l) (13.2.77 - 15.5.77)

	13/2	20/2	27/2	6/3	13/3	20/3	27/3	3/4	10/4	17/4	24/4	1/5	8/5	15/5
Feed	349	-	-	424	>2300	364	417·5	312·5	-	-	342·5	367·5	392·5	-
SG Biol	25	-	-	182	112	53	53	29	-	-	93	24	27	-
LS Biol	26	-	-	183	140	53	50	37	-	-	125	38	42	-
SS	23	-	-	164	136	42	46	31	-	-	82	28	39	-
LG	39	-	-	158	172	68	70	47	-	-	156	66	105	-
SG	23	-	-	140	114	54	50	34	-	-	98	27	35	-
LS	26	-	-	167	130	57	49	37	-	-	125	47	50	-
SS Biol	26	-	-	177	200	57	45	37	-	-	83	23	33	-
LG Biol	34	-	-	140	128	71	66	45	-	-	126	56	84	-
B50 Biol	41	-	-	170	136	54	40	71	-	-	110	28	53	-
B90 Biol	37	-	-	147	136	69	56	70	-	-	113	48	52	-
FLE2cw	30	-	-	132	166	71	81	34	-	-	98	44	62	-
FLW1cw	44	-	-	132	168	64	60	49	-	-	100	41	61	-
B50	44	-	-	173	124	42	40	35	-	-	76	33	31	-
B90	42	-	-	163	150	73	63	50	-	-	91	23	32	-
FLM2cw	42	-	-	144	172	77	65	45	-	-	98	43	64	-
FLM1cw	48	-	-	132	177	82	59	61	-	-	96	44	61	-

Appendix 7.E.4. cont. Weekly Averaged BOD data (mg/l) (22/5/77 - 17.7.77)

	22/5	29/5	5/6	12/6	19/6	26/6	3/7	10/7	17/7	$\bar{x}$	S.D.
Feed	-	249	402.5	-	319.5	316.5	332.5	320	329	352.5	82.3
SG Biol	-	23	68	-	35	37	33	45	47	66.8	52.2
LS Biol	-	21	71	-	26	38	34	44	48	69.6	50.2
SS	-	19	54	-	25	30	27	37	38	61.2	45.5
LG	-	26	101	-	53	67	65	69	68	85.2	53.5
SG	-	22	73	-	35	44	38	54	52	64.0	40.5
LS	-	21	84	-	45	53	44	50	53	67.9	46.6
SS Biol	-	21	62	-	26	38	33	44	40	64.0	49.7
LG Biol	-	30	102	-	50	41	59	75	69	80.0	49.6
B50 Biol	-	20	36	-	30	33	23	18	33	50.5	37.2
B90 Biol	-	22	61	-	26	42	26	31	42	59.9	37.1
FLW2cw	-	30	87	-	29	48	40	57	60	68.8	46.2
FLE1cw	-	20	87	-	29	39	34	58	59	68.0	46.0
B50	-	16	46	-	28	24	19	19	30	44.7	33.0
B90	-	26	67	-	24	35	22	31	41	56.8	40.2
FLM2cw	-	35	118	-	38	42	31	74	83	73.4	45.3
FLM1cw	-	37	115	-	38	40	29	73	83	72.3	44.4

Appendix 7.E.5. Weekly Averaged COD Data (mg/l) (29.7.76 - 7.11.76)

	8/8	15/8	22/8	29/8	5/9	12/9	19/9	26/9	3/10	10/10	17/10	24/10	31/10	7/11
Feed	252	446	505	513	720	500	470	557	1110	379	269	312	-	418
SG Biol	94	100	285	267	318	237	172	188	109	128	71	62	-	160
LS Biol	82	76	223	234	300	223	181	195	91	125	68	84	-	170
SS	62	50	195	226	264	196	164	165	84	111	63	62	-	164
LG	106	112	253	253	322	247	210	198	81	141	86	94	-	213
SG	50	78	248	223	260	224	151	163	87	114	73	80	-	177
LS	82	64	267	223	258	206	151	172	82	129	80	72	-	197
SS Biol	84	48	215	216	254	198	163	160	79	115	64	66	-	176
LG Biol	98	54	248	227	292	246	209	209	85	127	65	84	-	199
B50 Biol	68	48	137	148	214	150	127	144	65	104	79	68	-	124
B90 Biol	82	82	202	170	236	170	169	191	71	107	74	62	-	183
FLE2cw	74	68	207	163	298	193	166	179	60	113	97	76	-	197
FLE1cw	102	60	188	153	248	184	151	179	62	118	80	80	-	181
B50	70	52	139	147	196	140	101	134	70	97	66	62	-	122
B90	86	60	189	151	220	154	148	175	68	99	65	66	-	179
FLM2cw	78	58	191	173	246	184	171	192	74	151	76	62	-	180
FLM1cw	78	100	191	152	232	182	161	171	70	127	81	70	-	181

Appendix 7.E.5. cont. Weekly Averaged COD Data (mg/l) (14.11.76 - 6.2.77)

	14/11	21/11	28/11	5/12	12/12	19/12	26/12	2/1	9/1	16/1	23/1	30/1	6/2
Feed	563	536	675	361	319	562	312	-	356	281	322	-	-
SG Biol	165	204	223	106	124	196	82	-	84	120	94	-	-
LS Biol	191	217	232	115	110	202	76	-	76	102	94	-	-
SS	172	202	223	105	115	205	92	-	87	132	107	-	-
LG	199	252	262	127	143	216	96	-	91	126	101	-	-
SG	174	212	238	110	123	186	84	-	85	108	95	-	-
LS	168	218	257	104	113	208	74	-	76	111	102	-	-
SS Biol	169	193	208	105	109	184	86	-	86	119	99	-	-
LG Biol	201	231	241	118	137	208	90	-	93	120	98	-	-
B50 Biol	141	147	195	110	87	140	64	-	71	122	99	-	-
B90 Biol	159	163	203	93	88	168	70	-	72	112	97	-	-
FLE2cw	153	187	248	104	110	201	96	-	91	113	102	-	-
FLE1cw	169	206	224	106	112	179	68	-	78	105	99	-	-
B50	201	115	171	85	91	144	64	-	77	113	97	-	-
B90	173	158	193	94	100	162	78	-	73	106	100	-	-
FLM2cw	165	162	246	129	122	191	88	-	82	116	101	-	-
FLM1cw	153	186	229	182	121	191	86	-	87	113	98	-	-

Appendix 7.E.5. cont. Weekly Averaged COD Data (mg/l) (13.2.77 - 15.5.77)

	13/2	20/2	27/2	6/3	13/3	20/3	27/3	3/4	10/4	17/4	24/4	1/5	8/5	15/5
Feed	218	-	-	400	600	405	331	396	-	-	426	375	386	-
SG Biol	66	-	-	392	308	247	106	86	-	-	194	102	116	-
LS Biol	60	-	-	410	326	221	124	98	-	-	216	111	137	-
SS	72	-	-	388	318	199	123	88	-	-	178	102	109	-
LG	70	-	-	336	322	208	159	104	-	-	232	157	196	-
SG	74	-	-	326	268	212	119	90	-	-	182	108	118	-
LS	84	-	-	340	280	214	119	92	-	-	190	128	137	-
SS Biol	68	-	-	394	364	203	124	114	-	-	182	95	106	-
LG Biol	60	-	-	324	312	222	135	100	-	-	204	134	168	-
B50 Biol	70	-	-	432	246	192	119	198	-	-	198	146	140	-
B90 Biol	144	-	-	360	222	210	140	188	-	-	204	130	138	-
FLE2cw	78	-	-	288	278	200	138	110	-	-	206	115	142	-
FLE1cw	72	-	-	286	254	181	120	104	-	-	198	113	139	-
B50	66	-	-	502	230	183	105	118	-	-	170	94	123	-
B90	80	-	-	424	252	211	126	148	-	-	212	98	119	-
FLM2cw	86	-	-	318	266	196	117	126	-	-	164	114	134	-
FLM1cw	78	-	-	292	234	193	102	126	-	-	178	112	125	-

Appendix 7.E.5. Weekly Averaged COD Data (mg/l) (22.5.77 - 17.7.77)

	22/5	29/5	5/6	12/6	19/6	26/6	3/7	10/7	17/7	$\bar{x}$	S D
Feed	-	338	420	-	396	458	334	388	396	436	157.7
SG Biol	-	88	172	-	96	138	96	147	145	156.1	79.1
LS Biol	-	103	189	-	93	141	94	149	149	156.1	78.4
SS	-	81	168	-	89	128	88	139	141	145.1	72.9
LG	-	128	252	-	123	185	147	183	186	177.4	71.9
SG	-	98	180	-	98	143	108	156	159	148.3	65.9
LS	-	110	195	-	103	153	115	162	168	153.9	68.4
SS Biol	-	88	171	-	86	127	100	143	147	146.4	75.1
LG Biol	-	117	226	-	116	177	135	176	181	165.8	71.1
B50 Biol	-	81	182	-	82	112	75	109	90	131.4	68.9
B90 Biol	-	100	183	-	95	120	80	120	139	143.5	61.1
FLE2cw	-	98	190	-	80	124	85	147	147	144.2	59.5
FLE1cw	-	97	186	-	84	128	85	149	141	140.2	57.4
B50	-	77	177	-	80	111	76	107	86	124.6	75.9
B90	-	92	193	-	86	121	75	115	136	138.1	69.1
FLM2cw	-	100	203	-	77	135	102	138	160	145.5	60.0
FLM1cw	-	95	197	-	80	124	94	139	157	142.8	54.3

Appendix 7.E.6 Weekly Averaged Shaken Solids (29/7/76-7/11/76) (mg/l)

	8/8	15/8	22/8	29/8	5/9	12/9	19/9	26/9	3/10	10/10	17/10	24/10	31/10	7/11
Feed	86	150	163.5	183.5	228	342	166	192	180.5	177.5	160	168	-	243.5
SG biol	115	107	135	118	212	146	166	139	199	135	85	70	-	363
LS biol	147	116	113	144	293	127	149	108	187	132	85	96	-	262
SS	84	159	105	171	231	118	127	160	153	130	83	82	-	314
LG	101	146	111	166	284	134	161	145	112	182	106	225	-	169
SG	60	147	104	127	282	137	125	86	132	129	98	93	-	392
LS	65	118	139	180	273	135	115	97	109	220	102	153	-	280
SS biol	63	141	119	201	224	110	178	104	150	146	76	72	-	187
LG biol	115	123	139	141	224	214	166	148	121	130	86	129	-	216
B50 biol	94	91	120	139	151	104	109	132	174	205	92	97	-	164
B90 biol	66	87	149	163	140	147	162	157	94	156	101	82	-	225
FLE 2cw	157	112	155	136	124	181	179	120	110	146	109	175	-	242
FLE 1cw	255	80	146	149	159	157	170	210	140	191	114	155	-	335
B50	126	101	132	126	115	105	157	117	160	218	108	79	-	197
B90	94	85	117	171	166	113	179	167	130	121	93	71	-	308
FLM 2cw	99	82	144	149	157	119	211	135	158	171	104	81	-	186
FLM 1cw	99	80	142	179	182	135	180	123	143	177	94	141	-	286

Appendix 7.E.6 (cont) Weekly Averaged Shaken Solids (14/11/76-6/2/77)(mg/l)

	14/11	21/11	28/11	5/12	12/12	19/12	26/12	2/1	9/1	16/1	23/1	30/1	6/2
Feed	219.5	216.5	232	194.5	169.5	225.5	191	-	138.5	149	168.5	-	-
SG biol	273	135	144	148	153	113	166	-	104	153	98	-	-
LS biol	219	178	175	145	144	124	118	-	143	130	138	-	-
SS	211	179	155	134	126	136	341	-	124	115	101	-	-
LG	175	159	165	150	124	132	161	-	177	103	106	-	-
SG	151	146	167	108	161	127	161	-	135	109	136	-	-
LS	248	217	164	217	168	143	246	-	121	108	186	-	-
SS biol	183	153	162	140	129	117	148	-	130	107	103	-	-
LG biol	155	168	151	132	136	138	260	-	130	130	100	-	-
B50 biol	144	165	188	103	88	116	108	-	108	113	112	-	-
B90 biol	227	138	148	102	73	125	120	-	131	112	114	-	-
FLE 2cw	156	157	183	104	99	146	127	-	118	133	117	-	-
FLE 1cw	239	197	154	164	119	233	167	-	147	195	122	-	-
B50	354	148	140	94	87	105	113	-	106	138	106	-	-
B90	205	136	148	93	96	145	123	-	122	98	146	-	-
FLM 2cw	187	150	131	145	93	169	122	-	108	139	145	-	-
FLM 1cw	234	164	143	114	136	157	188	-	150	162	213	-	-

Appendix 7.E.6 (cont) Weekly Averaged Shaken Solids (13/2/77-15/5/77) (mg/l)

	13/2	20/2	27/2	6/3	13/3	20/3	27/3	3/4	10/4	17/4	24/4	1/5	8/5	15/5
Feed	134	-	-	253	251	233	190·5	244	-	-	306	182	238	-
SG biol	137	-	-	418	307	258	134	112	-	-	255	115	152	-
LS biol	102	-	-	397	297	237	117	131	-	-	358	103	182	-
SS	158	-	-	402	289	232	127	83	-	-	289	109	229	-
LG	106	-	-	376	256	233	138	176	-	-	279	135	241	-
SG	113	-	-	319	170	245	153	98	-	-	220	98	114	-
LS	263	-	-	364	190	255	130	95	-	-	297	95	177	-
SS biol	114	-	-	435	248	246	127	162	-	-	269	124	139	-
LG biol	133	-	-	345	231	263	126	85	-	-	262	145	164	-
B50 biol	119	-	-	578	193	245	223	209	-	-	188	136	162	-
B90 biol	105	-	-	415	187	261	181	237	-	-	290	132	129	-
FLE 2cw	176	-	-	385	195	237	178	134	-	-	258	193	183	-
FLE 1cw	149	-	-	463	297	215	146	127	-	-	260	228	197	-
B50	115	-	-	562	267	287	163	127	-	-	208	109	127	-
B90	129	-	-	401	224	271	181	197	-	-	228	97	117	-
FLM 2cw	294	-	-	462	273	273	155	173	-	-	238	234	159	-
FLM 1cw	264	-	-	392	310	274	140	182	-	-	271	223	199	-

Appendix 7.E.6 (cont) Weekly Averaged Shaken Solids (22/5/77-17/7/77) (mg/l)

	22/5	29/5	5/6	12/6	19/6	26/6	3/7	10/7	17/7	$\bar{x}$	SD
Feed	-	146	246·5	-	229·5	209·5	175	267·5	231	202.1	49.6
SG biol	-	209	190	-	129	136	137	152	170	166.4	73.8
LS biol	-	134	162	-	130	136	123	173	175	164.9	70.7
SS	-	164	238	-	99	114	82	129	232	167.1	78.2
LG	-	113	184	-	115	163	112	155	251	163.9	65.5
SG	-	209	155	-	115	161	99	167	159	151.5	65.3
LS	-	132	175	-	119	190	125	241	203	175.8	68.1
SS biol	-	151	224	-	111	178	103	129	224	157.1	67.4
LG biol	-	124	220	-	121	137	109	148	261	162.2	58.2
B50 biol	-	104	195	-	157	130	121	114	128	151.8	81.1
B90 biol	-	110	216	-	152	157	101	103	156	146.9	73.7
FLE 2cw	-	115	193	-	118	138	108	174	184	160.4	54.0
FLE 1cw	-	152	200	-	190	183	112	197	201	187.6	68.8
B50	-	116	257	-	160	119	91	98	127	155.5	89.9
B90	-	144	210	-	139	136	96	103	193	149.5	69.9
FLM 2cw	-	127	224	-	135	143	77	132	149	161.6	75.5
FLM 1cw	-	144	237	-	162	131	103	110	206	176.1	70.9

Appendix 7.E.7 Weekly Averaged Settled Solids (29/7/76-31/10/76) (mg/l)

	8/8	15/8	22/8	29/8	5/9	12/9	19/9	26/9	3/10	10/10	17/10	24/10	31/10
Feed	86	150	163·5	183·5	228	342	166	192	180·5	177·5	160	168	-
SG biol	12	27	72	59	73	69	62	67	55	45	23	25	-
LS biol	17	31	58	71	79	66	62	57	37	37	21	24	-
SS	8	15	59	71	73	49	52	58	25	37	23	26	-
LG	15	43	82	73	92	75	69	67	37	47	30	44	-
SG	9	31	69	61	68	61	44	42	28	37	22	24	-
LS	10	34	69	64	73	53	43	42	30	52	23	33	-
SS biol	4	13	68	67	67	45	66	52	32	36	22	22	-
LG biol	5	22	86	76	66	71	72	64	39	39	25	29	-
B50 biol	3	16	68	55	46	38	44	48	32	35	25	27	-
B90 biol	15	21	75	48	60	57	67	73	28	41	24	25	-
FLE 2cw	15	28	69	58	66	74	69	60	29	41	39	35	-
FLE 1cw	10	20	77	52	67	64	64	76	29	43	41	35	-
B50	8	17	57	51	35	36	36	50	26	43	23	24	-
B90	10	29	69	50	55	41	54	73	32	33	26	27	-
FLM 2cw	8	32	76	53	68	49	72	64	42	44	32	32	-
FLM 1cw	10	23	79	56	70	48	60	61	31	39	25	27	-

Appendix 7.E.7 (cont) Weekly Averaged Settled Solids (7/11/76-6/2/77) (mg/l)

	7/11	14/11	21/11	28/11	5/12	12/12	19/12	26/12	2/1	9/1	16/1	23/1	30/1	6/2
Feed	243.5	219.5	216.5	232	194.5	169.5	225.5	191	-	138.5	149	168.5	-	-
SG biol	128	68	59	76	43	44	54	51	-	36	41	35	-	-
LS biol	61	77	69	80	43	44	60	43	-	41	40	38	-	-
SS	60	66	58	61	39	42	68	76	-	37	51	47	-	-
LG	65	71	71	72	52	48	65	45	-	38	43	47	-	-
SG	74	62	55	66	42	43	51	49	-	40	40	43	-	-
LS	70	65	70	75	48	50	71	60	-	38	40	47	-	-
SS biol	58	69	60	74	41	50	56	45	-	36	38	37	-	-
LG biol	61	73	60	73	47	52	73	53	-	39	43	46	-	-
B50 biol	45	55	49	68	39	28	43	28	-	35	42	50	-	-
B90 biol	66	66	52	63	37	30	56	39	-	40	42	46	-	-
FLE 2cw	69	64	61	81	44	38	62	39	-	42	45	36	-	-
FLE 1cw	64	70	47	69	42	45	67	38	-	43	39	47	-	-
B50	41	86	52	57	30	34	37	34	-	34	48	38	-	-
B90	71	73	53	65	34	33	52	29	-	35	40	44	-	-
FLM 2cw	62	69	63	77	51	41	61	48	-	43	42	46	-	-
FLM 1cw	63	65	67	70	47	45	66	51	-	42	45	51	-	-

Appendix 7E.7 (cont) Weekly Averaged Settled Solids 13/2/77-15/5/77 (mg/l)

	13/2	20/2	27/2	6/3	13/3	20/3	27/3	3/4	10/4	17/4	24/4	1/5	8/5	15/5
Feed	134	-	-	253	251	233	190.5	244	-	-	306	182	238	-
SG biol	62	-	-	168	159	143	59	33	-	-	173	36	45	-
LS biol	60	-	-	157	179	147	57	30	-	-	195	49	54	-
SS	68	-	-	165	177	130	49	28	-	-	196	36	58	-
LG	77	-	-	145	112	144	65	45	-	-	203	49	69	-
SG	67	-	-	152	114	111	54	35	-	-	187	41	43	-
LS	87	-	-	156	108	110	51	29	-	-	186	45	58	-
SS biol	77	-	-	181	118	109	55	45	-	-	175	39	45	-
LG biol	70	-	-	145	135	114	62	32	-	-	176	52	64	-
B50 biol	43	-	-	205	95	84	62	99	-	-	183	57	40	-
B90 biol	29	-	-	157	88	99	82	106	-	-	184	43	55	-
FLE 2cw	28	-	-	131	104	94	68	68	-	-	212	54	66	-
FLE 1cw	36	-	-	124	104	84	67	57	-	-	149	54	60	-
B50	29	-	-	204	81	87	54	56	-	-	150	35	40	-
B90	25	-	-	159	151	108	83	79	-	-	179	33	43	-
FLM 2cw	37	-	-	157	102	96	70	67	-	-	169	50	63	-
FLM 1cw	36	-	-	137	109	94	61	74	-	-	159	54	59	-

Appendix 7.E.7 (cont) Weekly Averaged Settled Solids 22/5/77-17/7/77 (mg/l)

	22/5	29/5	5/6	12/6	19/6	26/6	3/7	10/7	17/7	$\bar{x}$	SD
Feed	-	146	246.5	-	229.5	209.5	175	267.5	231	202.1	49.6
SG biol	-	42	66	-	39	43	43	56	62	62.9	38.9
LS biol	-	29	66	-	46	51	36	56	104	63.4	41.0
SS	-	32	57	-	33	34	34	44	70	59.3	41.2
LG	-	38	85	-	50	79	55	63	86	68.1	34.8
SG	-	39	62	-	39	57	50	61	67	57.4	33.6
LS	-	38	65	-	48	74	59	70	73	62.0	33.2
SS biol	-	43	73	-	38	51	37	55	65	58.1	35.9
LG biol	-	36	82	-	50	61	49	61	83	63.7	33.2
B50 biol	-	27	54	-	34	34	28	36	36	52.2	38.7
B90 biol	-	38	86	-	40	56	32	47	54	58.1	34.2
FLE 2cw	-	33	81	-	41	57	33	70	59	60.6	33.8
FLE 1cw	-	37	88	-	51	54	30	56	60	57.9	26.5
B50	-	30	80	-	32	31	25	37	34	48.8	35.7
B90	-	31	81	-	42	47	34	39	48	56.7	37.1
FLM 2cw	-	42	92	-	45	51	29	57	56	60.5	30.7
FLM 1cw	-	35	77	-	44	47	28	52	64	58.2	28.9

Appendix 7.E.8. Weekly Averaged Ammoniacal Nitrogen Data (mg N/l) (29.7.76 - 7.11.76)

	8/8	15/8	22/8	29/8	5/9	12/9	19/9	26/9	3/10	10/10	17/10	24/10	31/10	7/11
Feed	11.5	15.5	15.3	13.9	17.4	13.4	7.0	7.5	5.2	6.9	5.8	9.0	-	6.2
SG Biol	14.4	14.5	15.5	13.6	16.7	12.5	11.5	6.6	5.5	7.4	4.9	13.0	-	13.8
LS Biol	15.0	17.5	17.5	14.9	17.4	12.3	12.4	8.2	6.3	8.3	6.3	10.0	-	15.2
SS	15.0	15.7	18.2	15.3	17.6	13.0	12.6	8.2	6.3	8.3	6.1	9.7	-	12.5
LG	13.8	17.9	18.6	13.9	17.4	12.5	12.6	8.7	6.5	7.9	6.0	11.5	-	14.2
SG	9.5	17.4	17.0	14.2	17.0	13.6	14.6	10.2	6.6	8.7	6.3	12.0	-	13.0
LS	14.9	15.3	19.4	15.3	17.8	13.8	14.0	8.2	6.7	9.2	6.5	12.4	-	15.2
SS Biol	14.5	17.3	16.4	15.5	17.2	13.0	12.4	8.2	6.7	8.3	6.2	12.5	-	14.4
LG Biol	13.4	18.6	17.2	16.2	18.6	12.9	12.6	8.8	6.6	8.3	6.3	9.7	-	15.2
B50 Biol	12.3	14.0	18.2	14.4	16.6	12.5	12.6	11.3	7.5	6.8	4.8	13.0	-	9.6
B90 Biol	11.6	14.6	22.0	16.4	16.6	15.0	15.2	12.4	8.4	7.1	5.4	13.0	-	10.2
FLE2cw	11.3	14.5	16.2	14.4	17.4	12.9	14.0	11.7	7.0	7.9	5.2	9.0	-	9.6
FLE1cw	12.7	16.7	16.6	14.4	17.2	12.5	11.5	11.5	6.0	5.9	4.8	10.6	-	15.0
B50	12.5	15.5	19.4	14.6	15.9	14.2	13.5	13.0	6.6	6.9	4.8	10.8	-	14.8
B90	13.2	14.6	20.6	16.4	17.6	14.6	15.6	12.6	7.1	8.1	5.7	13.0	-	12.5
FLM2cw	11.2	13.2	17.8	14.9	16.7	12.9	14.0	11.7	6.6	6.9	4.8	11.5	-	13.7
FLM1cw	12.9	13.2	18.4	14.4	16.4	12.9	12.6	10.3	6.5	6.1	4.4	12.0	-	11.3

Appendix 7.E.8. cont. Weekly Averaged Ammoniacal Nitrogen Data (mg N/l) (14.11.76 - 6.2.77)

	14/11	21/11	28/11	5/12	12/12	19/12	26/12	2/1	9/1	16/1	23/1	30/1	6/2
Feed	11.3	17.7	18.5	16.5	4.9	6.5	3.8	-	5.5	7.75	7.75	-	5.0
SG Biol	20.9	17.0	18.5	17.7	6.0	7.75	7.6	-	5.95	7.15	6.6	-	10.6
LS Biol	20.0	16.8	19.0	18.0	7.5	9.0	10.1	-	7.15	8.4	9.2	-	11.2
SS	24.8	16.9	19.7	17.7	6.9	9.15	9.5	-	7.3	8.6	9.1	-	9.6
LG	17.8	18.3	19.9	17.0	7.65	9.15	10.4	-	7.5	8.0	8.75	-	11.0
SG	21.5	18.3	19.5	17.7	7.25	9.25	9.25	-	6.75	8.6	9.2	-	11.2
LS	21.2	18.3	19.7	17.5	7.65	10.2	10.4	-	7.3	8.75	8.5	-	11.7
SS Biol	20.6	18.0	19.0	18.3	7.0	9.0	10.0	-	7.15	9.95	9.4	-	11.7
LG Biol	22.8	18.3	19.0	17.5	7.65	8.05	10.1	-	7.5	8.25	8.9	-	11.2
B50 Biol	28.5	17.3	19.0	17.0	6.5	8.95	8.1	-	5.0	7.1	8.15	-	10.2
B90 Biol	12.5	17.7	20.5	16.6	8.3	11.2	10.6	-	7.9	10.3	8.6	-	11.5
FLE2cw	15.9	17.5	18.0	15.8	7.5	10.9	10.4	-	6.1	7.1	6.35	-	8.5
FLE1cw	12.4	16.8	18.5	16.0	8.3	10.25	8.25	-	6.1	7.5	7.75	-	8.6
B50	30.6	15.2	19.3	16.8	9.25	10.7	10.1	-	6.4	8.5	8.75	-	10.5
B90	18.5	17.5	20.7	17.0	8.2	11.2	11.0	-	7.0	10.2	9.1	-	11.7
FLM2cw	16.4	16.6	19.0	16.6	7.75	10.1	10.25	-	6.9	8.85	8.15	-	8.5
FLM1cw	14.8	17.0	19.0	16.6	7.75	8.8	9.5	-	6.25	8.4	8.0	-	8.6

Appendix 7.E.8. cont.

Weekly Averaged Ammoniacal Nitrogen Data (mg N/l) (13.2.77 - 15.5.77)

	13/2	20/2	27/2	6/3	13/3	20/3	27/3	3/4	10/4	17/4	24/4	1/5	8/5	15/5
Feed	5.8	6.4	-	12.4	11.65	7.50	8.5	-	8.5	-	9.3	12.4	15.7	-
SG Biol	8.8	6.2	-	51.6	29.5	8.9	10.9	-	10.7	-	9.8	11.8	15.9	-
LS Biol	9.3	5.9	-	57.2	29.9	9.4	11.6	-	11.3	-	11.4	12.4	17.0	-
SS	9.6	6.2	-	54.0	29.0	10.1	11.7	-	11.3	-	10.7	11.8	16.7	-
LG	9.7	6.3	-	31.0	24.4	10.2	12.0	-	11.0	-	11.3	12.6	17.8	-
SG	8.8	6.3	-	46.6	27.4	11.7	12.2	-	10.5	-	11.0	12.2	17.5	-
LS	8.6	6.4	-	50.4	27.3	10.6	12.2	-	10.7	-	11.0	12.4	17.5	-
SS Biol	5.2	5.9	-	65.4	23.6	10.1	12.2	-	11.3	-	11.3	12.2	17.2	-
LG Biol.	9.3	7.5	-	46.4	29.0	11.4	11.7	-	10.7	-	11.5	12.6	17.8	-
B50 Biol	8.5	6.3	-	60.8	19.3	8.7	11.7	-	9.5	-	9.0	11.6	17.8	-
B90 Biol	9.0	7.8	-	62.4	20.3	8.9	12.2	-	10.0	-	9.0	13.4	18.4	-
FLE2cw	7.4	7.7	-	28.4	18.8	9.7	11.3	-	8.5	-	9.0	12.2	17.0	-
FLE1cw	7.4	7.7	-	42.4	16.4	9.3	11.3	-	8.0	-	9.0	12.0	16.1	-
B50	9.0	7.5	-	76.0	21.1	9.6	12.5	-	8.3	-	9.7	11.3	17.2	-
B90	9.3	7.4	-	69.6	24.4	10.4	17.5	-	8.5	-	9.2	13.0	17.2	-
FLM2cw	7.4	7.2	-	42.6	19.0	8.3	12.2	-	8.7	-	9.4	12.6	16.7	-
FLM1cw	7.4	6.4	-	40.6	18.7	8.3	11.6	-	8.7	-	9.7	12.6	17.0	-

Appendix 7.E.8. cont. Weekly Averaged Ammoniacal Nitrogen Data (mgN/l) (22.5.77 - 17.7.77)

	22/5	29/5	5/6	12/6	19/6	26/6	3/7	10/7	17/7	$\bar{x}$	S.D.
Feed	-	7.8	11.2	-	6.8	6.2	8.4	10.2	11.7	9.762	4.042
SG Biol	-	11.0	11.2	-	8.6	6.4	8.4	17.0	16.0	12.643	8.020
LS Biol	-	13.7	14.3	-	10.0	6.6	10.2	17.5	15.7	13.684	8.482
SS	-	13.7	13.6	-	10.4	6.8	10.4	17.7	15.0	13.572	8.173
LG	-	12.7	13.6	-	10.2	6.8	10.5	16.3	14.3	12.870	5.176
SG	-	13.7	14.5	-	8.2	7.7	10.7	17.7	15.0	13.422	7.059
LS	-	13.7	14.7	-	10.4	7.7	10.5	17.0	14.7	13.798	7.450
SS Biol	-	13.5	13.5	-	10.8	8.3	10.7	17.7	14.7	13.812	9.339
LG Biol	-	13.7	13.8	-	8.0	7.7	10.7	16.5	15.2	13.589	7.176
B50 Biol	-	11.5	10.3	-	10.8	6.8	10.2	14.4	12.5	12.905	9.005
B90 Biol	-	14.0	14.7	-	11.5	7.0	11.4	16.0	13.0	13.722	8.745
FLE2cw	-	12.7	13.0	-	11.3	6.2	10.2	14.5	10.7	11.799	4.588
FLE1cw	-	11.7	12.0	-	10.2	5.7	8.7	14.3	10.7	11.921	6.131
B50	-	11.7	12.0	-	10.7	6.5	9.8	14.5	13.2	12.883	11.040
B90	-	13.2	14.3	-	12.0	6.8	9.8	16.5	13.5	14.300	9.854
FLM2cw	-	12.5	13.3	-	11.0	6.8	9.8	14.4	12.7	12.429	6.117
FLM1cw	-	13.0	13.3	-	11.3	6.5	9.8	14.5	12.0	12.134	5.961

Appendix 7.E.9. Weekly Averaged Oxidised Nitrogen Data (mgN/l) (29/7/76 - 7/11/76)

	8/8	15/8	22/8	29/8	5/9	12/9	19/9	26/9	3/10	10/10	17/10	24/10	31/10	7/11
Feed	0.5	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	2.10	0.50	1.40	-	-	0.50
SG Biol	0.4	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.75	0.30	0.30	-	-	0.30
LS Biol	0.3	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.70	0.30	0.30	-	-	0.25
SS	0.4	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.60	0.30	0.35	-	-	0.25
LG	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.50	0.10	0.30	-	-	0.20
SG	0.3	0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.40	0.20	0.35	-	-	0.30
LS	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.40	0.15	0.30	-	-	0.20
SS Biol	0.3	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.55	0.30	0.35	-	-	0.20
LG Biol	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.50	0.15	0.30	-	-	0.20
B50 Biol	0.6	0.7	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	0.55	0.30	0.50	-	-	0.60
B90 Biol	0.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	0.50	0.40	0.40	-	-	0.25
FLE2cw	0.2	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	0.60	0.30	0.55	-	-	0.25
FLE1cw	0.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	0.75	0.30	0.55	-	-	0.20
B50	0.7	0.5	0.4	0.6	<0.1	<0.1	<0.1	<0.1	0.70	0.50	0.60	-	-	0.35
B90	0.2	0.2	<0.1	0.6	<0.1	<0.1	<0.1	<0.1	0.50	0.40	0.50	-	-	0.25
FLM2cw	0.2	0.1	<0.1	0.6	<0.1	<0.1	<0.1	<0.1	0.60	0.30	0.45	-	-	0.25
FLM1cw	0.3	0.3	<0.1	0.6	<0.1	<0.1	<0.1	<0.1	0.75	0.40	0.50	-	-	0.25

Appendix 7.E.9. cont. Weekly Averaged Oxidised Nitrogen Data (mg N/l) (14/11/76 - 6/2/77)

	14/11	21/11	28/11	5/12	12/12	19/12	26/12	2/1	9/1	16/1	23/1	30/1	6/2
Feed	4.30	0.45	<0.1	<0.1	2.50	1.35	4.5	-	6.2	2.6	0	-	4.60
SG Biol	0.40	0.10	<0.1	<0.1	0.60	0.15	0.4	-	0.4	0	0	-	0.60
LS Biol	0.40	0.10	<0.1	<0.1	0.50	0.15	0.4	-	0.35	0	0	-	0.55
SS	0.35	0.10	<0.1	<0.1	0.55	0.30	0.65	-	0.60	0	0	-	1.00
LG	0.55	0.10	<0.1	<0.1	0.55	0.30	0.55	-	0.35	0	0	-	0.35
SG	0.40	0.10	<0.1	<0.1	0.50	0.10	0.50	-	0.40	0	0	-	0.70
LS	0.35	0.10	<0.1	<0.1	0.50	0.10	0.55	-	0.35	0	0	-	0.35
SS Biol	0.35	0.10	<0.1	<0.1	0.35	0.10	0.80	-	0.40	0	0	-	0.50
LG Biol	0.40	0.10	<0.1	<0.1	0.40	0.20	0.65	-	0.35	0	0	-	0.40
B50 Biol	0.40	0.10	<0.1	<0.1	0.80	0.30	1.00	-	1.35	0.5	0	-	0.60
B90 Biol	0.35	0.10	<0.1	<0.1	0.20	0.10	0.35	-	0.35	0	0	-	0.30
FLE2cw	0.20	0.10	<0.1	<0.1	0.40	0.20	1.00	-	0.90	0.3	0	-	0.80
FLE1cw	0.35	0.10	<0.1	<0.1	0.55	0.35	1.10	-	0.90	0.2	0.3	-	0.90
B50	0.30	0.25	<0.1	<0.1	0.90	0.35	1.00	-	1.15	0	0	-	0.80
B90	0.20	0.10	<0.1	<0.1	0.35	0.20	0.40	-	0.50	0	0	-	0.35
FLM2cw	0.35	0.10	<0.1	<0.1	0.40	0.20	0.90	-	0.70	0	0	-	1.00
FLM1cw	0.40	0.10	<0.1	<0.1	0.35	0.20	0.90	-	0.90	0	0	-	0.80

Appendix 7.E.9 (cont) Weekly Averaged Oxidised Nitrogen Data (mg N/l) (13/2/77-15/5/77) (mgN/l)

	13/2	20/2	27/2	6/3	13/3	20/3	27/3	3/4	10/4	17/4	24/4	1/5	8/5	15/5
Feed	3.60	2.25	-	2.80	2.30	1.00	3.10	-	0.60	-	0	2.00	1.10	-
SG biol	0.05	0.15	-	1.80	0.55	0.50	0.60	-	0.30	-	0	0.30	0.30	-
LS biol	0.10	0.15	-	2.00	0.50	0.70	0.40	-	0.60	-	0	0.30	0.20	-
SS	0.05	0.30	-	2.10	0.70	0.60	0.55	-	0.80	-	0	0.10	0.40	-
LG	0.15	0.45	-	2.50	0.70	0.20	0.35	-	0.05	-	0	0.10	0.30	-
SG	0.20	0.45	-	1.80	0.55	0.45	0.40	-	0.40	-	0	0.20	0.20	-
LS	0.45	0.45	-	1.90	0.50	0.25	0.50	-	0.35	-	0	0.30	0.15	-
SS biol	0.10	0.50	-	1.80	0.40	0.5	0.35	-	0.50	-	0	0.40	0.30	-
LG biol	0.10	0.30	-	2.00	0.35	0.3	0.30	-	0.35	-	0	0.50	0.20	-
B50 biol	0.15	0.35	-	2.40	0.65	0.45	0.75	-	0.70	-	0	0.50	0.40	-
B90 biol	0	0.10	-	1.80	0.55	0.35	0.50	-	0.50	-	0	0.75	0.30	-
FLE 2cw	0.55	0.10	-	2.50	0.90	0.35	0.85	-	0.35	-	0	0.90	0.25	-
FLE 1cw	0.65	0.10	-	1.75	1.00	0.70	0.80	-	0.30	-	0	0.90	0.30	-
B50	0.30	0.3	-	2.35	0.50	0.45	0.90	-	0.75	-	0	0.80	1.10	-
B90	0	0.3	-	2.00	0.40	0.30	0.55	-	0.50	-	0	0.60	0.65	-
FLM 2cw	0.50	0.3	-	2.30	0.80	0.45	0.80	-	0.35	-	0	0.80	0.30	-
FLM 1cw	0.70	0.55	-	2.50	1.10	0.45	0.95	-	0.50	-	0	0.60	0.35	-

Appendix 7.E.9 (cont) Weekly Averaged Oxidised Nitrogen Data (22/5/77-17/7/77) (mgN/l)

	22/5	29/5	5/6	12/6	19/6	26/6	3/7	10/7	17/7
Feed	-	2.50	0.05	-	0	0	0	0	0
SG biol	-	0.30	0.05	-	0.05	0	0	0	0
LS biol	-	0.20	0.05	-	0.05	0	0	0	0
SS	-	0.60	0.1	-	0.05	0	0	0	0
LG		0.40	0.05	-	0	0	0	0	0
SG	-	0.20	0.05	-	0	0	0	0	0
LS	-	0.10	0.05	-	0	0	0	0	0
SS biol	-	0.45	0.05	-	0	0	0	0	0
LG biol	-	0.30	0.05	-	0	0	0	0	0
B50 biol	-	1.70	0.30	-	1.05	0.65	2.1	0.05	0.1
B90 biol	-	0	0.05	-	0.50	0	0.7	0	0
FLE 2cw	-	0.30	0.05	-	0.40	0	0	0	0
FLE 1cw	-	0.50	0.05	-	0.90	0	0	0	0
B50	-	1.70	0.30	-	2.15	0.90	2.2	0.1	0.1
B90	-	0	0.20	-	1.05	0	0.65	0	0
FLM 2cw	-	0.30	0.05	-	0.55	0	0	0	0
FLM 1cw	-	0.50	0.05	-	0.70	0	0.15	0	0

Appendix 7.F.1. BOD Loading and Removal per unit of Specific Surface Area,(16/6/75-16/11/75).

Filter Media	Available Surface Area (m^2)	BOD Applied (g BOD/m^2/d)	BOD Removed (g BOD/m^2/d)
LG	145.7	23.31	15.72
LS	131.6	25.81	18.68
SG	203.9	16.65	12.30
SS	234.4	14.49	10.23
FLE	323	18.69	12.12
FLM	461.7	13.07	8.86
B90	323	18.69	12.94
B50	471.2	12.81	9.08

Appendix 7.F.2. BOD Loading and Removal per unit of Specific Surface Area,(29/1/76-29/7/76).

Filter Media	Available Surface Area (m^2)	BOD Applied (g BOD/m^2/d)	BOD Removed (g BOD/m^2/d)
LG	145.7	25.34	17.93
LS	131.6	28.06	20.32
SG	203.9	18.10	13.33
SS	234.4	15.75	11.69
FLE	323	21.22	15.79
FLM	461.7	14.85	10.81
B90	323	21.22	16.64
B50	471.2	14.55	12.06

Appendix 7.F.3. BOD Loading and Removal per unit of Specific Surface Area, (29/7/76-17/7/77).

Filter Media	Available Surface Area (m^2)	BOD Applied (g BOD/m^2/d)	BOD Removed (g BOD/m^2/d)
LG	145.7	25.18	19.12
LS	131.6	27.88	22.37
SG	203.9	17.99	14.56
SS	234.4	15.65	12.80
FLE	323	20.39	16.34
FLM	461.7	14.27	11.24
B90	323	20.39	16.97
B50	471.2	13.98	12.05

Appendix 7.F.4. Rate of Sludge Production vs. BOD Loading per unit of Specific Surface Area (16/6/75-16/11/75).

Filter Media	Available Surface Area (m^2)	BOD Applied (g BOD/m^2/d)	Sludge Production. (g/g BOD Removed)
LG	145.7	23.31	0.90
LS	131.6	25.81	0.97
SG	203.9	16.65	0.77
SS	234.4	14.49	0.75
FLE	323	18.69	0.81
FLM	461.7	13.07	0.82
B90	323	18.69	0.74
B50	471.2	12.81	0.68

Appendix 7.F.5. Rate of Sludge Production vs. BOD Loading per unit of Specific Surface Area. (29/1/76-29/7/76).

Filter Media	Available Surface Area (m^2)	BOD Applied (g BOD/m^2/d)	BOD Production (g/g BOD Removed)
LG	145.7	25.34	0.74
LS	131.6	28.06	0.71
SG	203.9	18.10	0.72
SS	234.4	15.75	0.69
FLE	323	21.22	0.75
FLM	461.7	14.85	0.73
B90	323	21.22	0.64
B50	471.2	14.55	0.58

Appendix 7.F.6. Rate of Sludge Production vs. BOD Loading per unit of Specific Surface Area. (29/7/76-17/7/77).

Filter Media	Available Surface Area (m^2)	BOD Applied (g BOD/m^2/d)	BOD Production (g/g BOD Removed)
LG	145.7	25.18	0.61
LS	131.6	27.88	0.61
SG	203.9	17.99	0.58
SS	234.4	15.65	0.56
FLE	323	20.39	0.61
FLM	461.7	14.27	0.63
B90	323	20.39	0.54
B50	471.2	13.98	0.53

Appendix 8.A.1. Volatile Solids Present in the Filters

October, 1975.

Media	0- 200	200- 600	600-1000	1000-1400	1400-1800
SS	6.0	8.1	4.8	6.3	4.6
LS	8.1	5.3	8.3	6.7	5.9
SG	4.3	7.2	11.5	6.8	4.8
LG	5.5	5.7	3.9	3.3	4.5
B90	9.5	13.8	18.7	18.8	14.5
B50	27.2	26.7	33.1	43.3	34.1

	0- 200	600-800	1200-1400
FLE	3.82	3.74	2.70
FLM	6.24	17.26	5.61

Depths expressed in mm.

Volatile Solids in kg/m^3.

Appendix 8.A.1.(cont) Volatile Solids Present in the Filters

January,1976.

Media	0- 200	200- 600	600-1000	1000-1400	1400-1800
SS	18.5	16.5	14.8	12.0	8.3
LS	3.2	3.3	6.5	5.0	5.2
SG	14.0	16.1	14.5	7.5	12 .4
LG	9.0	11.1	9.1	9.2	6.9
B90	10.8	11.2	13.7	7.4	4.3
B50	25.8	26.3	19.5	15.0	7.9

	0- 200	600-800	1200-1400
FLE	2.1	7.0	1.7
FLM	4.4	4.9	5.0

Depths expressed in mms.

Volatile Solids in kg/m^3.

Appendix 8.A.1.(cont) Volatile Solids Present in the Filters

April/May,1976.

Media	0- 200	200- 600	600-1000	1000-1400	1400-1800
SS	14.8	13.7	19.9	16.9	16.9
LS	15.9	13.2	17.3	13.1	9.1
SG	11.9	14.8	21.0	21.3	17.8
LG	6.3	8.7	18.3	22.2	13.3
B90	4.0	33.8	31.9	23.8	11.8
B50	30.0	43.2	21.5	9.6	7.7

	0-200	600-800	1200-1400
FLE	3.5	6.0	2.8
FLM	7.0	6.4	7.8

Depths expressed in mm.

Volatile solids in kg/m^3.

Appendix 8.A.1.(cont) Volatile Solids in the Filters, July,1976.

Media.	0 - 200	200- 600	600-1000	1000-1400	1400-1800
SS	14.1	10.7	10.8	8.6	6.5
LS	7.5	8.0	11.1	10.0	7.7
SG	9.1	14.4	8.9	10.6	6.8
LG	7.9	13.7	5.5	7.8	7.4
B90	12.8	18.3	14.5	9.6	8.4
B50	12.4	11.8	17.4	12.6	9.1

	0- 200	600-800	1200-1400
FLE	3.6	7.1	3.0
FLM	10.5	8.8	11.1

Depths expressed in mm.

Volatile solids in kg/m^3.

Appendix 8.A.1.(cont) Volatile Solids Present in the Filters, October,1976.

Media	0- 200	200- 600	600-1000	1000-1400	1400-1800
SS	10.2	10.1	8.9	8.4	5.6
LS	8.5	10.7	7.5	8.2	6.4
SG	10.0	11.4	9.0	6.4	6.9
LG	7.3	9.4	8.7	7.5	6.6
B90	20.2	18.3	15.2	16.4	9.4
B50	17.7	17.2	10.7	8.7	2.5

	0- 200	600-800	1200-1400
FLE	3.8	7.2	8.2
FLM	10.2	9.6	5.0

Depths expressed in mm.

Volatile solids in kg/m^3.

Appendix 8.A.1.(cont) Volatile Solids Present in the Filters

February/March,1977.

Media	0- 200	200-600	600-1000	1000-1400	1400-1800
SS	11.3	10.6	5.7	2.9	1.9
LS	1.8	16.3	10.7	4.2	3.0
SG	3.8	16.9	5.0	4.2	2.8
LG	9.2	15.4	6.3	1.5	1.3
B90	9.7	33.3	19.7	6.6	3.1
B50	9.1	20.2	12.8	5.1	1.7

	0- 200	600-800	1200-1400
FLE	0.6	2.0	3.3
FLM	1.7	3.6	4.5

Depths expressed in mm.

Volatile solids in kg/m^3.

Appendix 8.A.1.(cont) Volatile Solids Present in the Filters, May, 1977.

Media	0- 200	200- 600	600-1000	1000-1400	1400-1800
SS	11.5	12.8	15.8	16.3	19.5
LS	7.5	11.6	12.3	14.1	8.2
SG	8.6	14.2	19.3	10.3	13.3
LG	6.7	12.7	21.6	16.3	13.7
B90	5.5	10.7	7.0	7.1	6.0
B50	12.5	8.8	17.1	13.4	4.8

	0- 200	600- 800	1200-1400
FLE	5.4	7.1	4.6
FLM	4.6	7.9	2.3

Depths expressed in mm.

Volatile solids in kg/m^3.

Appendix 8.A.1.(cont) Volatile Solids Present in the Filters, August,1977.

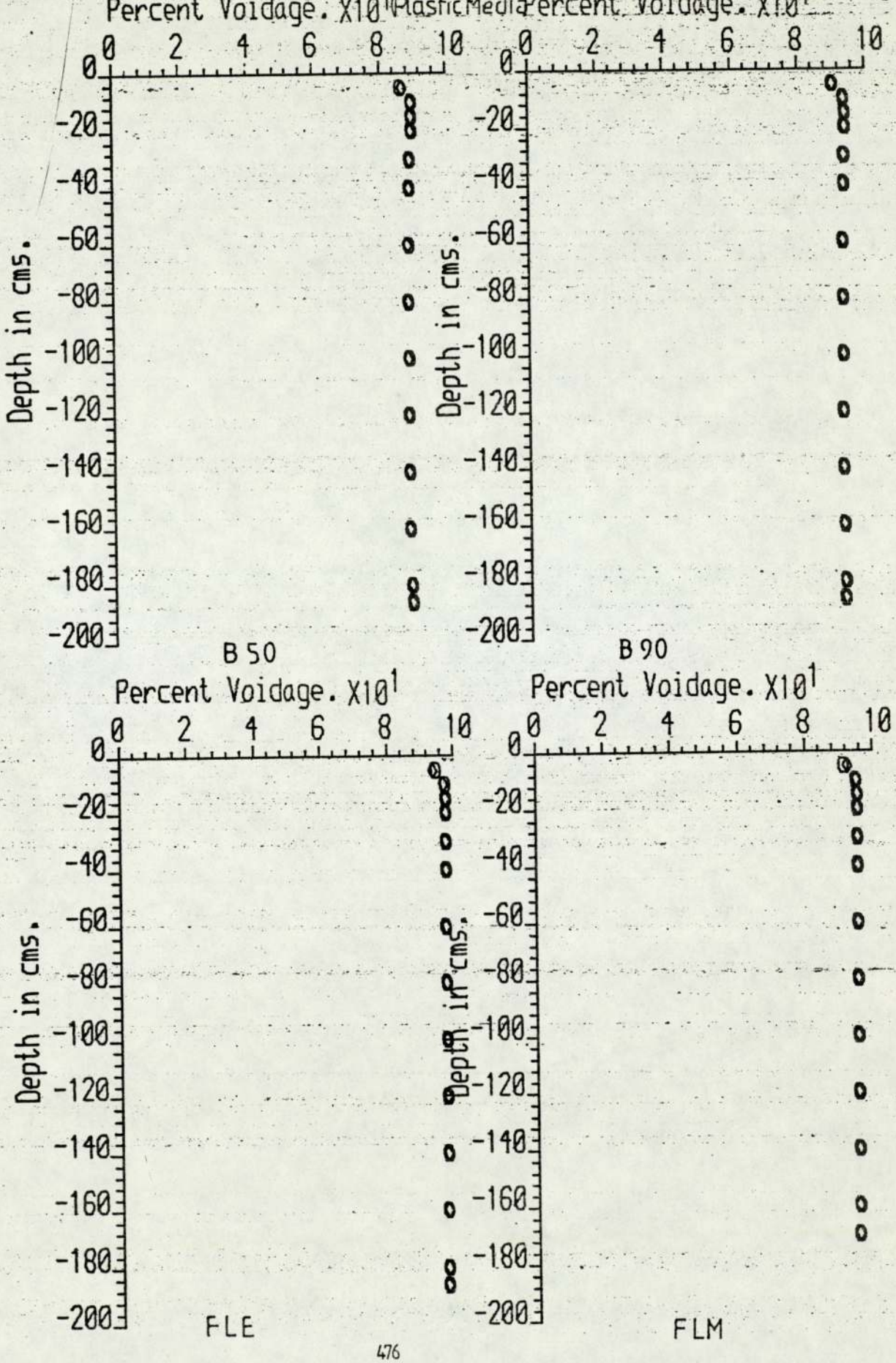
Media	0- 200	200- 600	600-1000	1000-1400	1400-1800
SS	10.4	6.5	8.3	6.6	5.3
LS	6.9	4.7	6.4	1.8	2.7
SG	6.2	6.4	8.7	5.4	3.6
LG	8.5	4.5	5.6	7.7	3.7
B90	4.1	6.3	9.4	14.4	14.3
B50	3.9	11.8	15.7	13.1	9.1

	0- 200	600-800	1200-1400
FLE	2.7	4.4	5.0
FLM	3.7	5.7	5.5

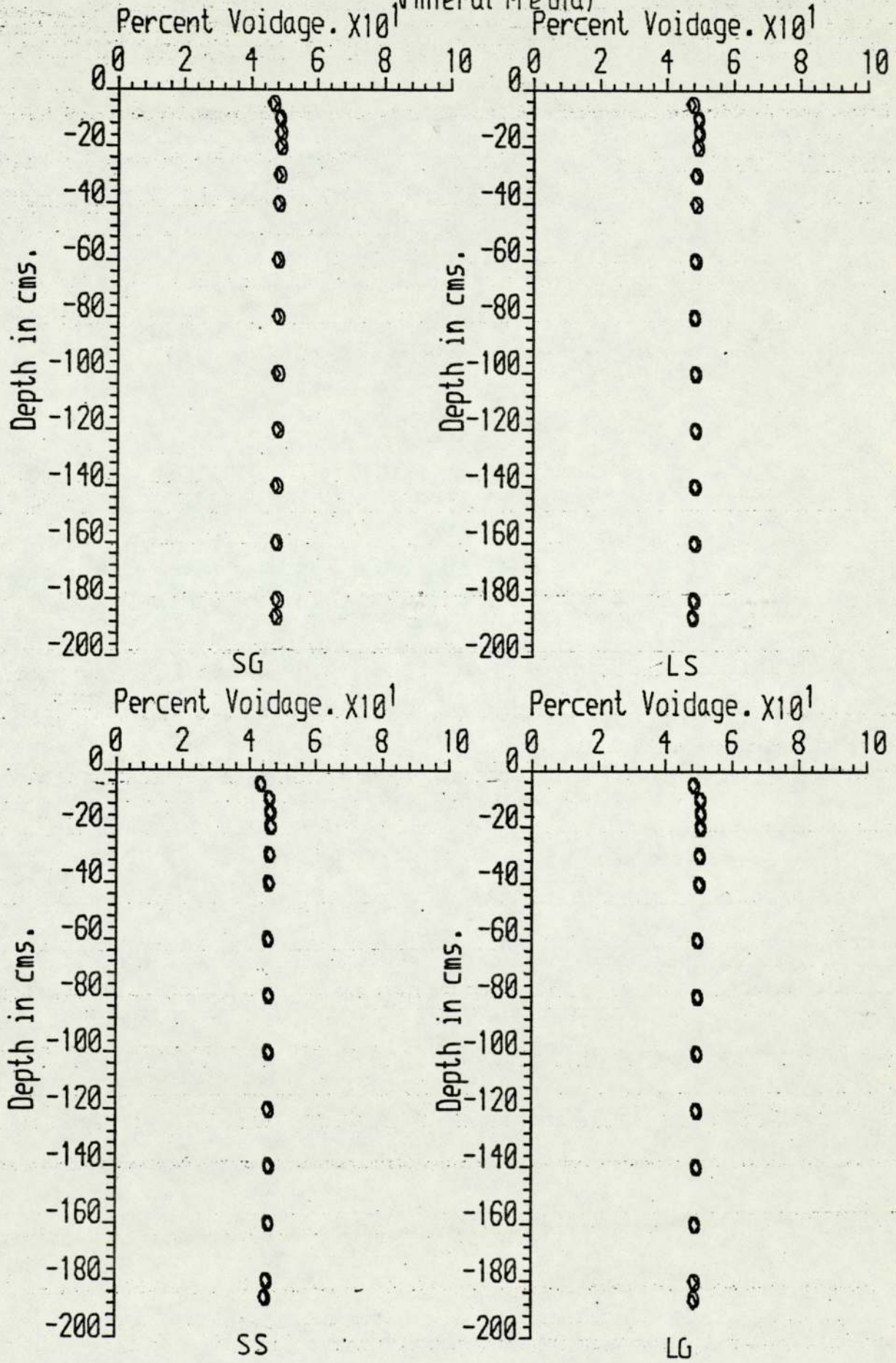
Depths expressed in mm.

Volatile solids in kg/m^3.

Appendix 8.A.2 Neutron Scatter Moisture Content Profiles April 1975

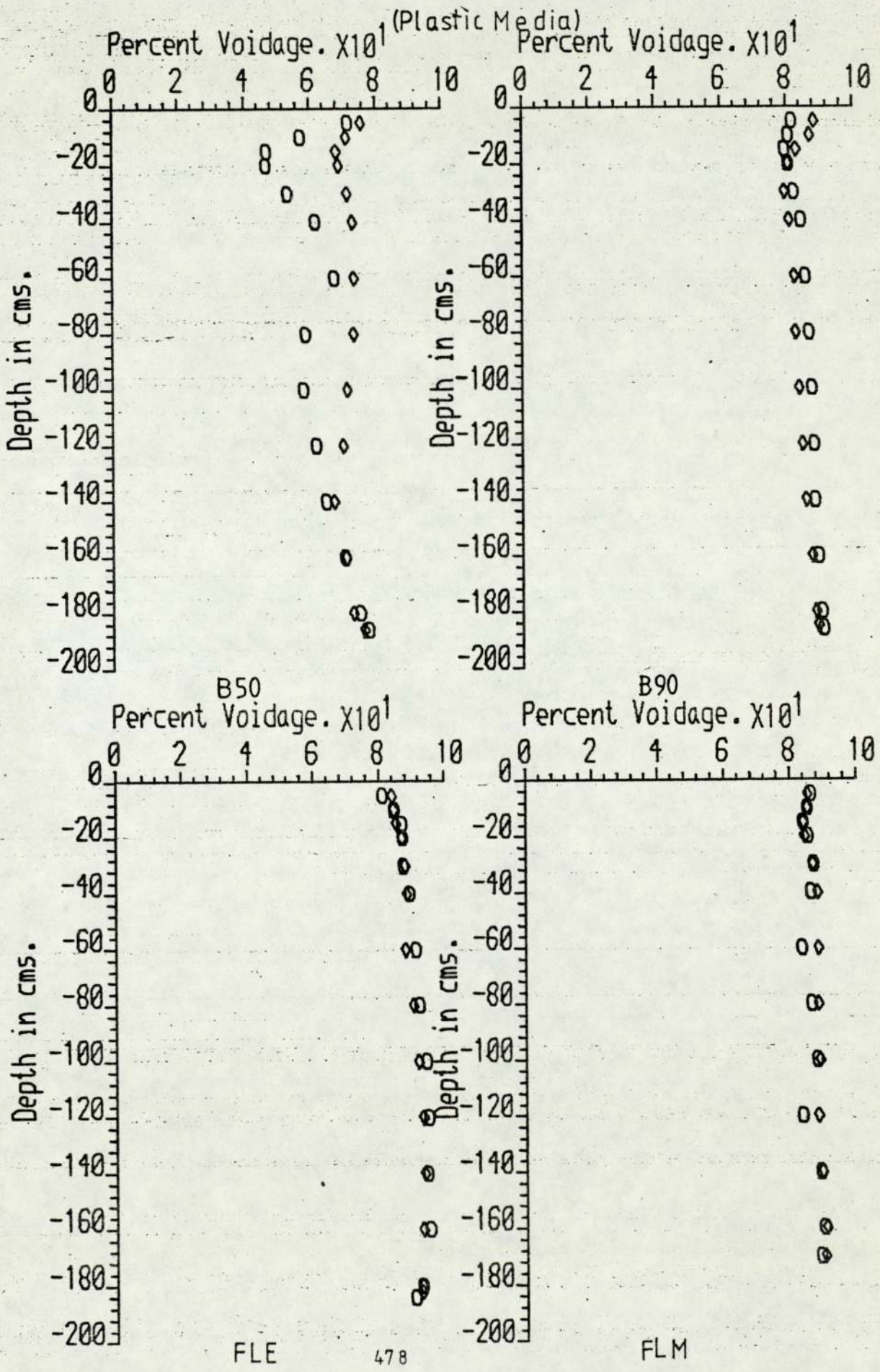


Appendix 8.A2 Neutron Scatter Moisture Content Profiles. April 1975
(Mineral Media)

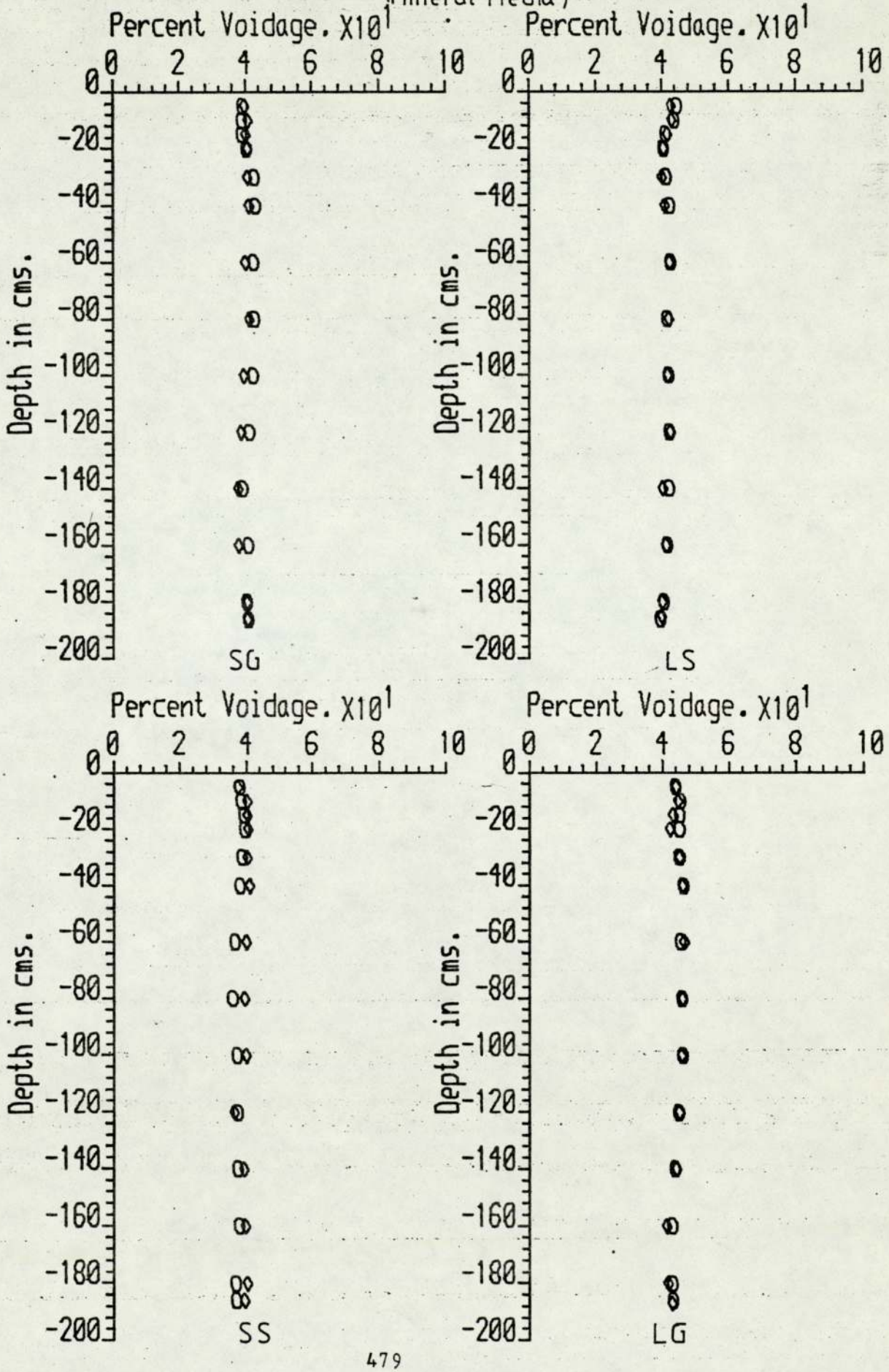


Appendix 8.A.2. Neutron Scatter Miosture Content Profiles. Sept. 1975

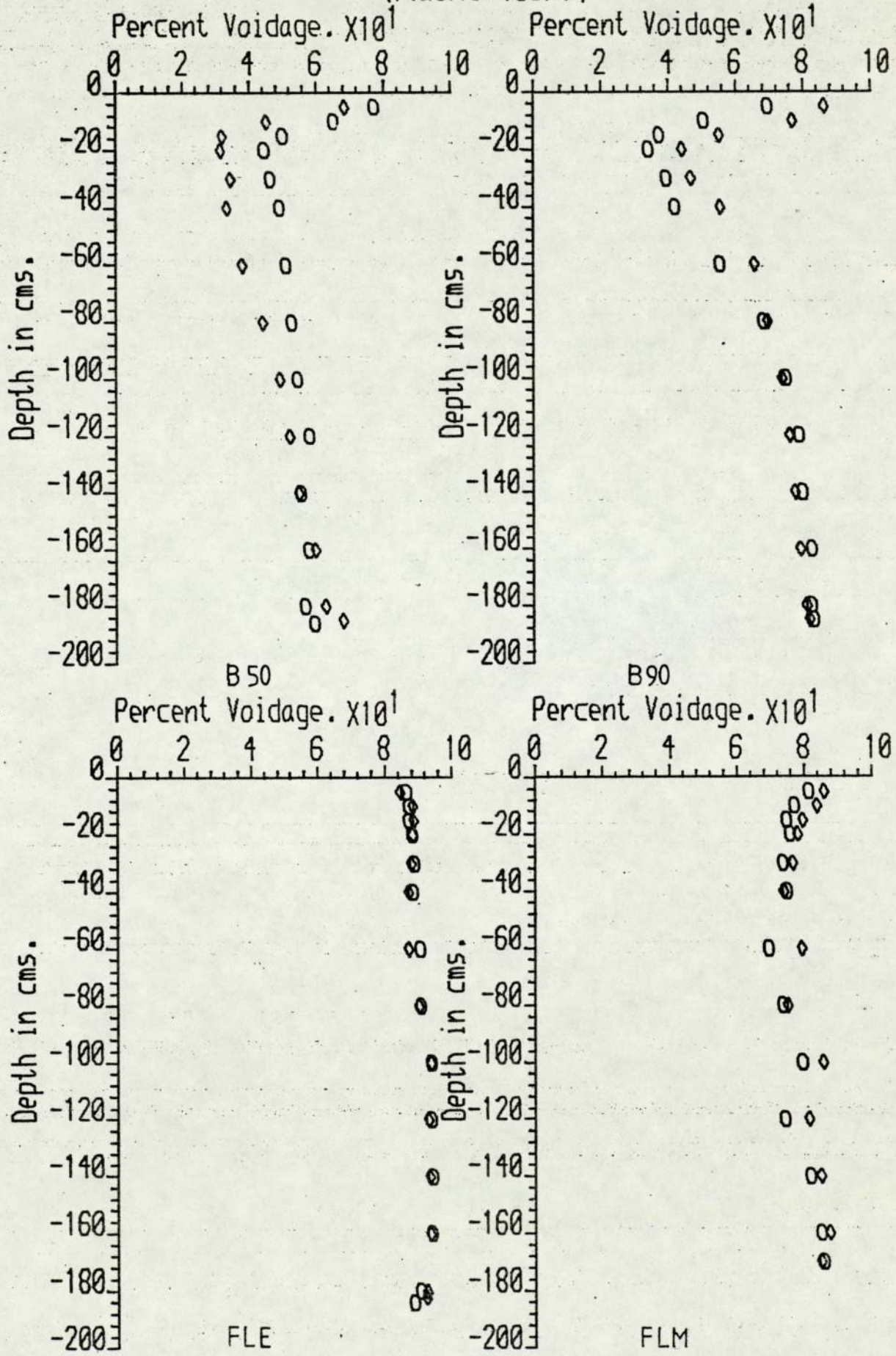
(Plastic Media)



Appendix 8.A2 Neutron Scatter Moisture Content Profiles Sept 1975
(Mineral Media)

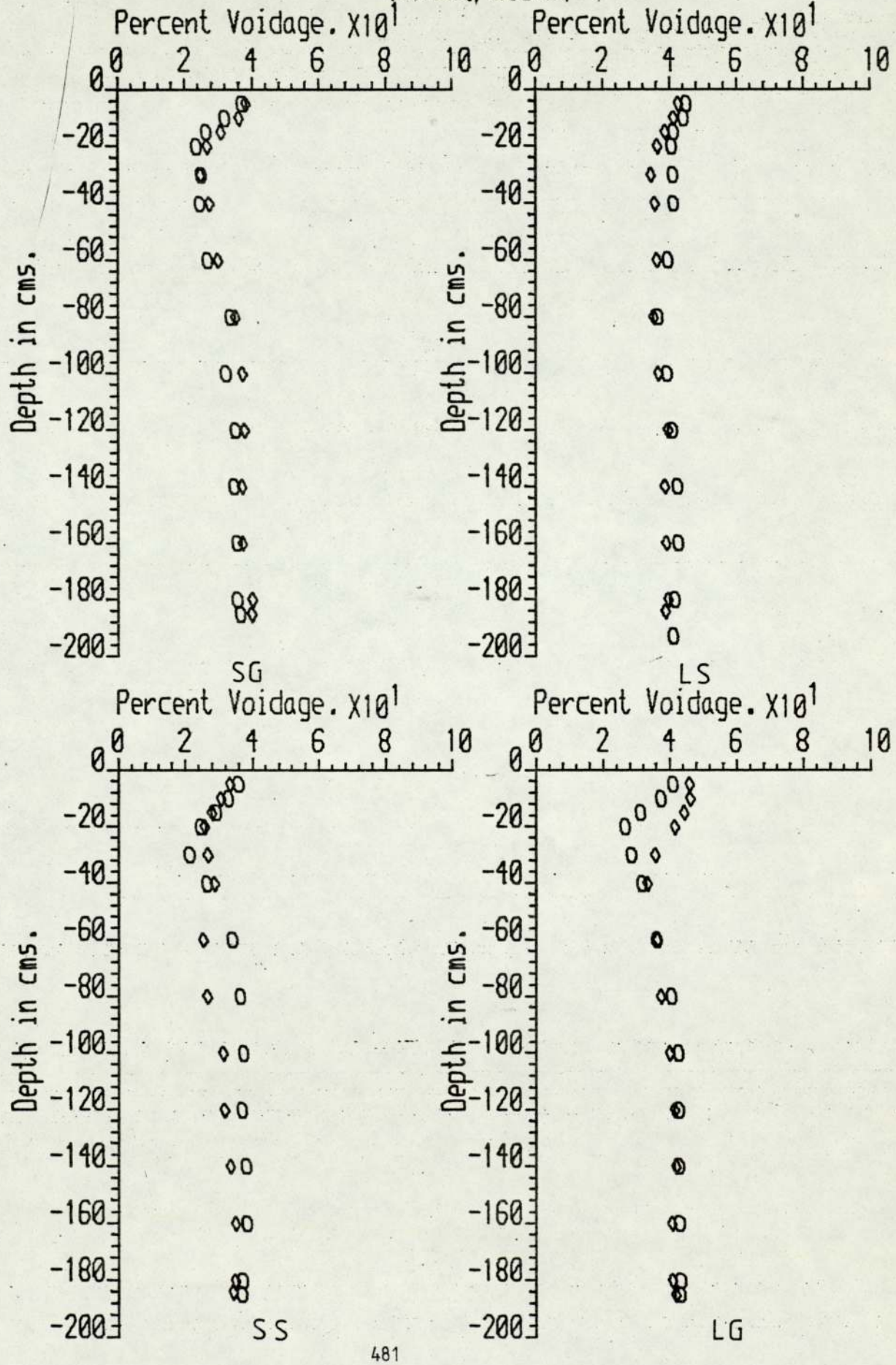


Appendix 8.A2 Neutron Scatter Moisture Content Profiles Oct 1975
(Plastic Media)

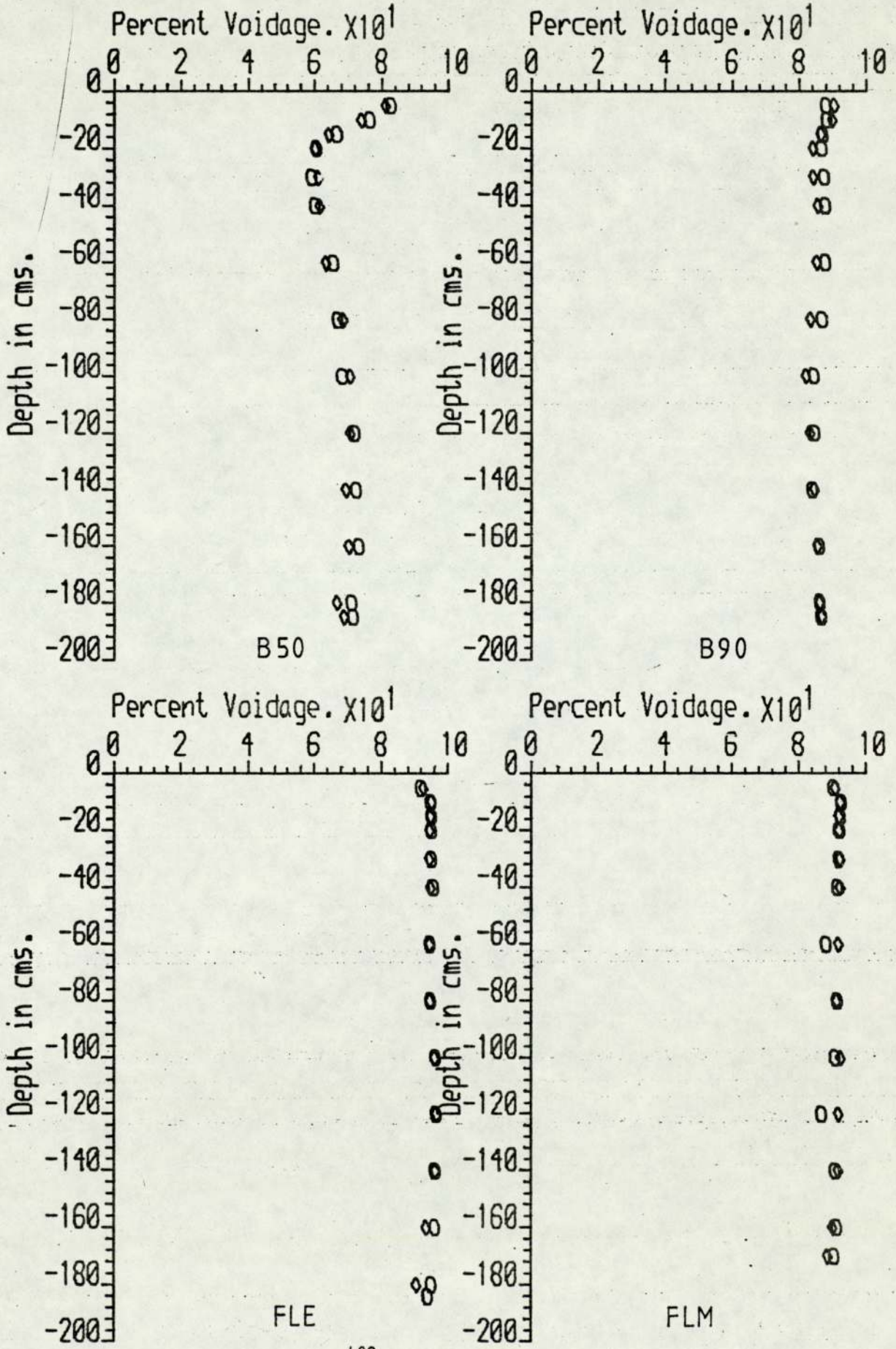


Appendix 8.A2 Neutron Scatter. Moisture Content Profiles Oct 1975

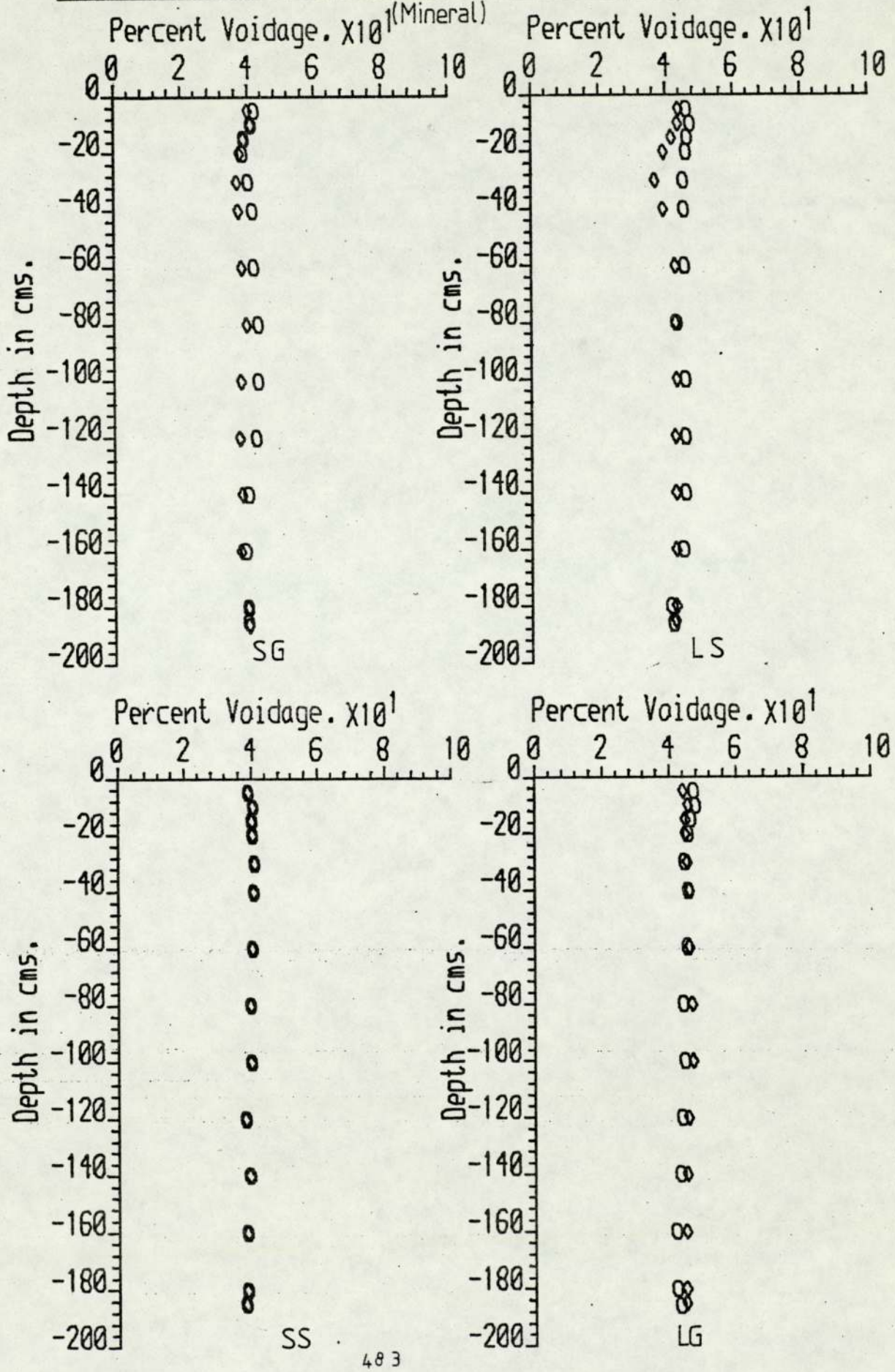
(Mineral Media)



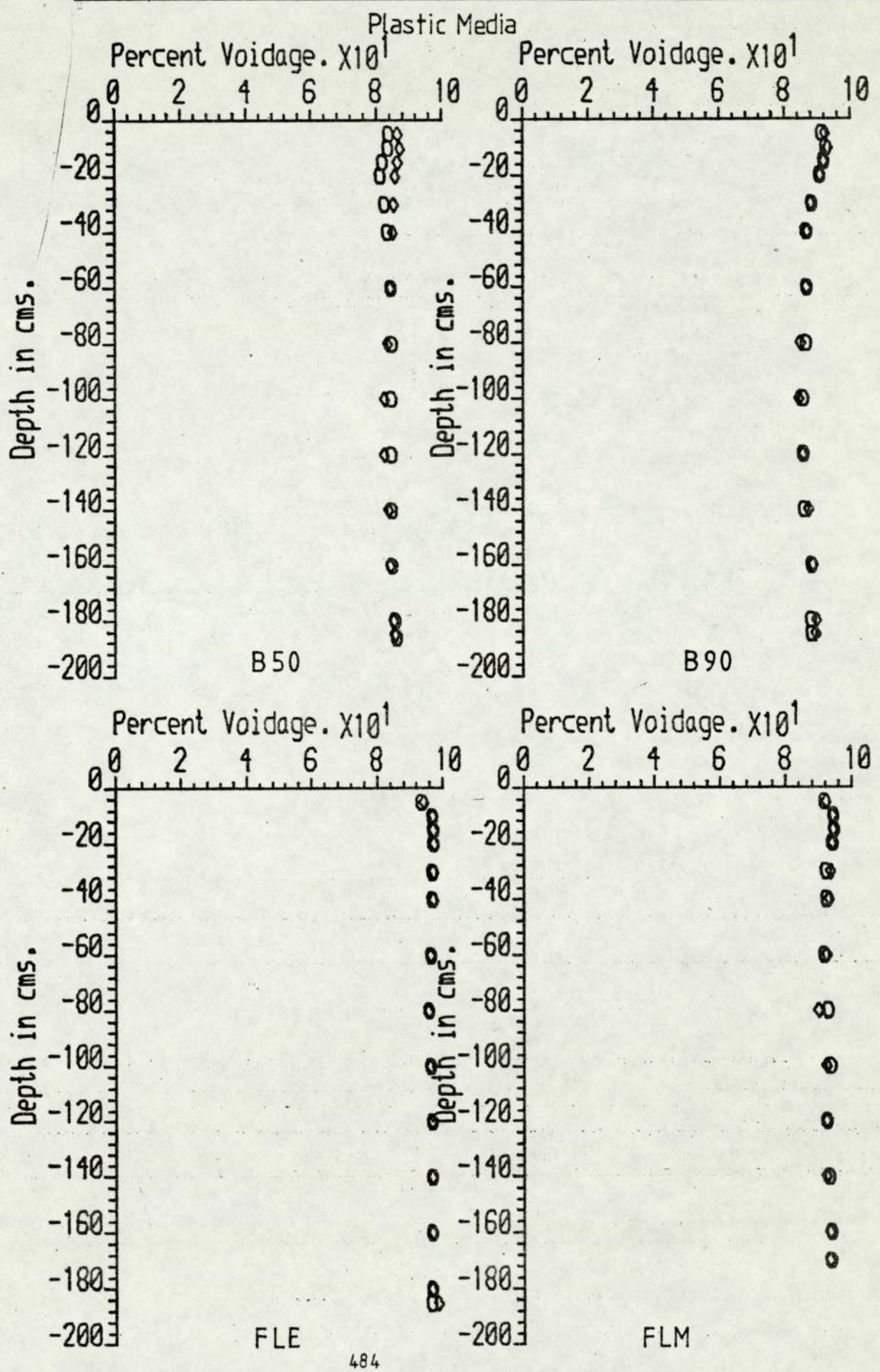
Appendix 8.A.2 Neutron Scatter Moisture Contents, November, 1975.



Appendix 8.A.2 Neutron Scatter Moisture Contents, November 1975.

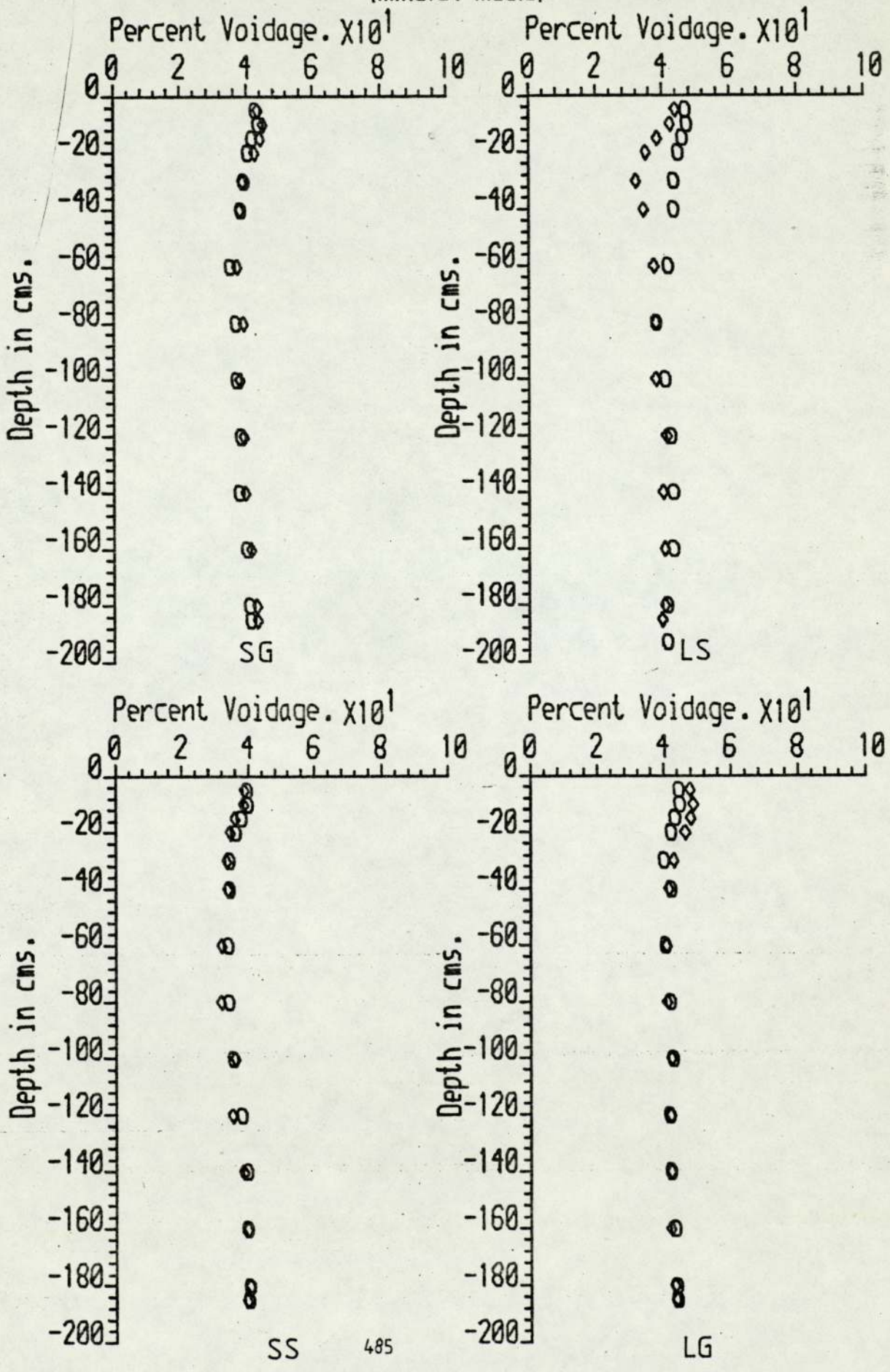


Appendix 8.A.2 Neutron Scatter Moisture Contents, December 1975.

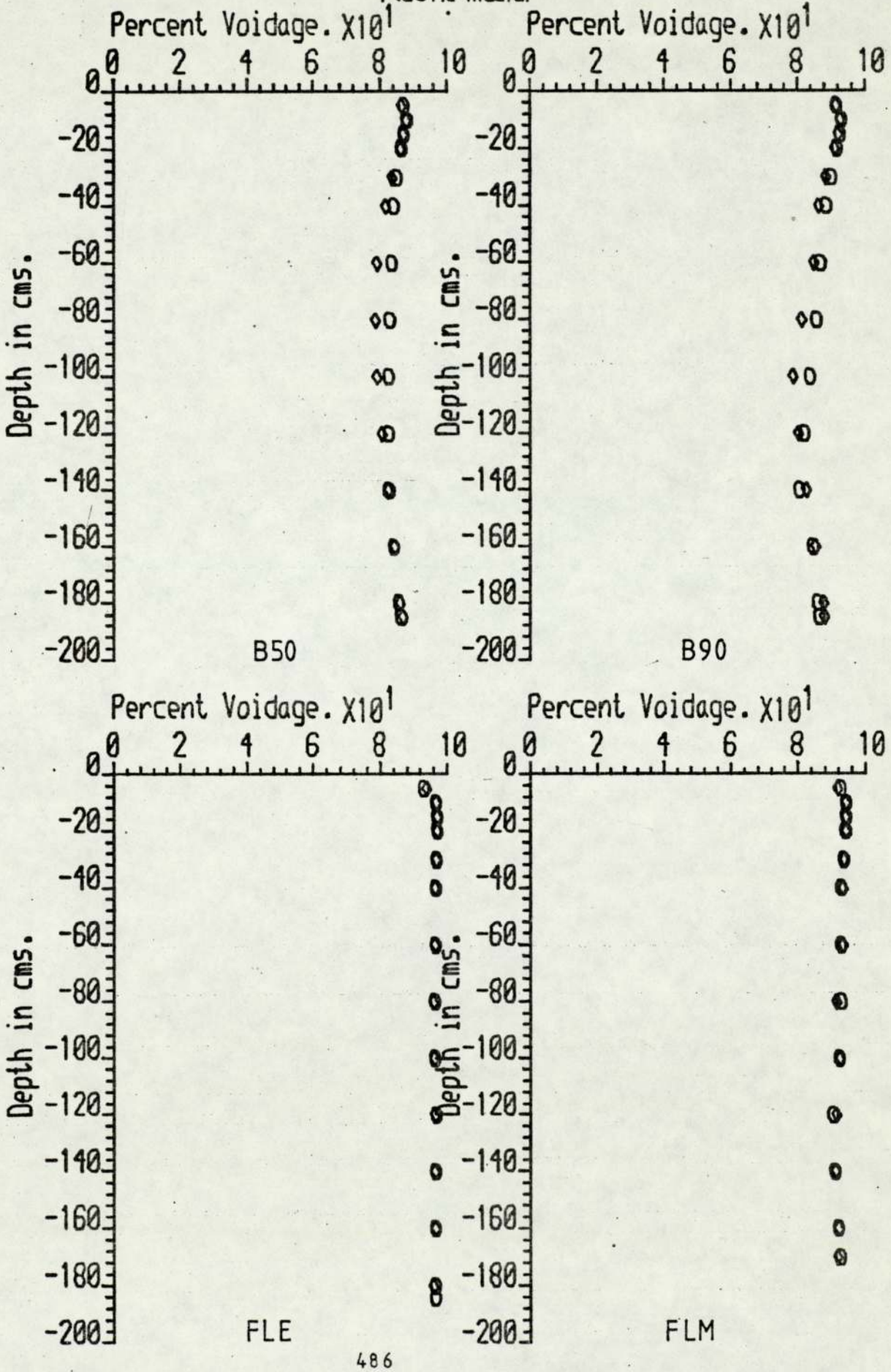


Appendix 8.A.2 Neutron Scatter Moisture Content, December, 1975.

(mineral media)

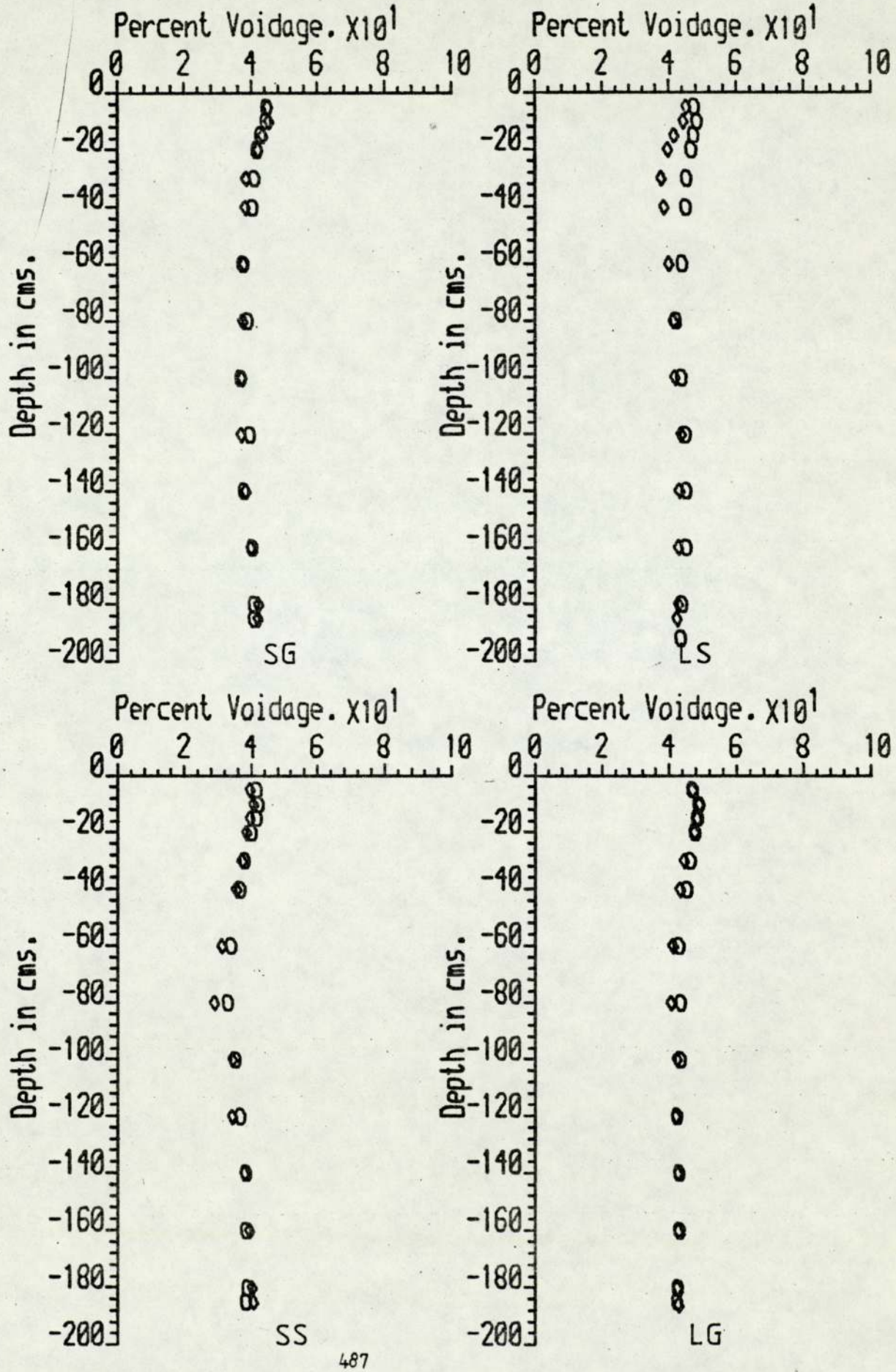


Appendix 8.A.2 Neutron Scatter Moisture Content, January, 1976.
Plastic media.



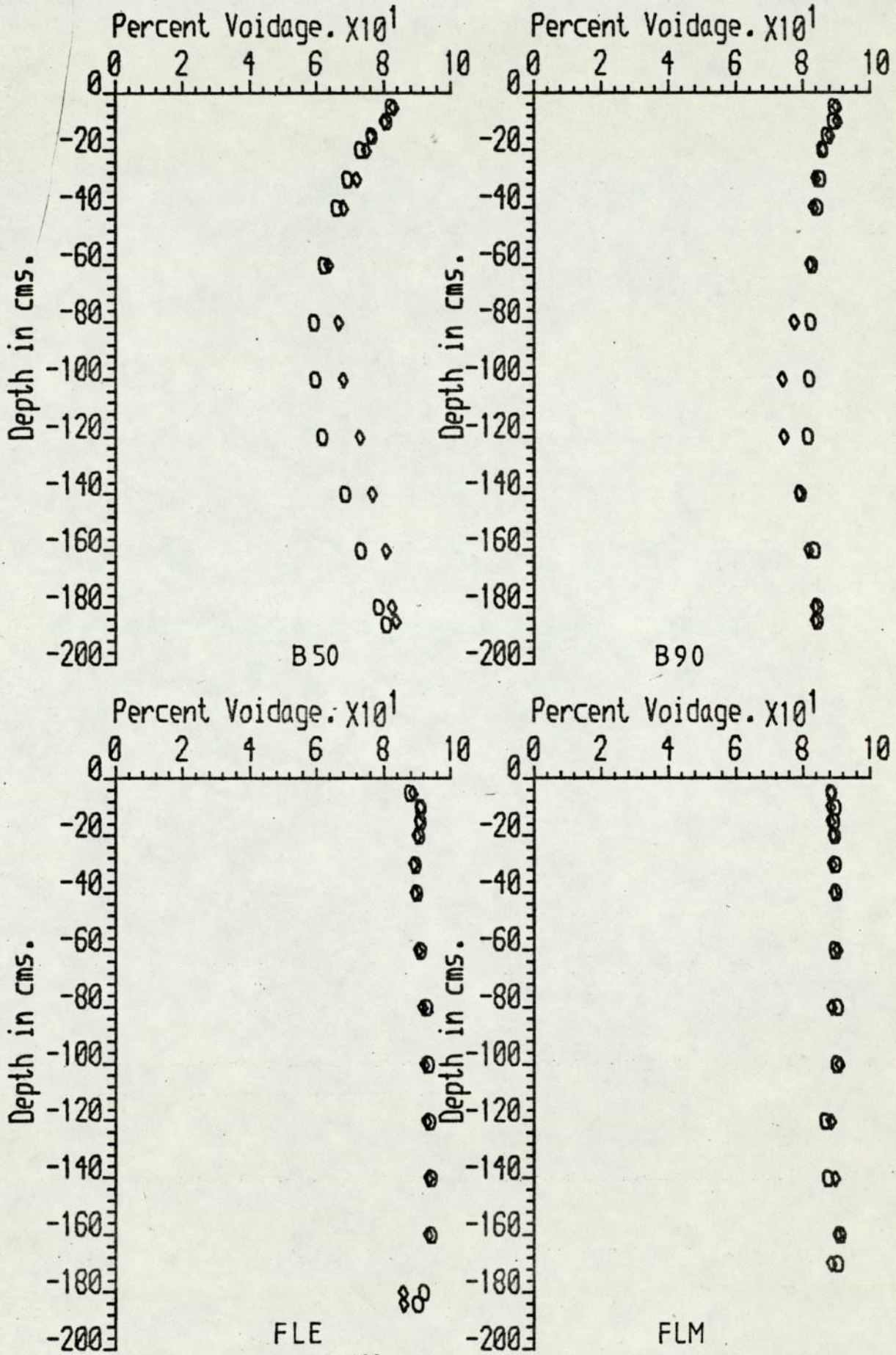
Appendix 8.A.2. Neutron Scatter Moisture Contents, January 1976

mineral media



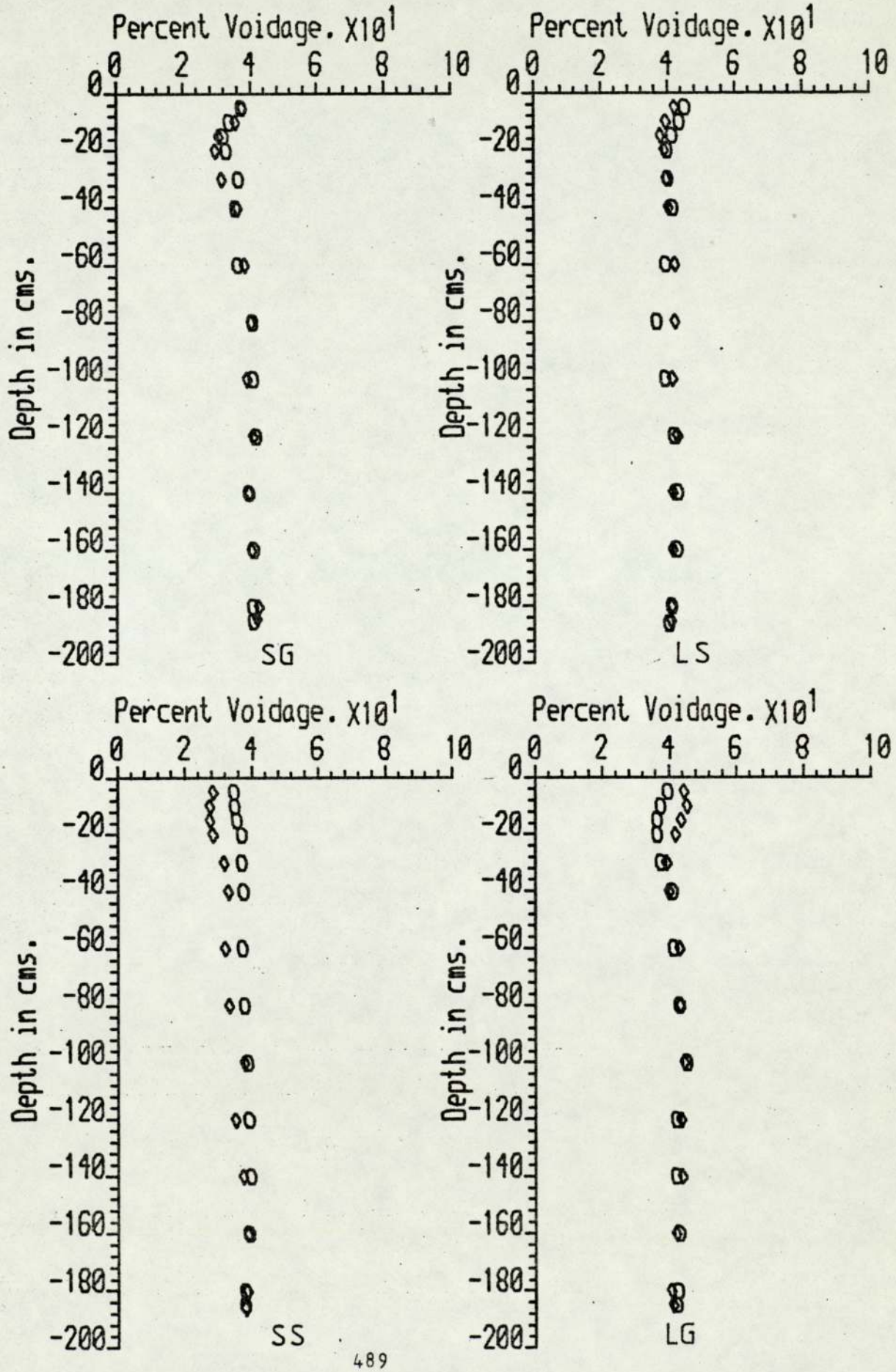
Appendix 8.A.2 Neutron Scatter Moisture Contents, February 1976.

Plastic media.



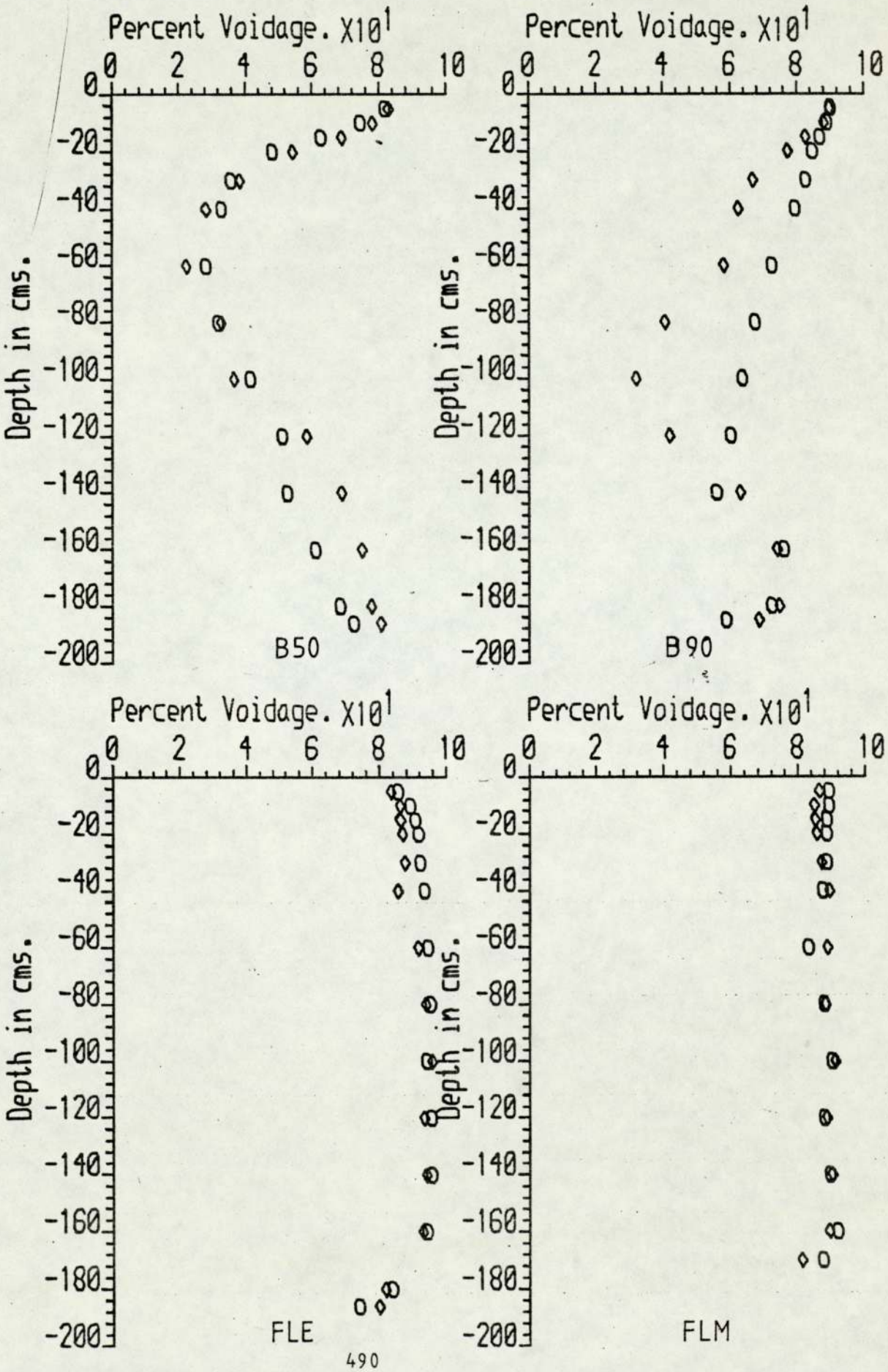
Appendix 8.A.2. Neutron Scatter Moisture Contents, February 1976.

Mineral media.



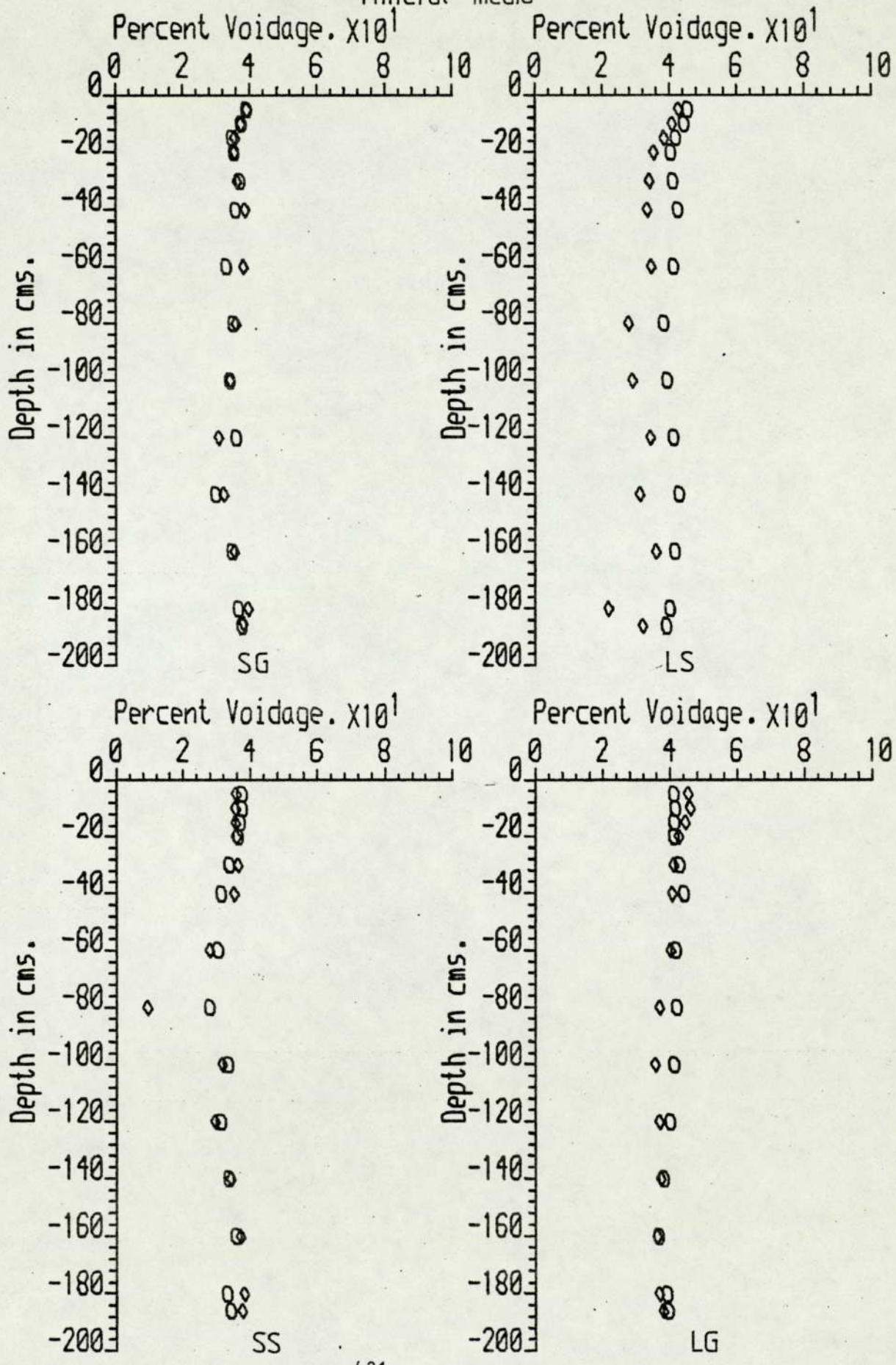
Appendix 8.A.2. Neutron Scatter Moisture Contents, March 1976.

Plastic media

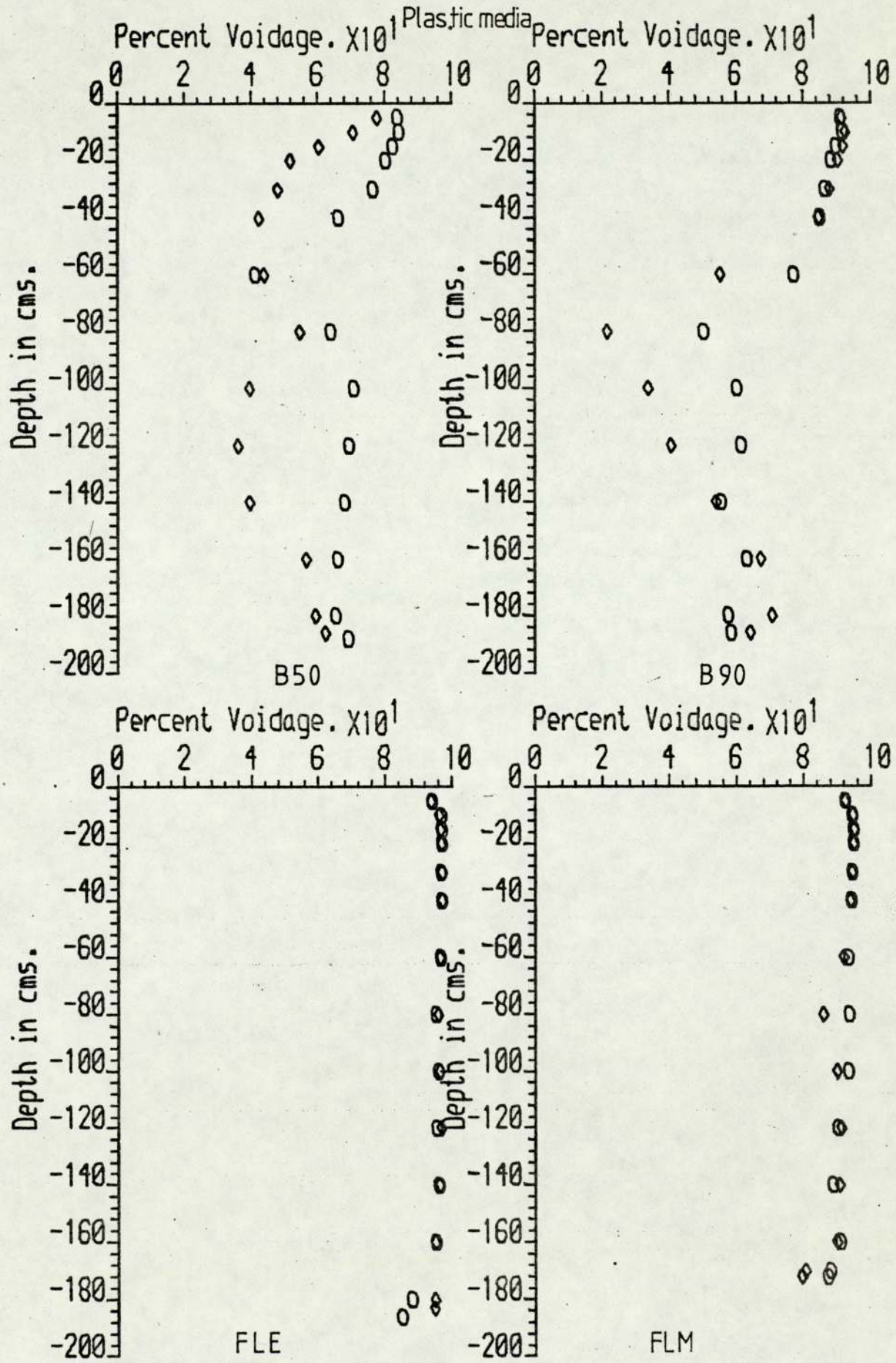


Appendix 8.A.2 Neutron Scatter Moisture Contents, March 1976

Mineral media

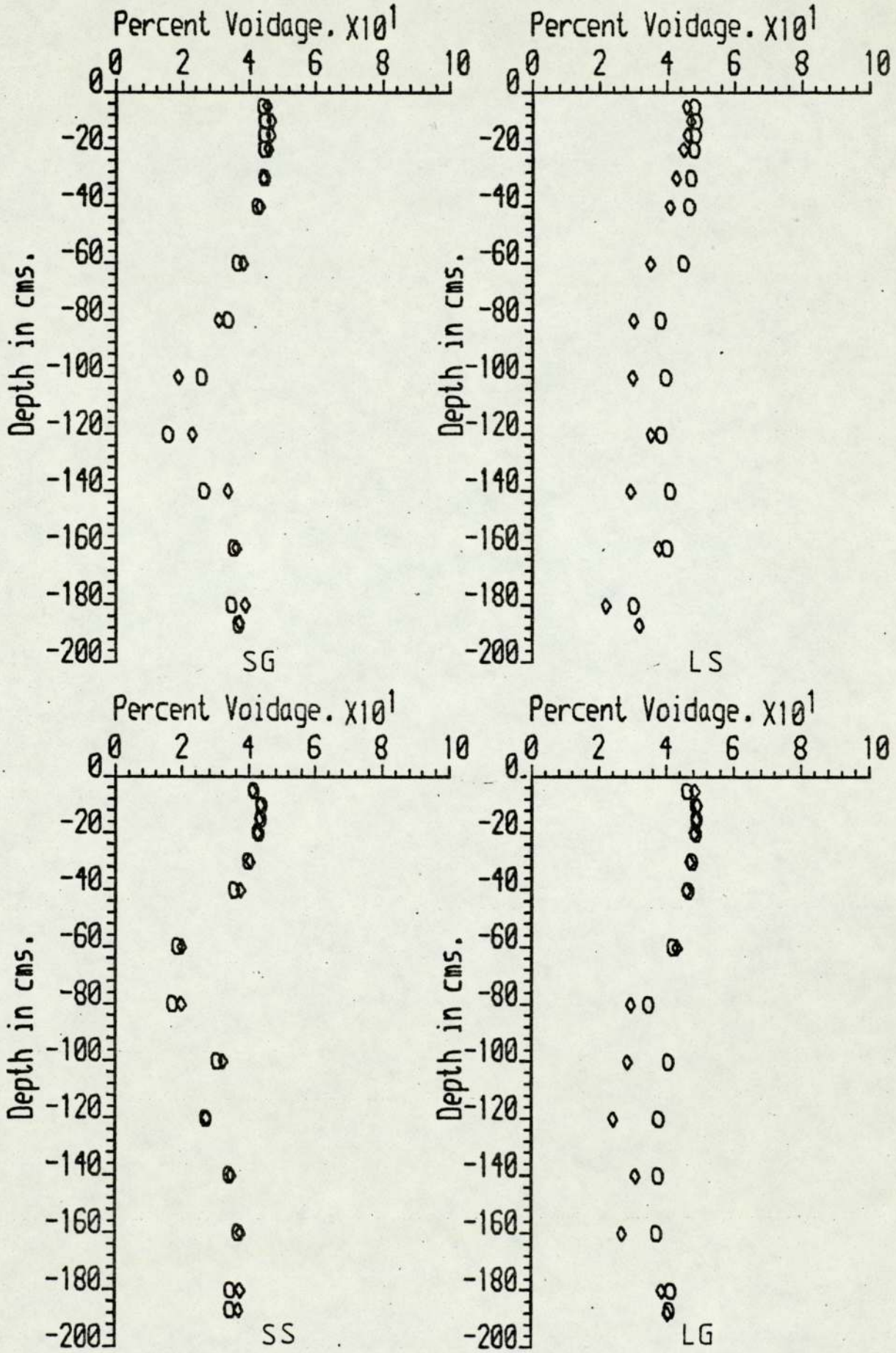


Appendix 8.A.2 Neutron Scatter Moisture Content, April 1976



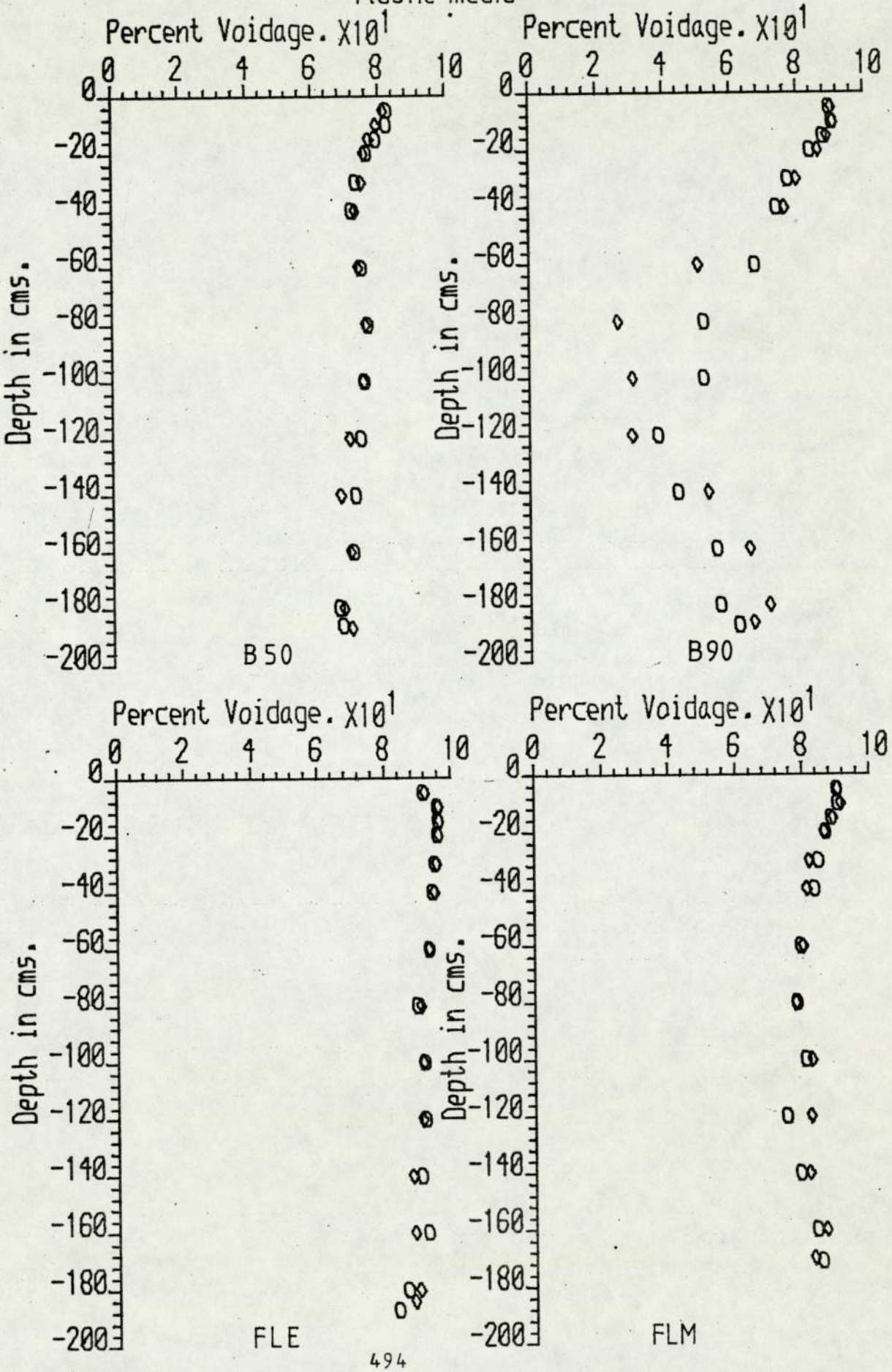
Appendix 8.A.2 Neutron Scatter Moisture Contents, April 1976

Mineral media

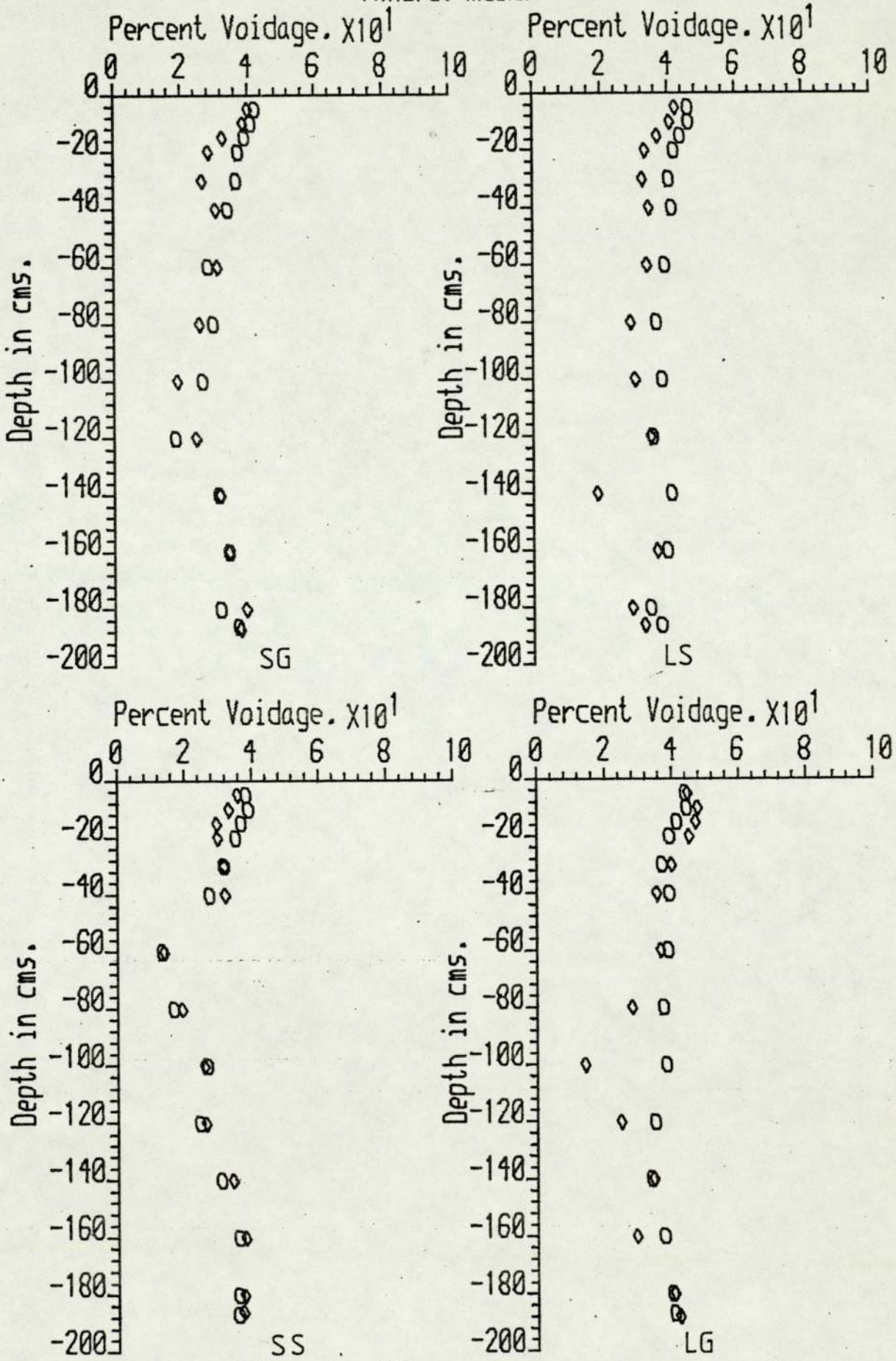


Appendix 8.A.2 Neutron Scatter Moisture Contents, May 1976.

Plastic media

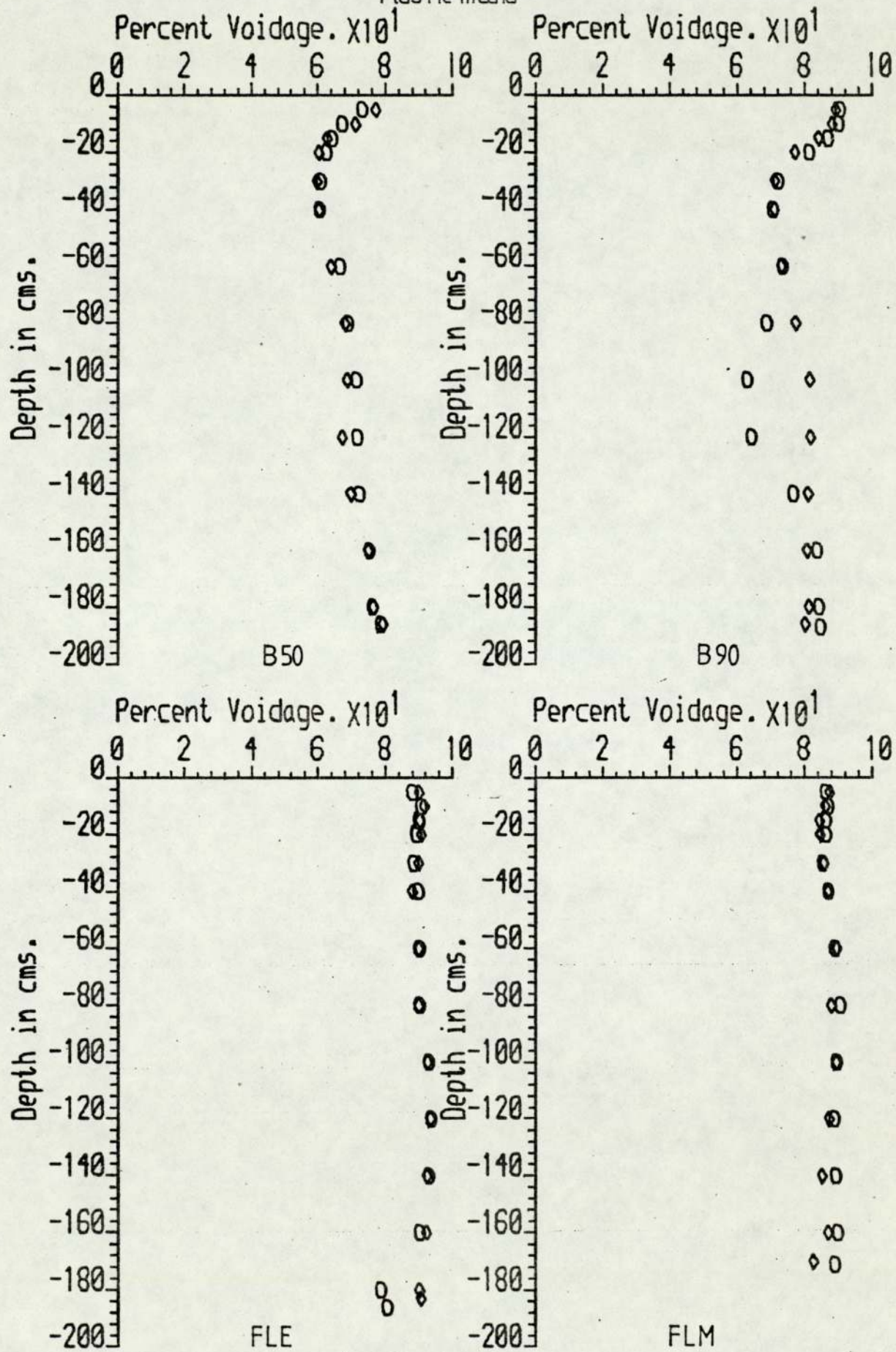


Appendix 8.A.2 Neutron Scatter Moisture Contents, May 1976
Mineral media.

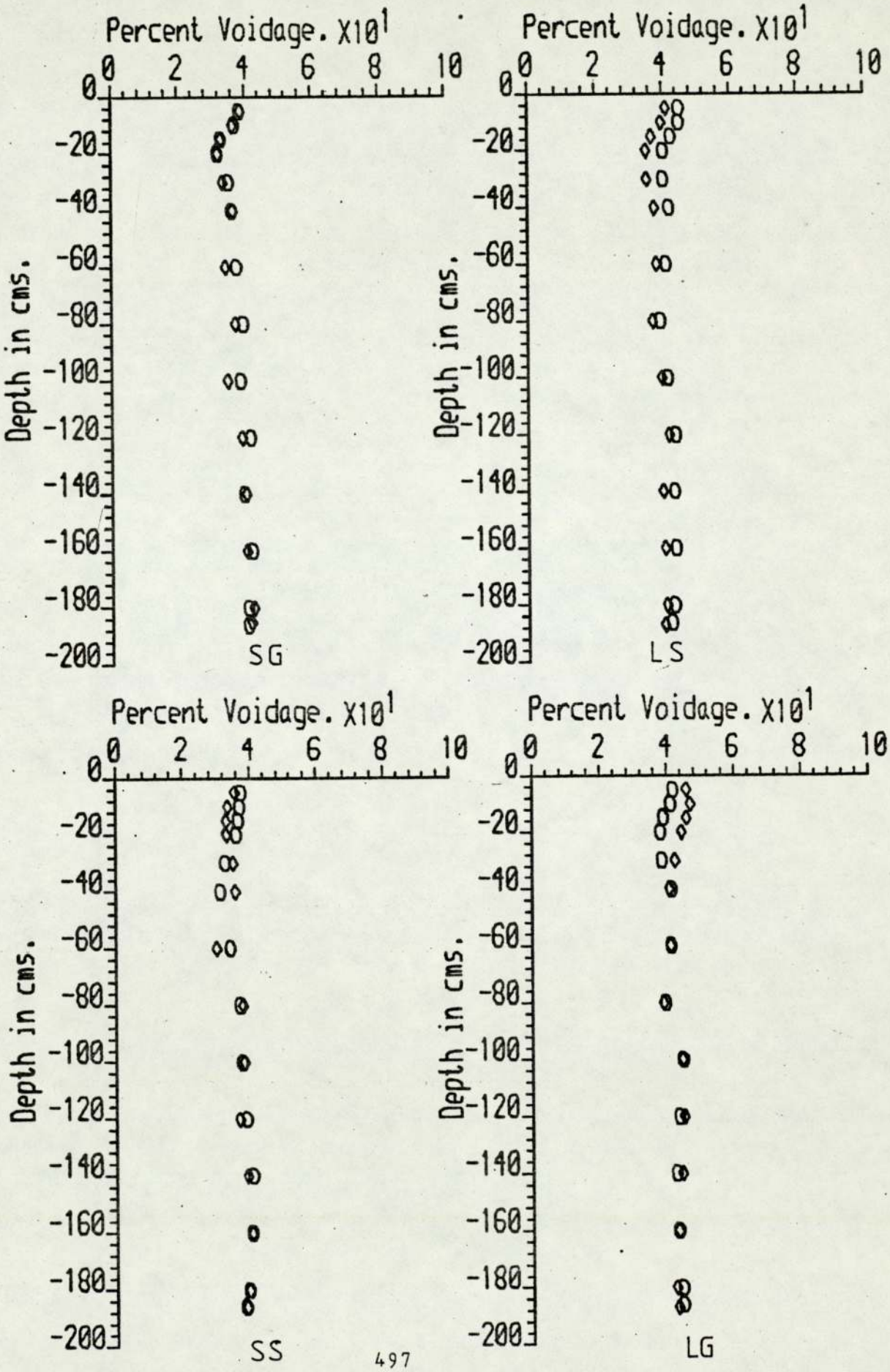


Appendix 8.A.2 Neutron Scatter Moisture Contents, June 1976.

Plastic media

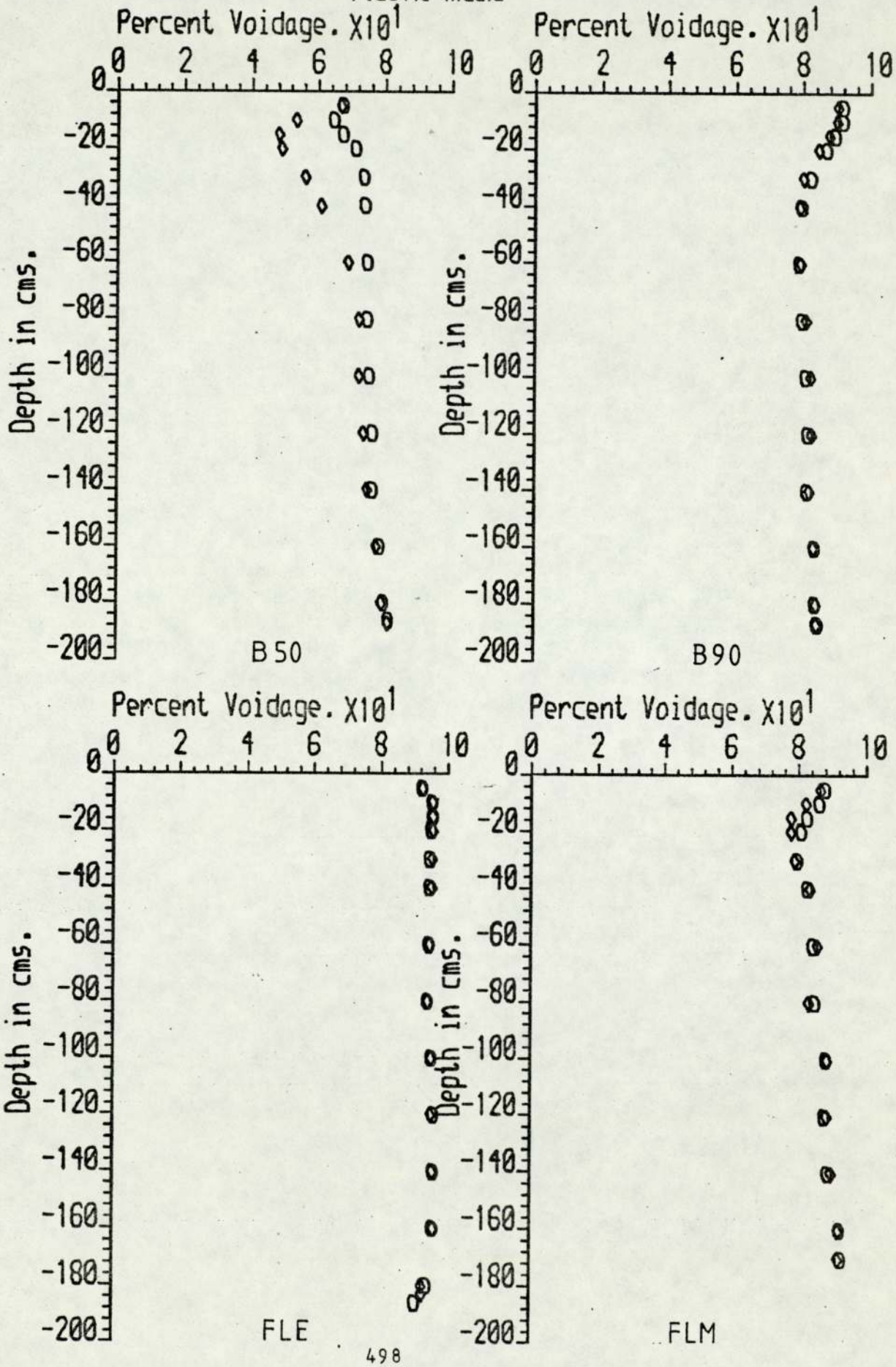


Appendix 8A.2 Neutron Scatter Moisture Contents, June 1976.



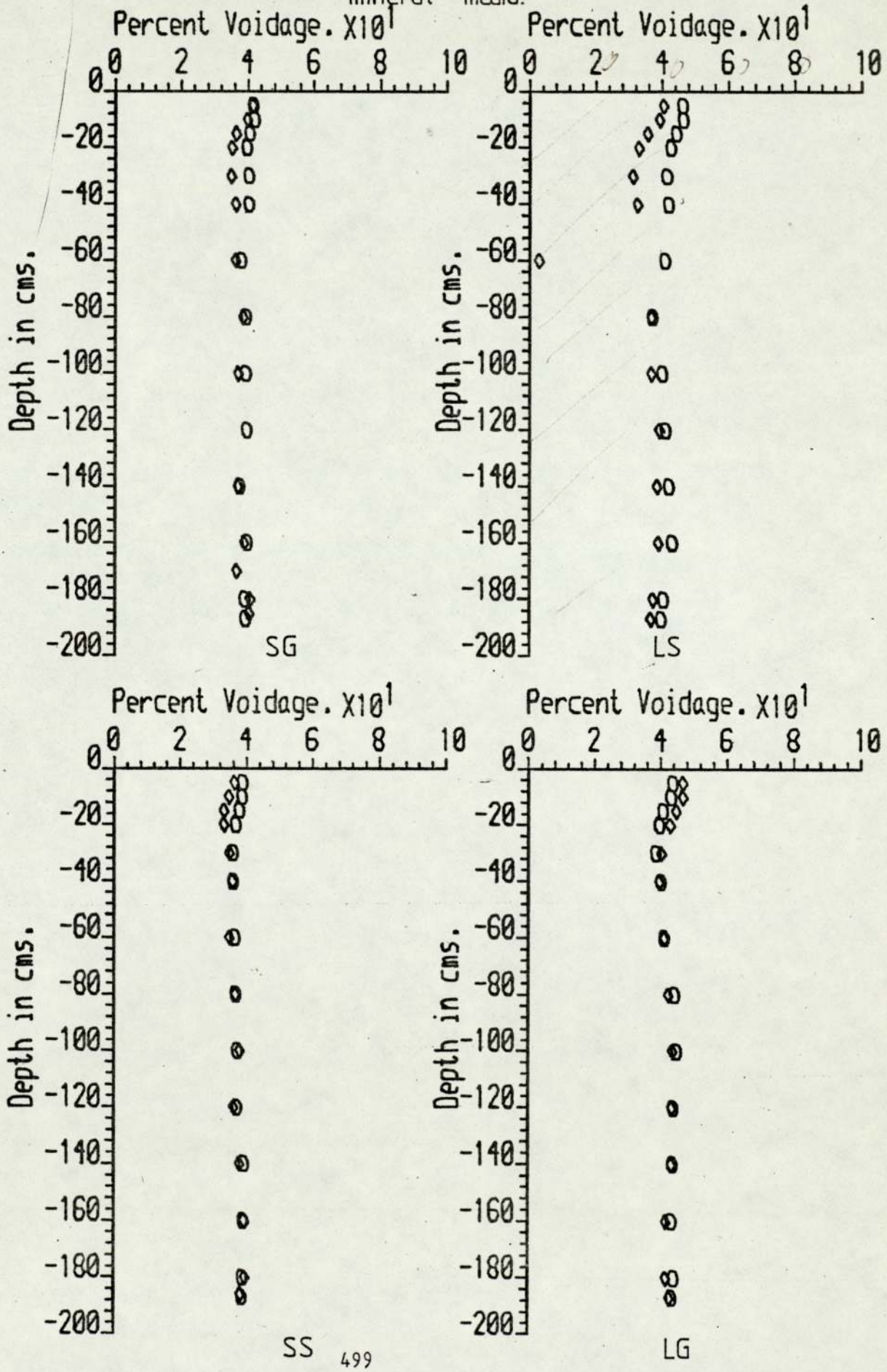
Appendix 8A.2 Neutron Scatter Moisture Contents, July 1976

Plastic media

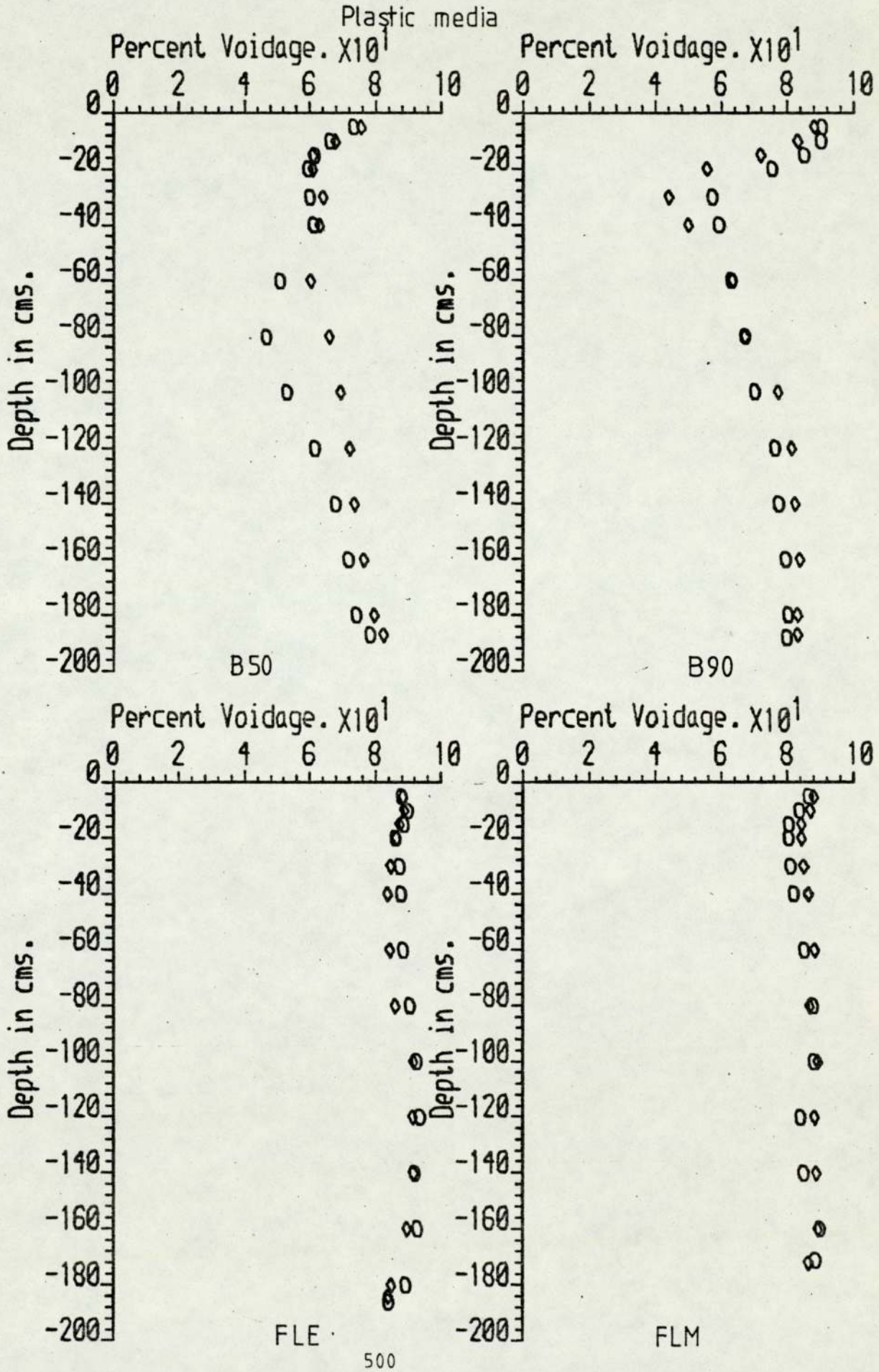


Appendix8.A.2 Neutron Scatter Moisture Contents, July 1976

mineral media.

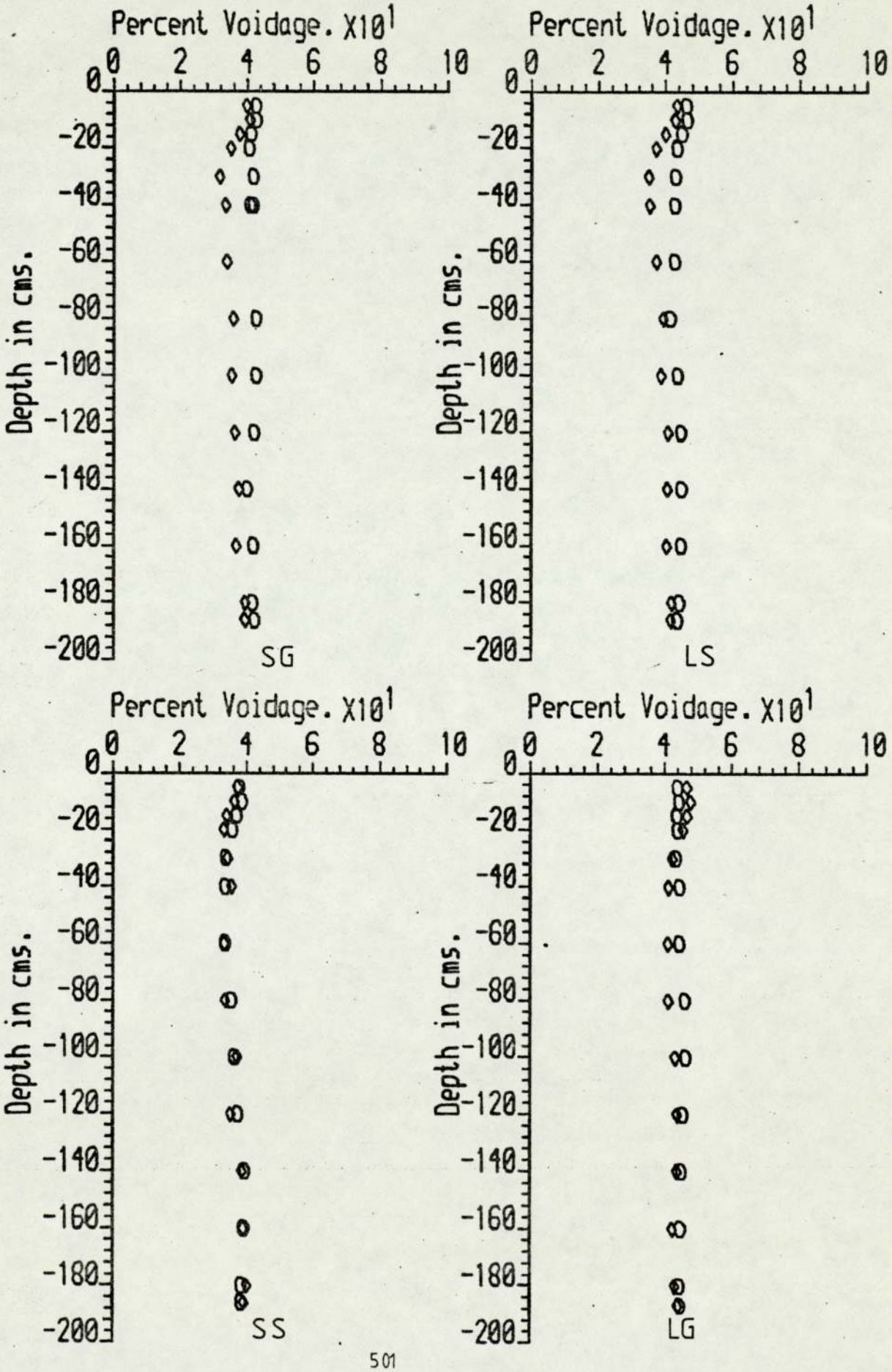


Appendix 8.A.2 Neutron Scatter Moisture Contents, September 1976



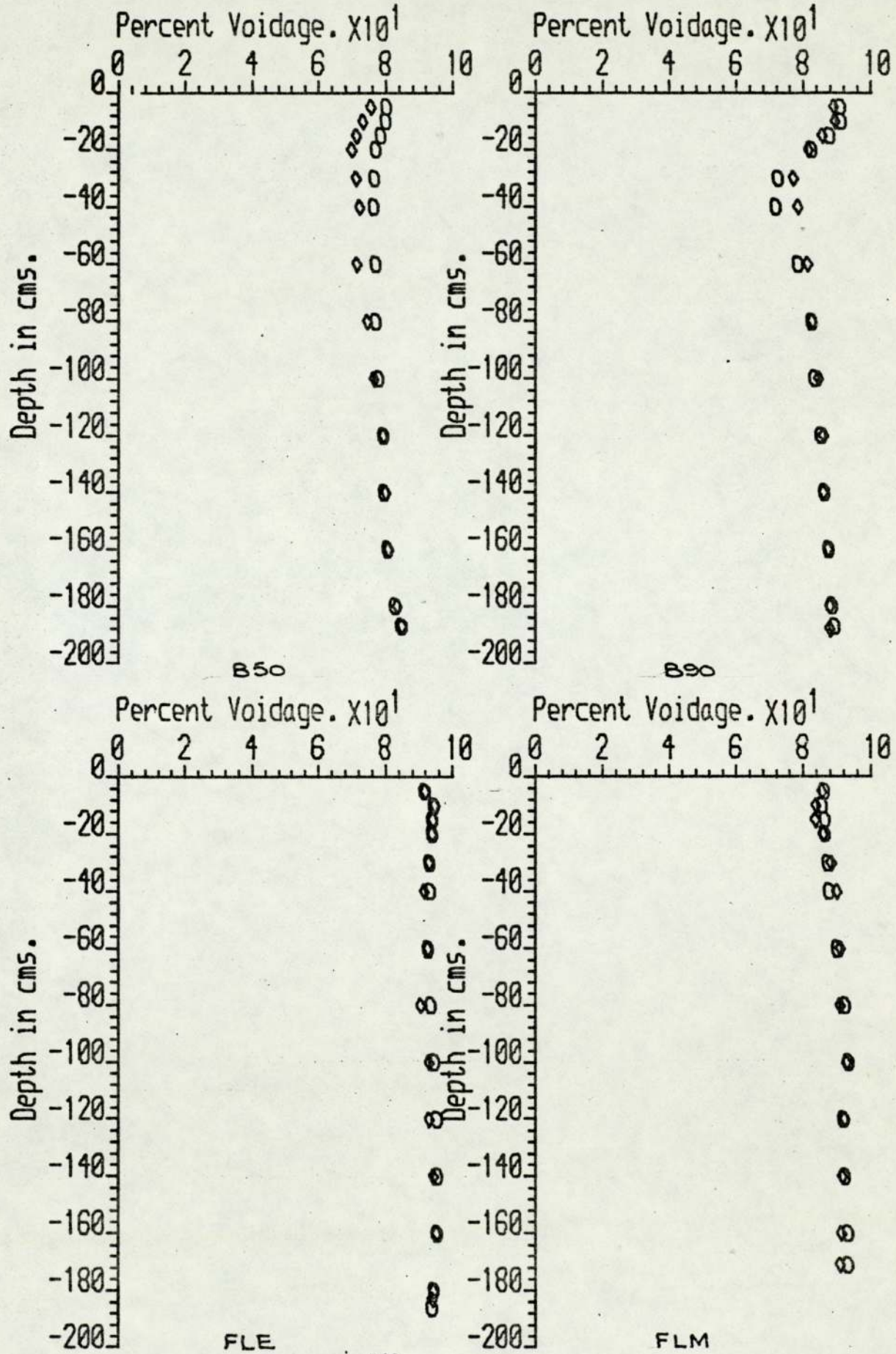
Appendix 8.A.2 Neutron Scatter Moisture Contents, September 1976

Mineral media.



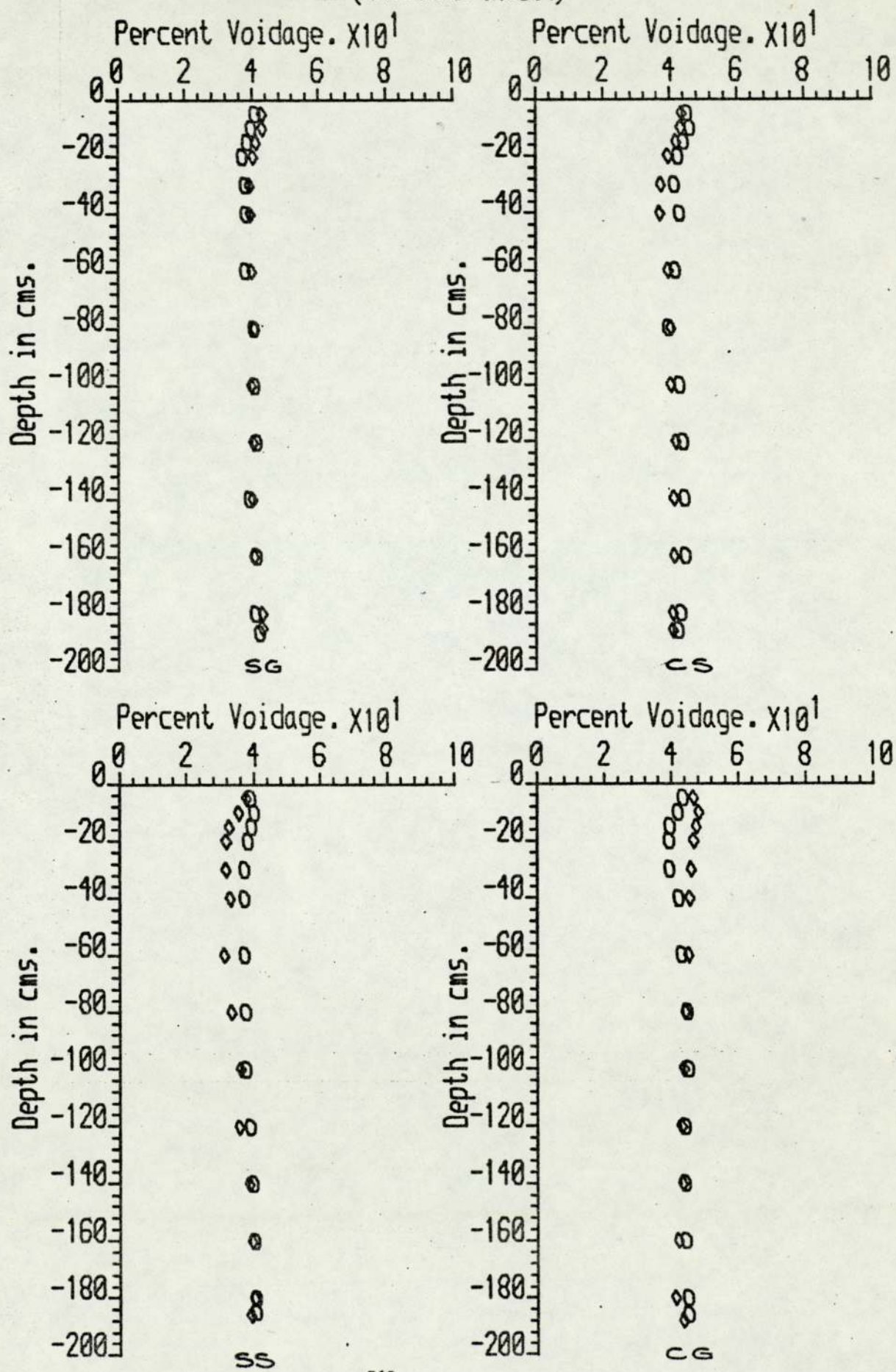
APPENDIX 8.A2. NEUTRON SCATTER MOISTURE CONTENT PROFILES OCT. 76

(PLASTIC MEDIA)



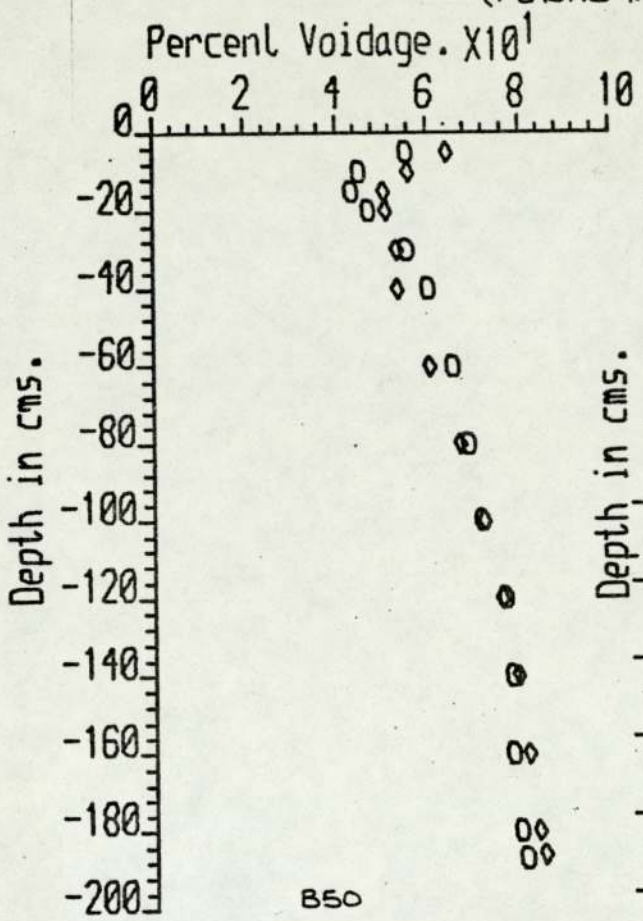
APPENDIX 8.A2. NEUTRON SCATTER MOISTURE CONTENT PROFILES OCT. 76

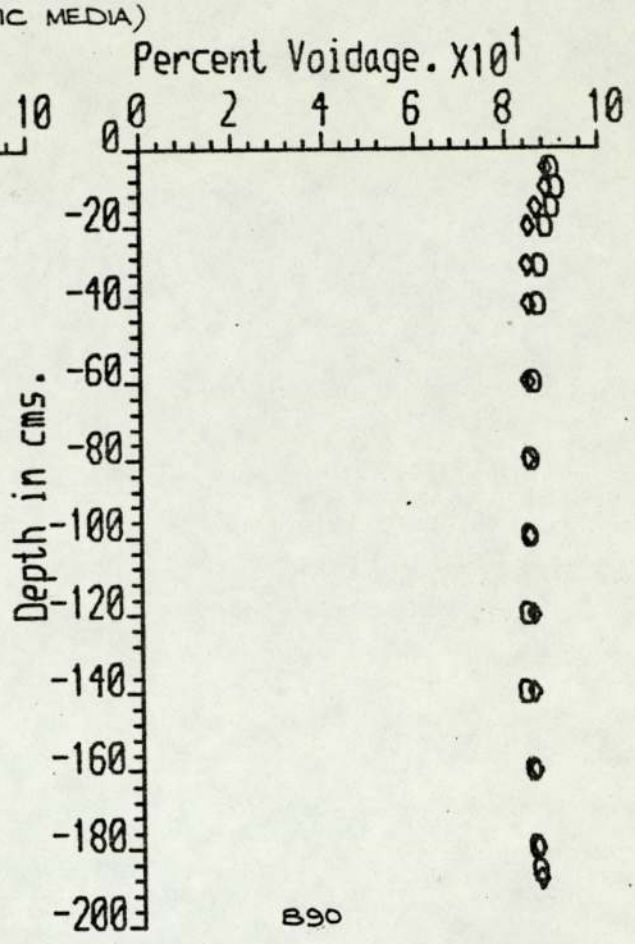
(MINERAL MEDIA)

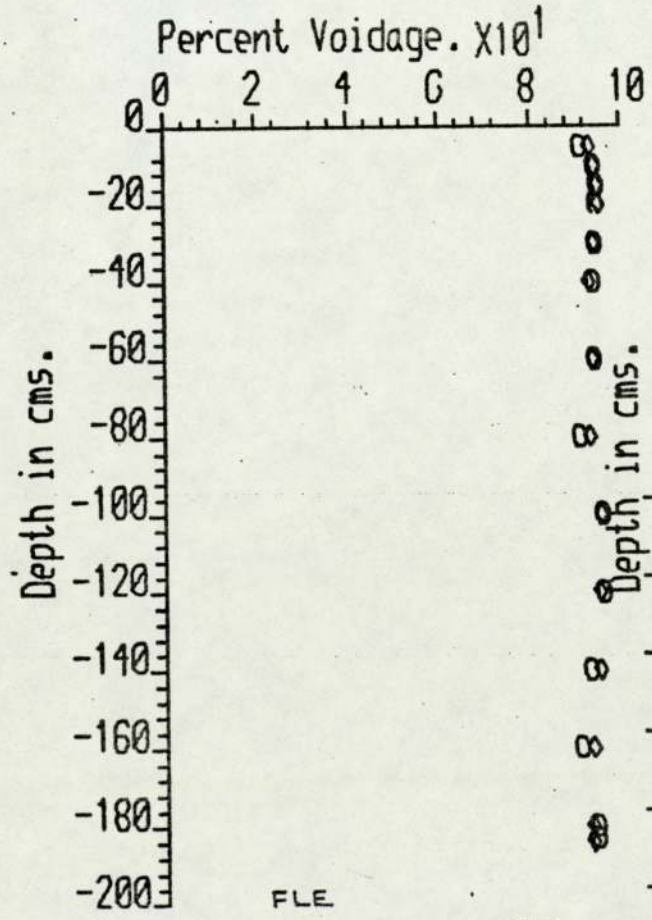


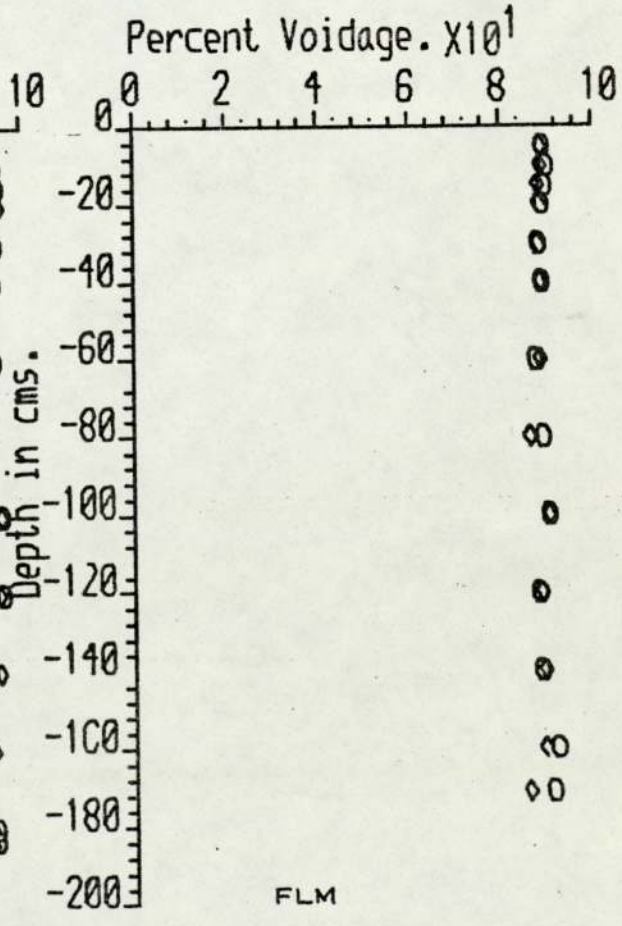
APPENDIX 8 A2. NEUTRON SCATTER MOISTURE CONTENT PROFILES. Nov. 76

(PLASTIC MEDIA)



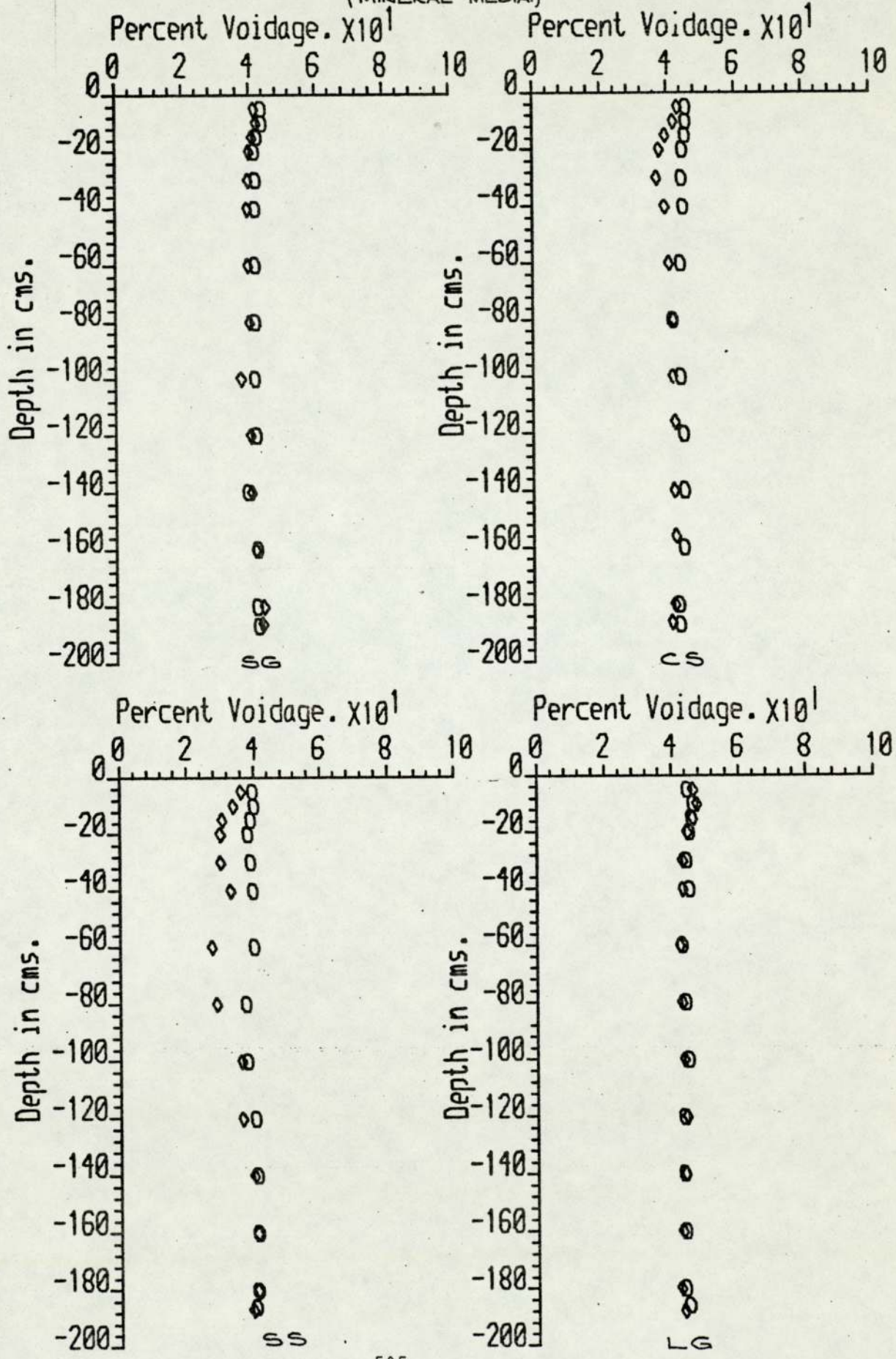






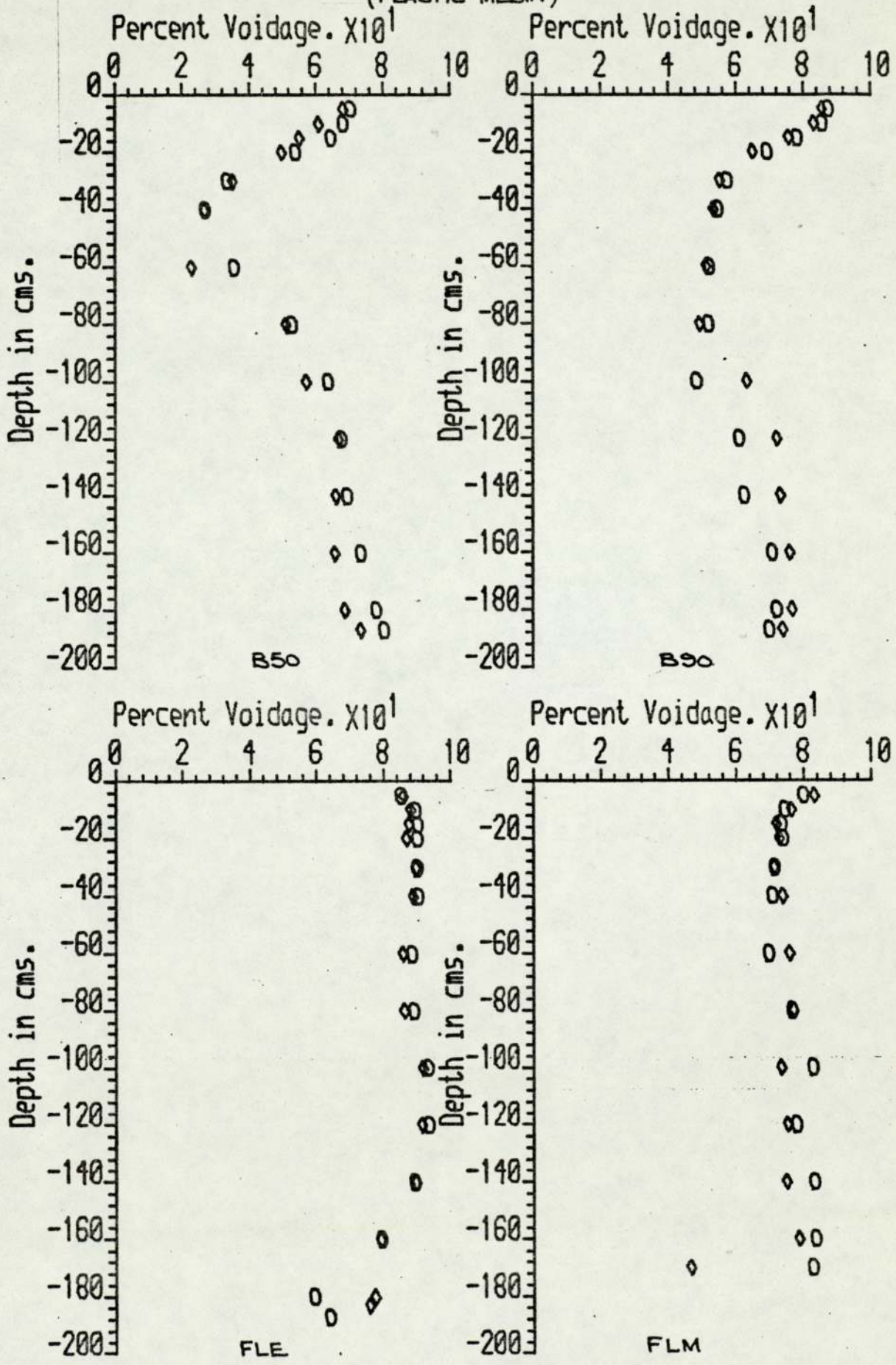
APPENDIX 8. A2. NEUTRON SCATTER MOISTURE CONTENT PROFILES NOV. 76

(MINERAL MEDIA.)



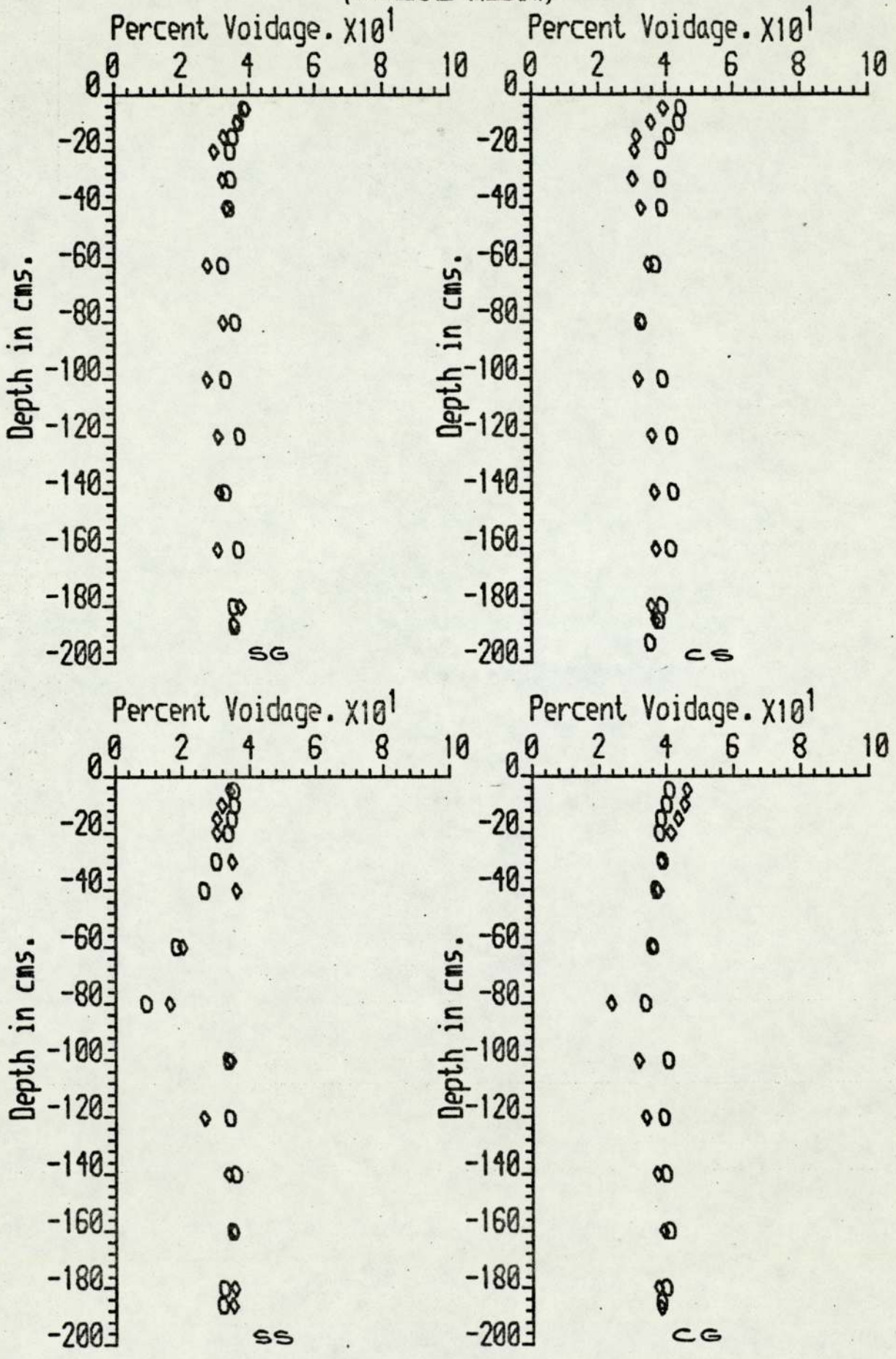
APPENDIX 8.A2. NEUTRON SCATTER MOISTURE CONTENT PROFILES. DEC 76

(PLASTIC MEDIA)

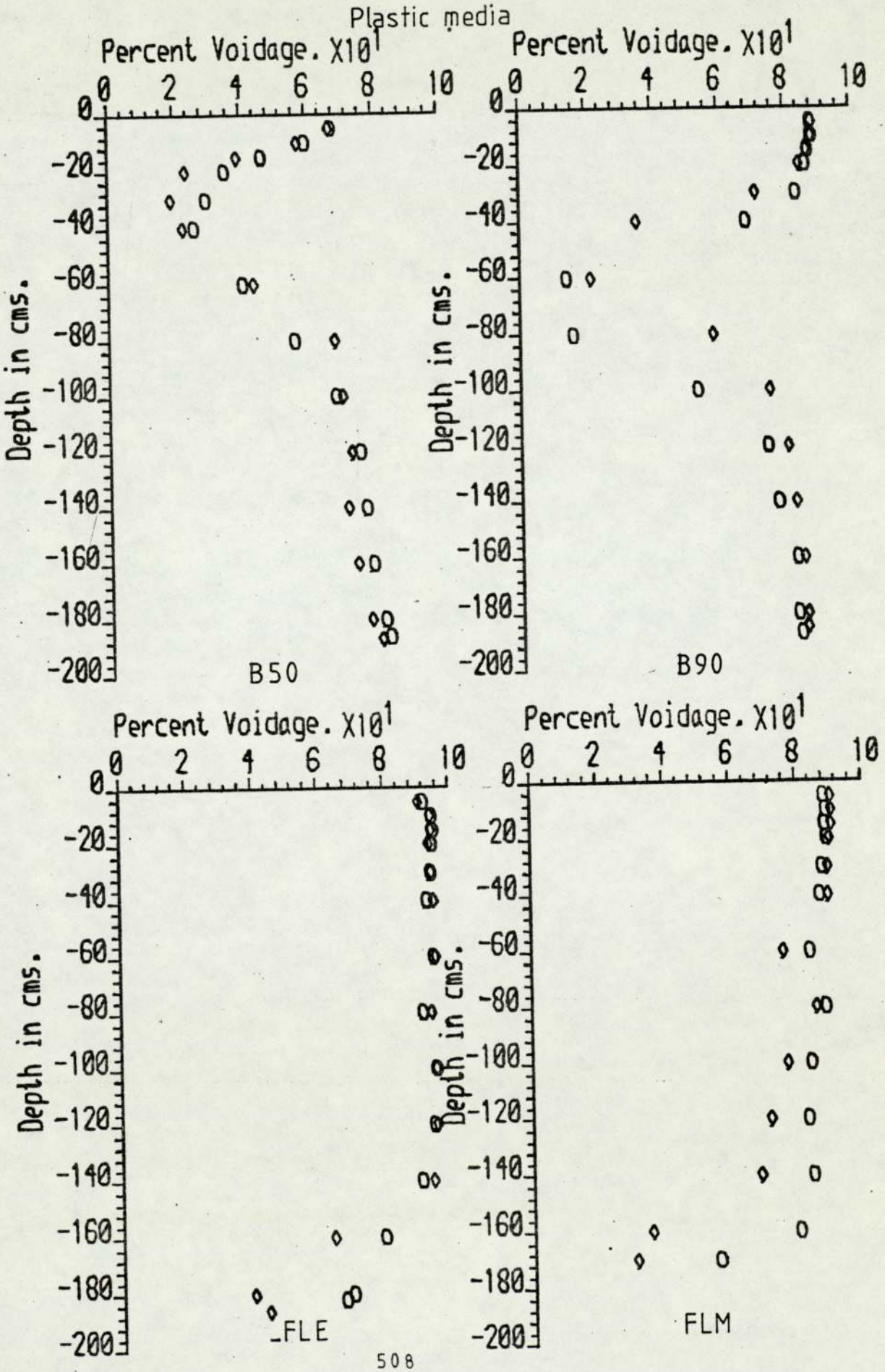


APPENDIX 8.A2. NEUTRON SCATTER MOISTURE CONTENT PROFILES. DEC.76.

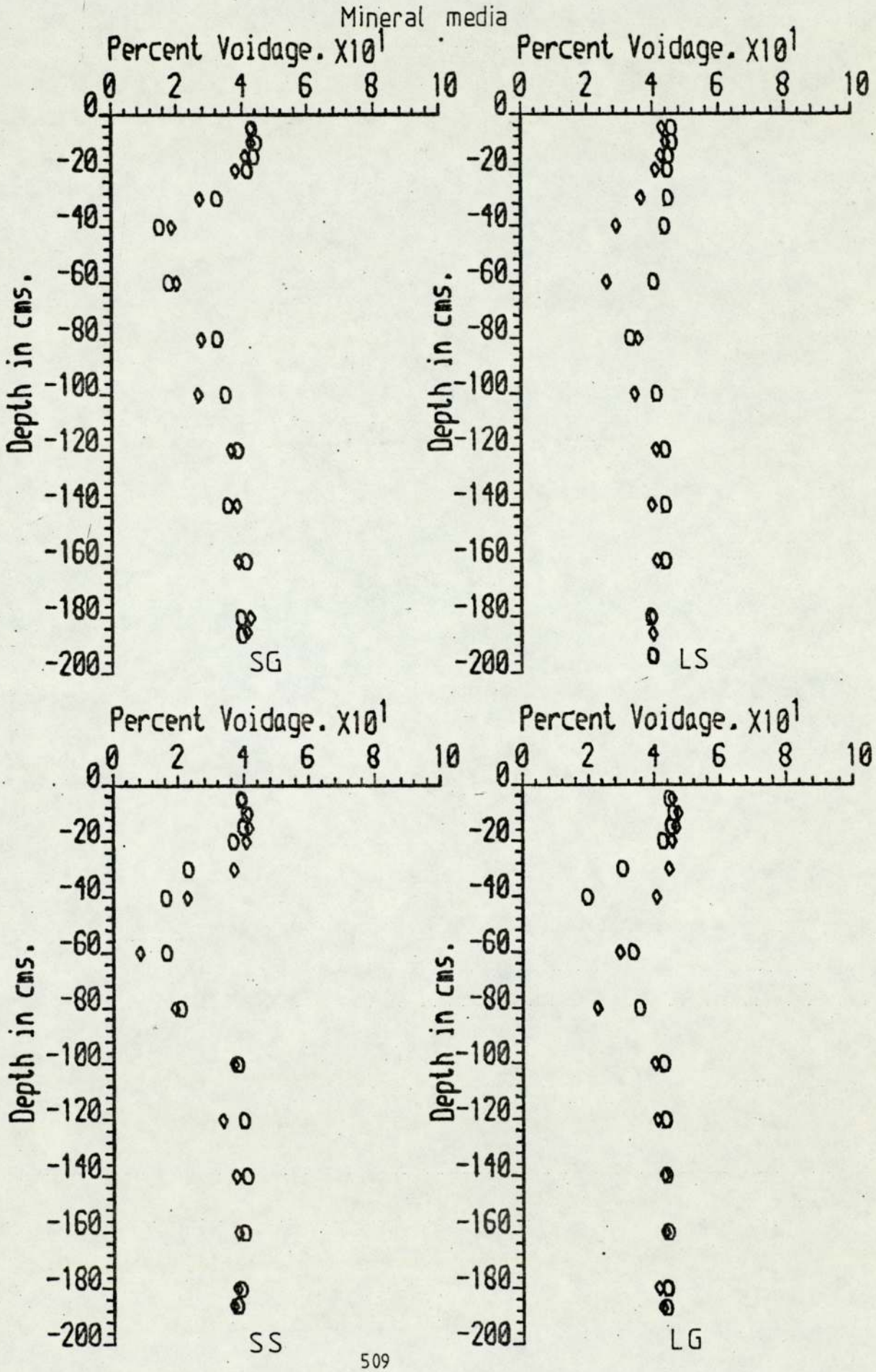
(MINERAL MEDIA.)



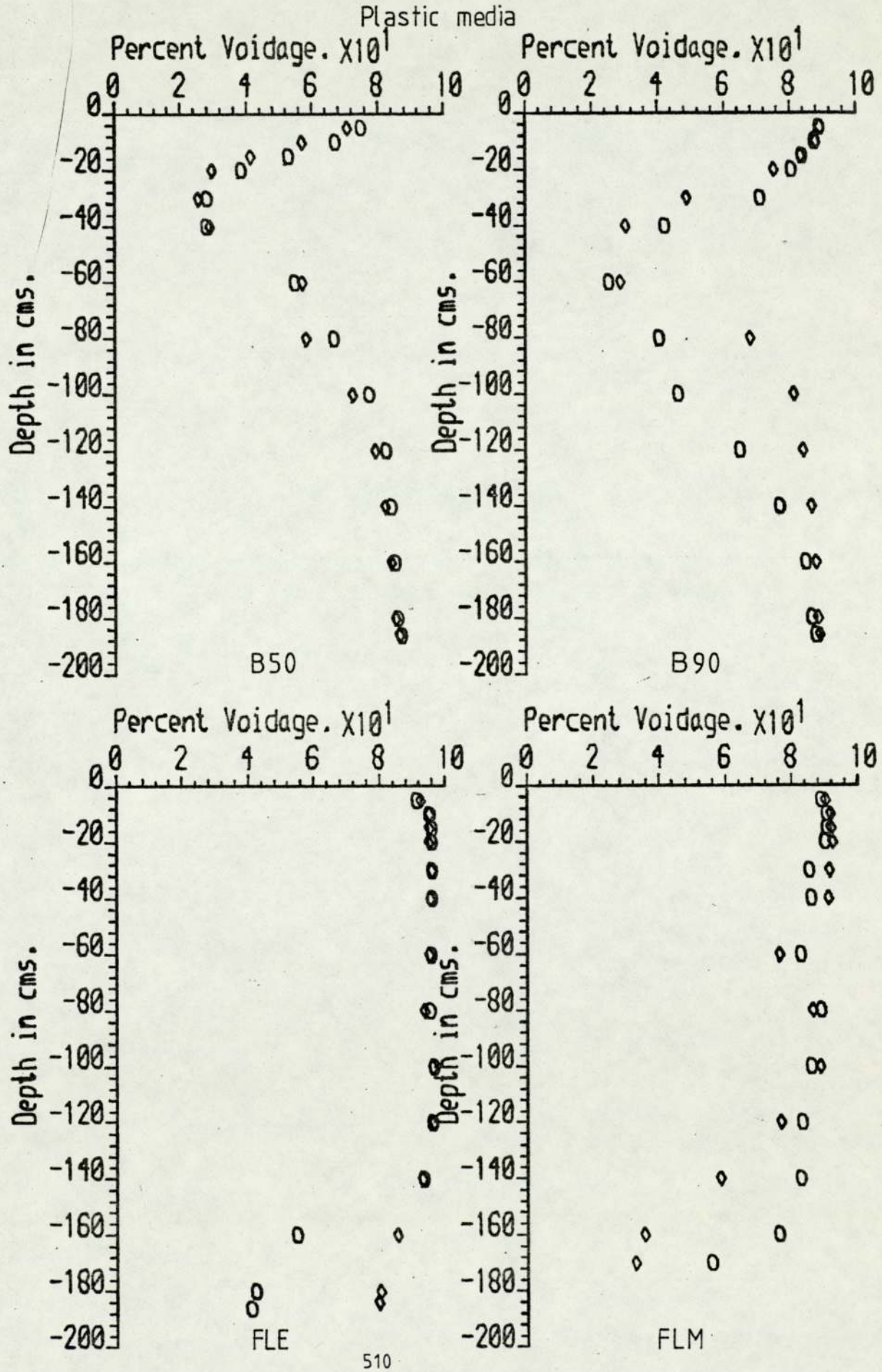
Appendix 8.A.2 Neutron Scatter Moisture Contents, January 1977



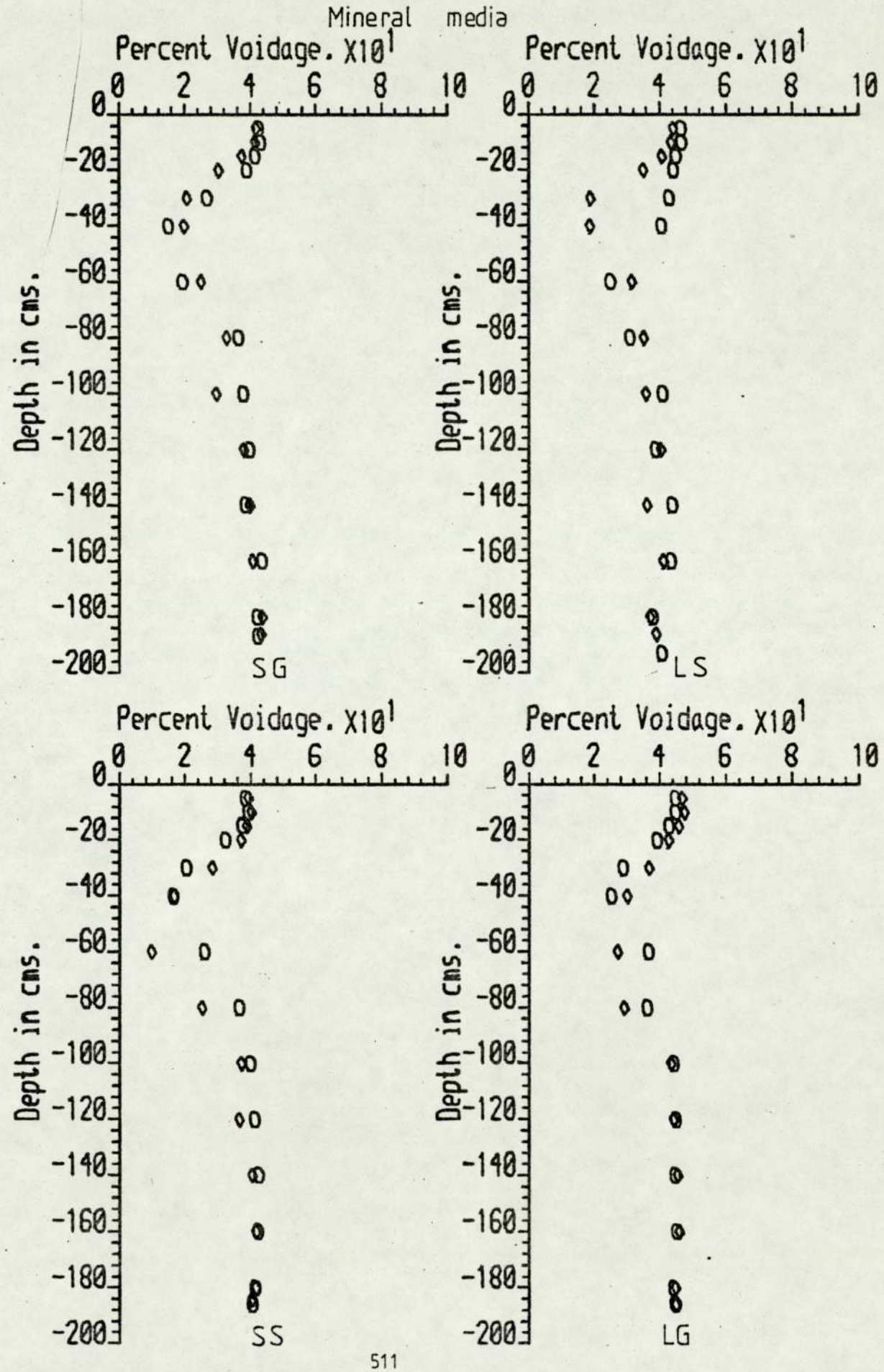
Appendix 8.A.2 Neutron Scatter Moisture Contents, January 1977.



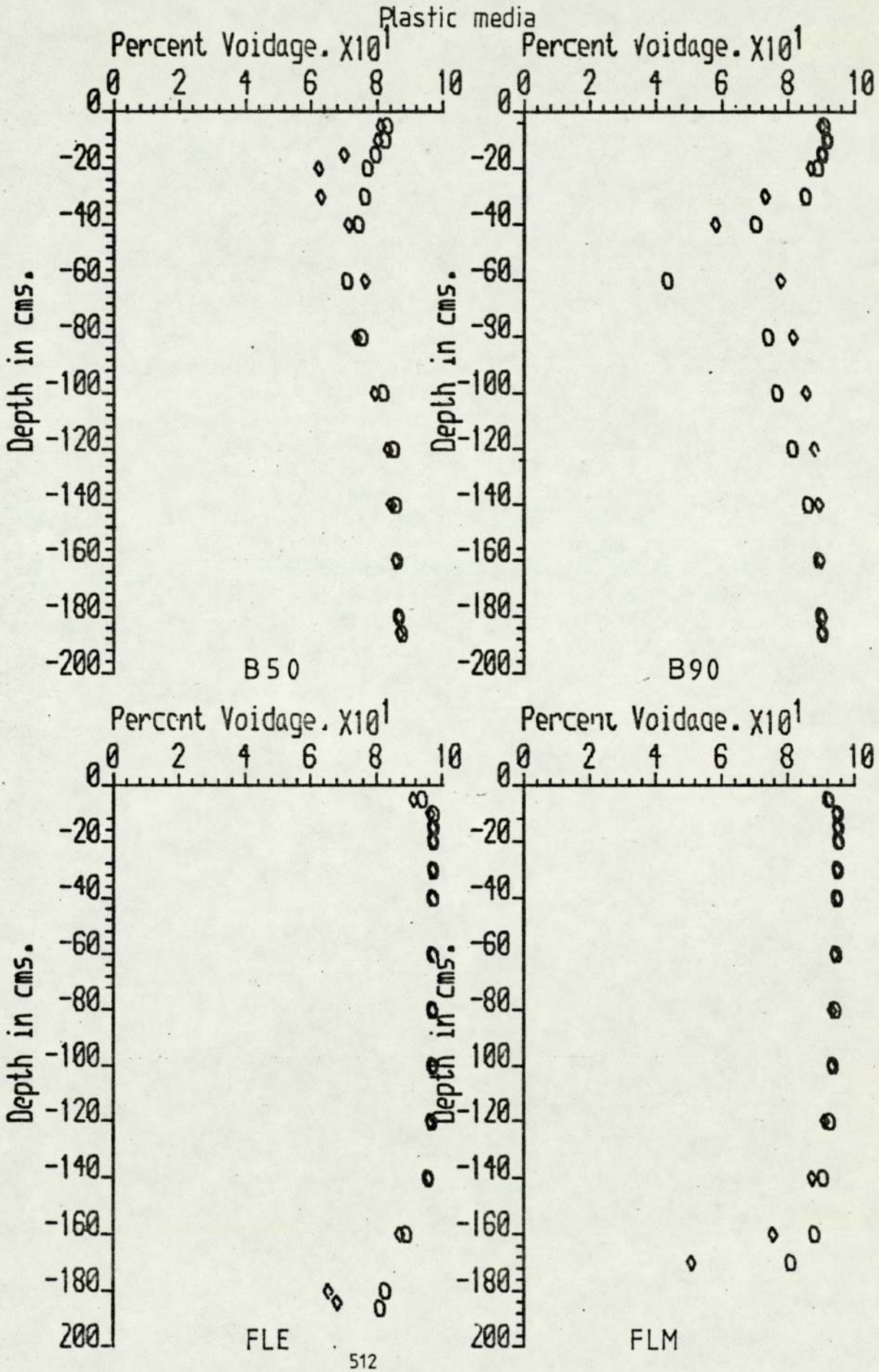
Appendix 8.A.2 Neutron Scatter Moisture Contents, February 1977.



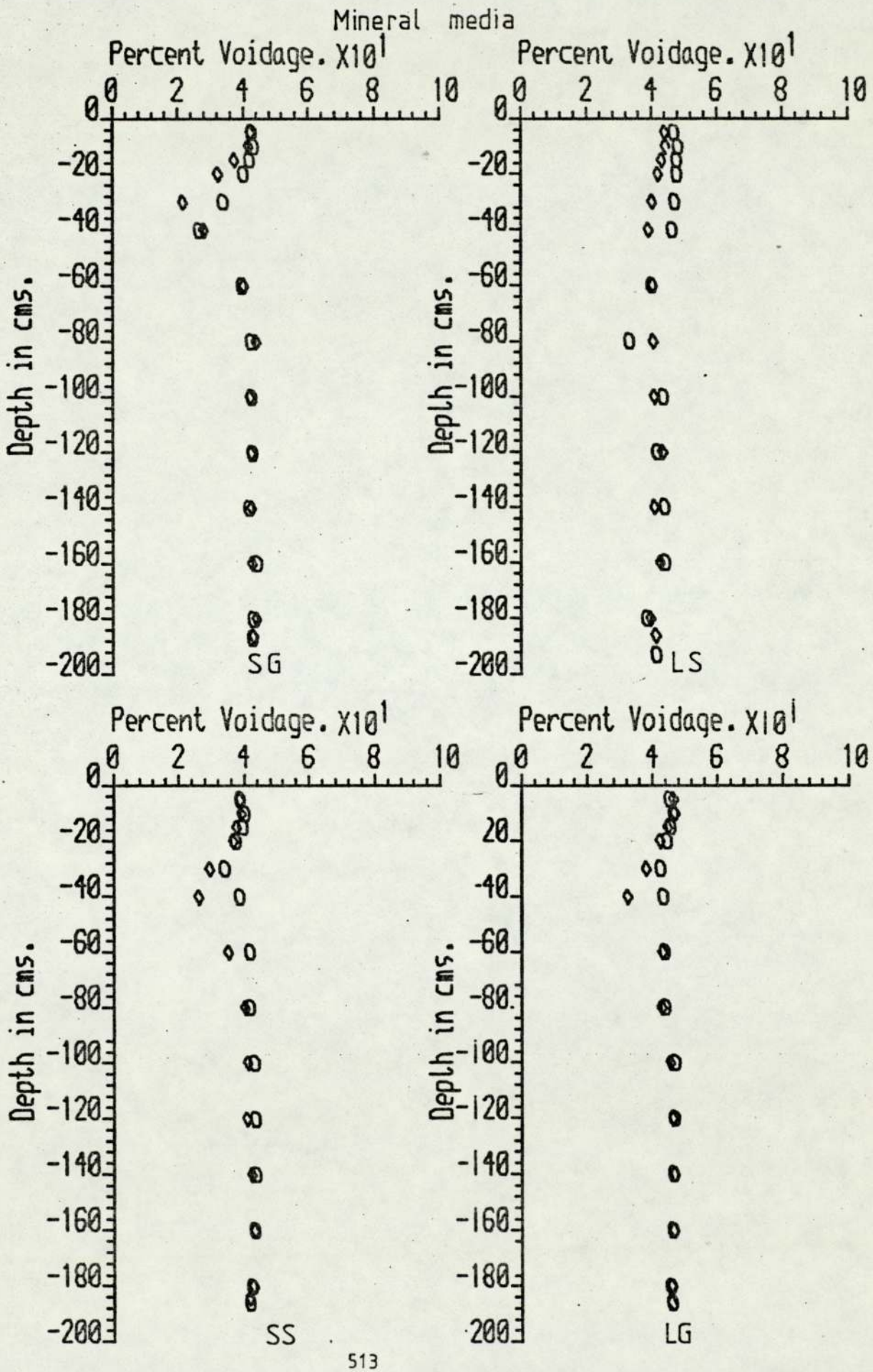
Appendix 8.A.2 Neutron Scatter Moisture Contents, February 1977



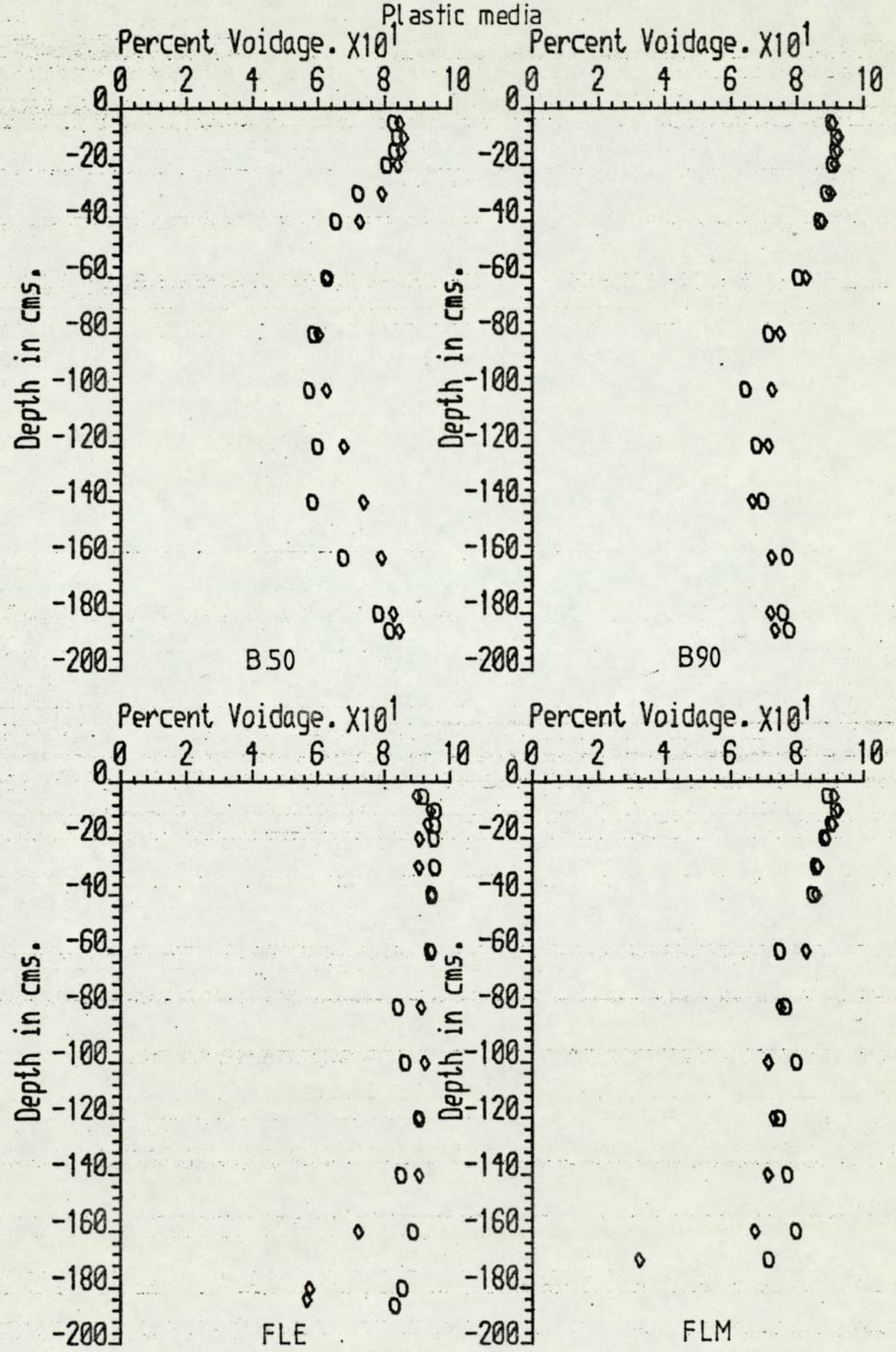
Appendix 8A.2 Neutron Scatter Moisture Contents, March 1977.



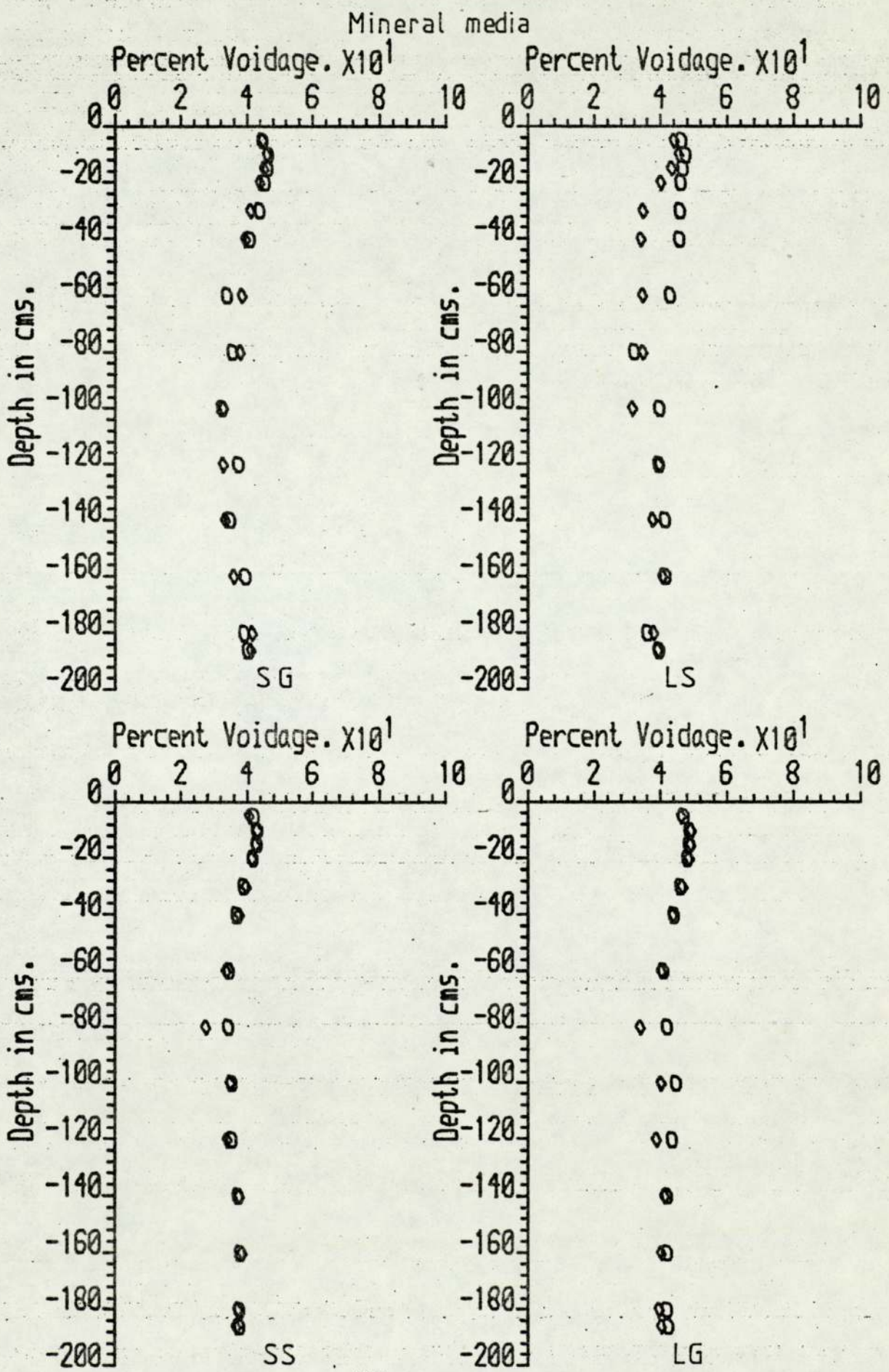
Appendix 8.A.2 Neutron Scatter Moisture Contents, March 1977



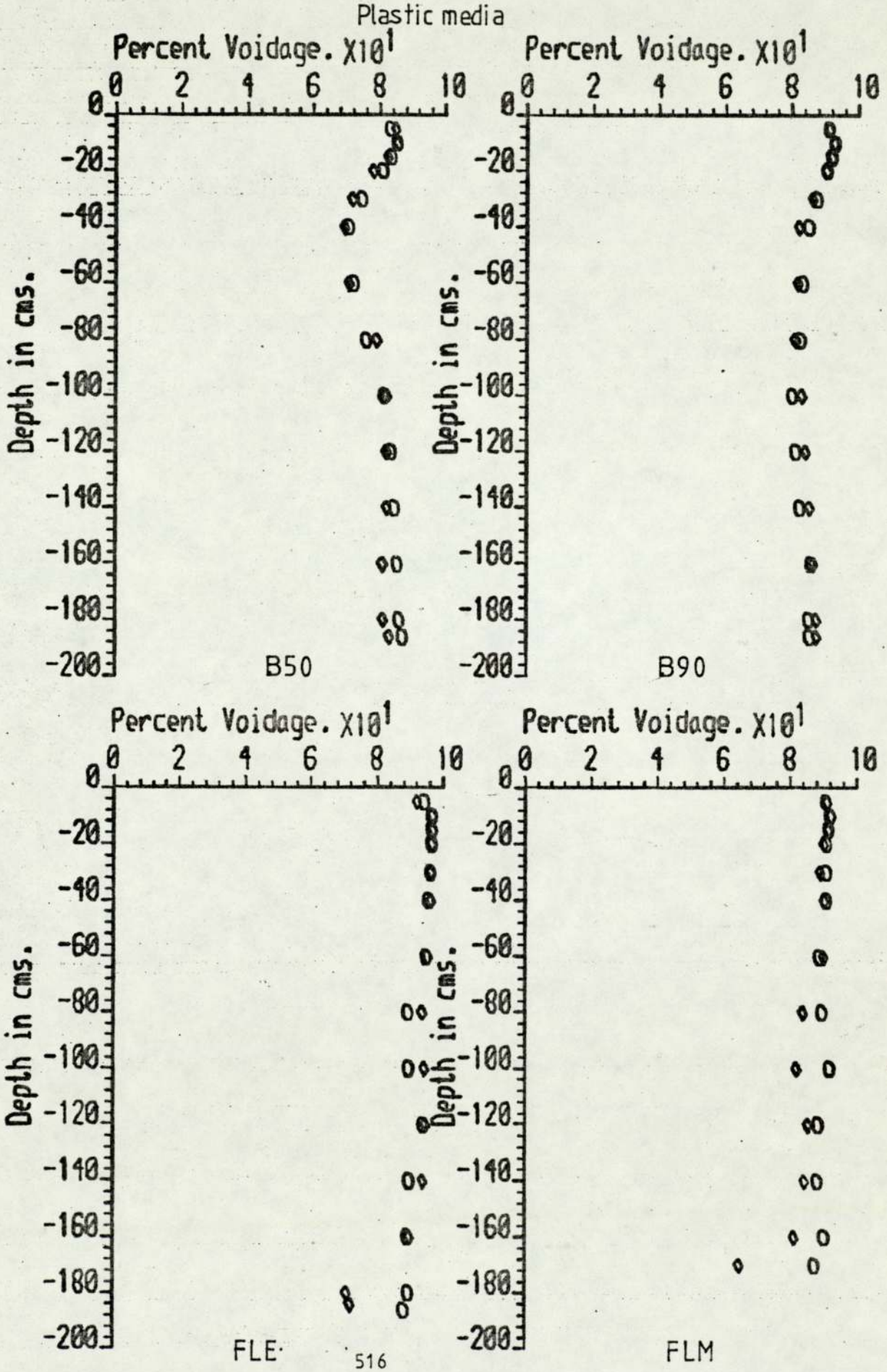
Appendix 8A.2 Neutron Scatter Moisture Contents, May 1977.



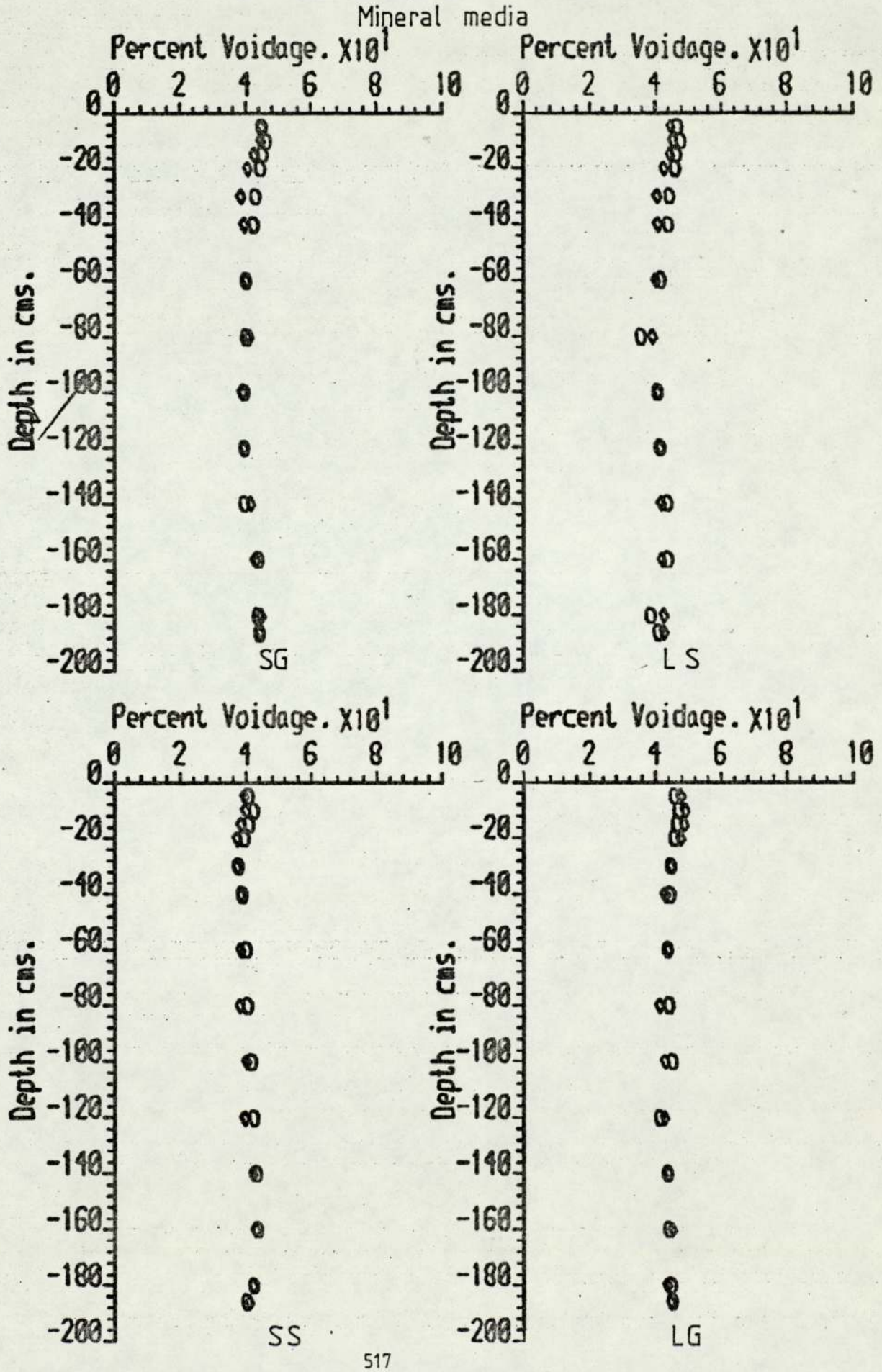
Appendix 8A.2 Neutron Scatter Moisture Contents, May1977.



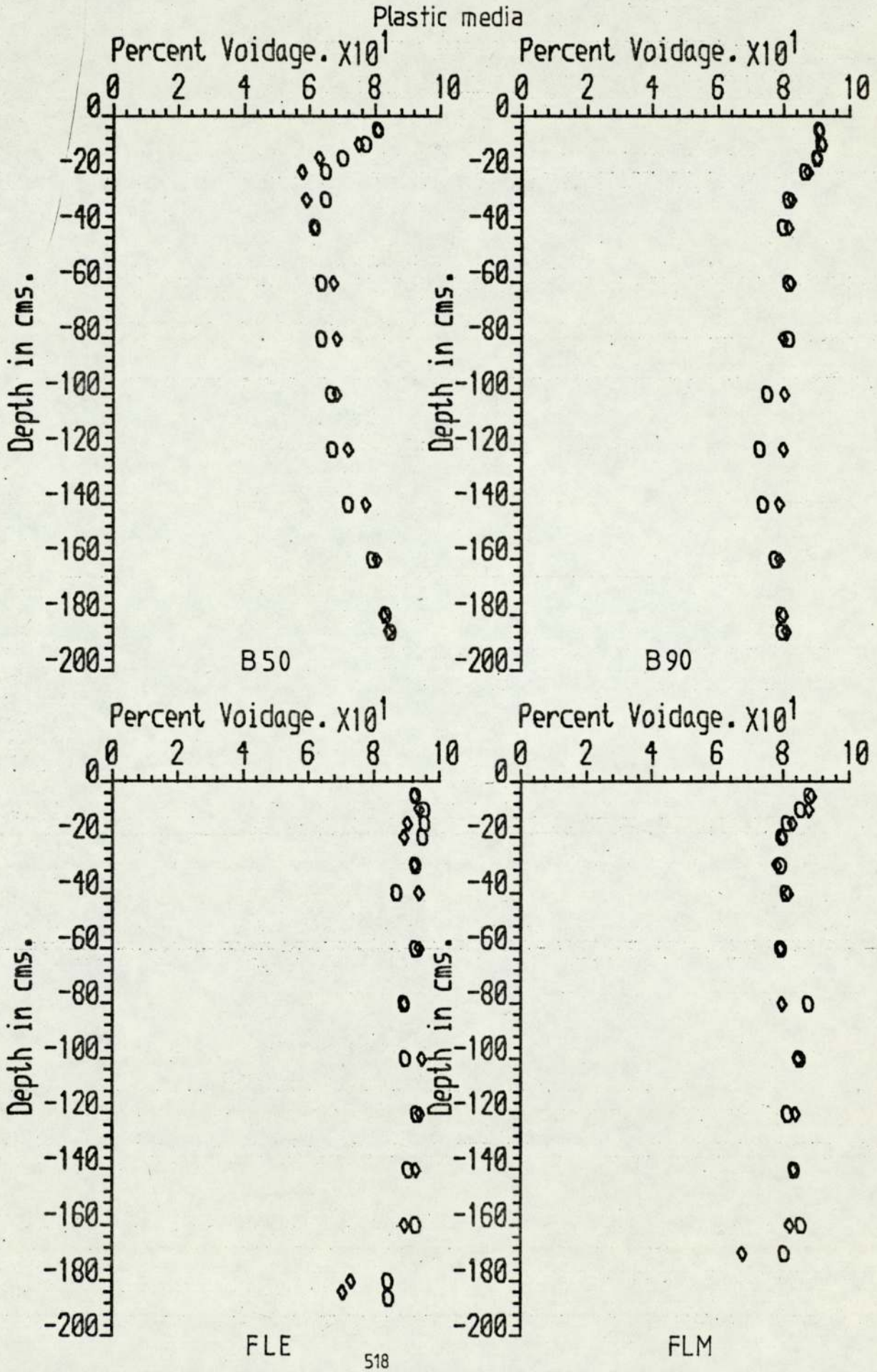
Appendix 8A.2 Neutron Scatter Moisture Contents, June 1977.



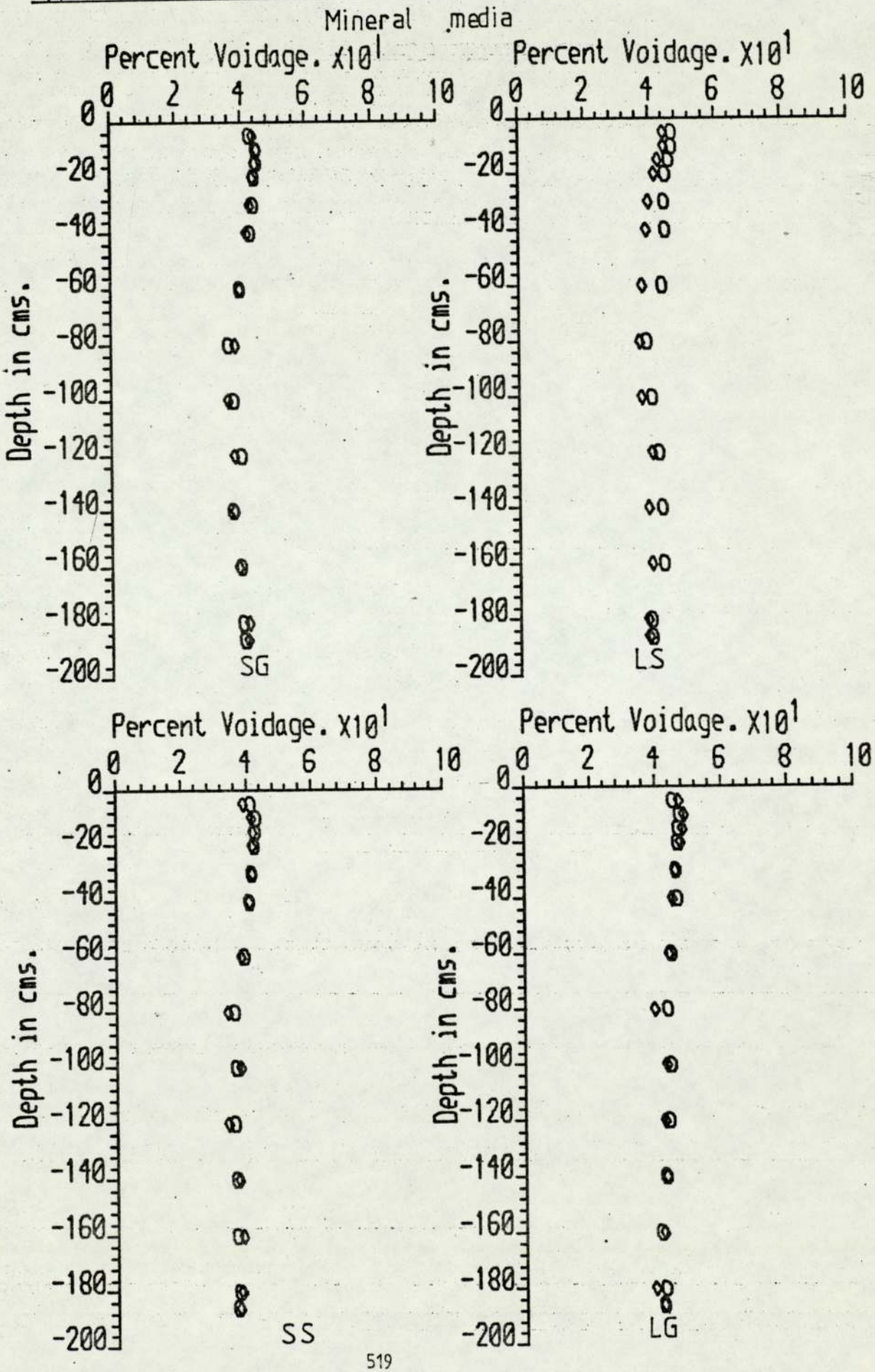
Appendix 8A.2 Neutron Scatter Moisture Contents, June 1977.



Appendix 8.A.2 Neutron Scatter Moisture Contents, July 1977.



Appendix 8.A.2 Neutron Scatter Moisture Contents, July 1977



Appendix 8.A.3. Results of Retention Time Tests on Clean Media devoid of Filter Film.(May 1975)

Media	16%ile.	50%ile.	NaCl Recovered. (g)
LS	2.2	5.5	73.3
LSbiol	2.0	4.75	67.2
SS	3.6	7.7	113.7
SSbiol	1.8	4.75	53.7
LG	0.75	2.0	40.6
LGbiol	0.70	2.1	46.7
SG	1.5	4.0	58.6
SGbiol	1.4	3.4	48.3
B90	0.25	1.7	56.3
B90biol	0.5	1.7	66.1
B50	1 .2	2.8	55.9
B50biol	0.8	2.7	65.5
FLE1 cw	0.65	1,6	99.4
FLE2cw	0.7	1.7	58.2
FLM1cw	0.65	1.8	101.3
FLM2cw	0.65	2.0	67.0

Percentile times in minutes.

Appendix 8.A.3.(cont.) Results of Retention Time Tests on the High Rate Filters, October, 1975.

Media	16%ile.	50%ile.	NaCl Recovered. (g)
LS	5.7	23.0	36.7
LSbiol	3.5	15.7	24.0
SS	16.0	32.0	56.0
SSbiol	10.5	36.5	59.8
LG	1.35	5.7	38.0
LGbiol	2.5	12.1	59.9
SG	5.75	24.4	39.8
SGbiol	4.0	22.0	43.2

Percentile times in minutes.

Appendix 8.A.3. (cont) Results of Retention Time Tests on the High Rate Filters, October/November 1976.

Media.	16%ile.	50%ile.	NaCl Recovered (g)
LS	5.75	17.2	28.1
LSbiol	11.3	24.4	2 6.5
SS	5.5	11.1	12.3
SSbiol	5.5	12.4	12.9
LG	6.1	17.7	34.5
LGbiol	3.3	9.5	28.7
SG	6.1	16.9	17.6
SGbiol	3.3	8.9	26.2
B90	14.4	37.4	36.5
B90biol	4.7	12.2	8.1
B50	12.2	30.8	30.8
B50biol	12.4	22.2	21.9
FLE1cw	7.25	23.0	22.2
FLE2cw	6.5	32.6	53.3
FLM1cw	11.1	31.0	42.7
FLM2cw	12.5	45.0	81.5

Percentile Times in minutes.

Appendix8.A.3.(cont) Results of Retention Time Tests on the High Rate Filters, July,1977.

Media.	16%ile.	50%ile.	NaCl Recovered. (g)
LS	11.75	29.1	38.5
LSbiol	8.3	23.4	26.2
SS	20.1	42.2	38.8
SSbiol	17.8	37.4	34.1
LG	5.7	17.9	32.0
LGbiol	8.25	23.4	47.6
SG	11.0	28.5	38.9
SGbiol	14.2	32.6	63.3
B90	10.6	33.0	46.9
B90biol	16.25	37.0	76.6
B50	17.0	29.5	22.3
B0biol	22.0	57.0	47.5
FLE1cw	4.1	16.6	45.1
FLE2cw	7.6	30.0	62.9
FLM1cw	5.0	26.5	71.7
FLM2cw	5.6	23.6	38.2

Percentile times in minutes.

Appendix 8.B.1. Microscopic Examinations of Filter Films, October, 1975.

	Depth (mm)	Zoogleal Bacteria	Filamentous Bacteria	Fusarium-coarse	Fusarium-fine	Algae	Holotrichia	Peritrichia	Heterotrichida	Hypotrichida	Rotifera	Nematoda
125/75mm Slag	0 – 200	a		a		c						o
	200 – 600	c		a			o			f		c
	600 – 1000	c	r	c			o			c		c
	1000 – 1400	c		c			o	r		o	r	r
	1400 – 1800	c		c			f			f	c	o
89/50mm Slag	0 – 200	a		r	a	a						c
	200 – 600	a		a						r		r
	600 – 1000	a	c	a			r	o		o		o
	1000 – 1400	a		a						c		r
	1400 – 1800	a	c	c								
125/75mm Granite	0 – 200	a			c	c						r
	200 – 600	a		c	a	r		r				r
	600 – 1000	a	f	a								f
	1000 – 1400	a	c	a						r	r	r
	1400 – 1600	a	f	c				c		c		
89/50mm Granite	0 – 200	a			a	c						
	200 – 600	a		a	o							o
	600 – 1000	a		a			o		o			o
	1000 – 1400	o		a						o		o
	1400 – 1800	c		a								r

Appendix 8.B.1. Microscopic Examinations of Filter Films, October, 1975.

	Depth (mm)	Zoogleal Bacteria	Filamentous Bacteria	Fusarium-coarse	Fusarium - fine	Algae	Holotrichia	Peritrichia	Heterotrichida	Hypotrichida	Rotifera	Nematoda
Biopac 50	0 – 200	a	c		a	r						o
	200 – 600	a	c		a							f
	600 –1000	a	c		a							o
	1000 –1400	a	f		c							o
	1400 – 1800	a	c		c							r
Biopac 90	0 – 200	a	c		a	c						c
	200 – 600	a		f	a							c
	600 – 1000	a			a							r
	1000 – 1400	a			a							
	1400 – 1800	a	f		a							
Flocor E	0 – 200	a		a		f						c
	600 – 800	a		a			o		o	c		o
	1200 - 1400	c		a			o	r		c	r	f
Flocor M	0 - 200	f		a	a	f						
	600 – 800	a	f	a	a		r	o				f
	1200 – 1400	f		c	o		o			o		

Appendix 8.B.1. Macroscopic Examination Of the Filter Films, October, 1975.

(Individuals/m^3)

Depth (mm)		Volatile Solids (kg/m^3)	Psychoda alternata larvae ($\times 10^{-6}$)	Psychoda alternata pupae ($\times 10^{-6}$)	Enchytraeidae ($\times 10^{-6}$)	Chironomus dorsalis ($\times 10^{-6}$)	Achorutes subviaticus ($\times 10^{-6}$)	Eristalis tenax ($\times 10^{-6}$)	Unidentified dipteran ($\times 10^{-6}$)
125/75 mm Slag									
0	200	8.1	2.339	0.828					
200	600	5.3	1.986	1.044	0.051	0.025			0.013
600	1000	8.3	1.190	1.068	0.158	0.053			0.035
1000	1400	6.7	0.344	0.115	1.375				0.014
1400	1800	5.9	0.366	0.647	0.302				0.048
89/50 mm Slag									
0	200	6.0	9.301	3.286	0.056				
200	600	8.1	6.525	6.047	0.080				
600	1000	4.8	2.650	1.623	0.979				0.048
1000	1400	6.3	2.138	1.655	1.552				0.103
1400	1800	4.6	2.559	0.955	1.165				0.095
125/75 mm Granite									
0	200	5.5	2.775	3.488	0.051				
200	600	5.7	2.938	1.655					0.083
600	1000	3.9	2.263	1.447	0.072				0.014
1000	1400	3.3	0.859	0.433	0.376				0.038
1400	1800	4.5	0.660	0.239	0.581				0.064
89/50 mm Granite									
0	200	4.3	2.368	1.808	0.051				
200	600	7.2	3.473	1.528	0.024				0.010
600	1000	11.5	1.337	0.883	0.107				0.048
1000	1400	6.8	1.044	0.522	0.051				0.178
1400	1800	4.8	0.458	0.201	0.105				0.124

Appendix8.B.1. Macroscopic Examination of the Filter Films, October,1975,

(Individuals/m^3)

Depth (mm)	Volatile Solids (kg/m^3)	Psychoda alternata larvae ($\times 10^{-6}$)	Psychoda alternata pupae ($\times 10^{-6}$)	Enchytraeidae ($\times 10^{-6}$)	Chironomus dorsalis ($\times 10^{-6}$)	Achorutes subviaticus ($\times 10^{-6}$)	Eristalis tenax ($\times 10^{-6}$)	Unidentified dipteran ($\times 10^{-6}$)
Biopac 50								
0 200	27.2	7.913	11.022					
200 600	26.7	3.353	6.288					
600 1000	33.1	4.202	7.539					
1000 1400	43.3	3.672	12.575					
1400 1800	34.1	4.473	2.209					
Biopac 90								
0 200	9.5	6.376	2.658					
200 600	13.8	7.857	6.067					
600 1000	18.7	8.140	5.094					
1000 1400	18.8	18.247	10.492					
1400 1800	14.5	10.063	3.782					
Flocor E								
0 200	3.82	1.097	0.217					
600 800	3.74	0.797	1.134					
1200 1400	2.70	0.510	0.276	0.045	0.003			
Flocor M								
0 200	6.24	0.557	1.707					
600 800	17.26	3.006	7.741					
1200 1400	5.61	1.239	2.598	0.012	0.012			

Appendix 8.B.1

Species of protozoa noted in samples of effluent taken from the beds of different media in the two evaluation filters at Hereford on 23 October 1975

Protozoal species	Filter bed no. and media.							
	Slag 89/50 A3,A7	Slag 125/75 A2,A6	Granite 89/50 A1,A5	Granite 125/75 A4,A8	Flocor E B3,B4	Flocor M B7,B8	Biopac 50 B1,B5	Biopac 90 B2,B6
Flagellates	+	+	+	+	+	+	+	+
Trachelophyllum pusillum			+		+			
Litonotus fasciola				+				
Chilodonella uncinata		+		+	+	+		
Chilodonella cucullulus			+	+			+	
Colpidium campylum				+	+			
Uronema nigricans	+	+	+	+	+	+		
Tetrahymena pyriformis					+			
Paramecium trichium	+		+					
Paramecium caudatum		+	+	+	+	+		
Vorticella convallaria					+	+		
Opercularia microdiscum				+			+	+
Aspidisca costata		+	+				+	+

Notes. Sewage contained apple crushing waste throughout October; extensive film accumulation on plastics media, particularly Biopac; Biopac 50 medium was ponding. Effluent channels coated with black slime, particularly in plastics media filter.

Appendix 8.B.2. Microscopic Examination of the Filter Films, January, 1976.

	Depth (mm)	Zoogleal Bacteria	Filamentous Bacteria	Fusarium-coarse	Fusarium-fine	Algae	Holotrichia	Peritrichia	Heterotrichida	Hypotrichida	Rotifera	Nematoda
125/75mm Slag	0 – 200	a	f		c		o					c
	200 – 600	a	f	a			r	o				c
	600 – 1000	a		c	o		o	r				f
	1000 – 1400	a	f	c			o	o				o
	1400 - 1800	a	o	c	o			f				f
89/50mm Slag	0 - 200	a	a		c		o					f
	200 - 600	a	f		a			o				f
	600 - 1000	a	f	a	a							o
	1000 - 1400	a		c	c			c				o
	1400 - 1800	a		a-	a			o				o
125/75mm Granite	0 - 200	a			a		o					c
	200 – 600	a	o		a		o	o				f
	600 - 1000	a		a	a		c	f				o
	1000 - 1400	a		a	a		o	f				f
	1400 - 1800	a		a	o		o	f				o
89/50mm Granite	0 - 200	c	o	a	o		f	o				c
	200 - 600	a		a			o	o				c
	600 - 1000	c		a			o	o				f
	1000 - 1400	a	o	a				f				c
	1400 - 1800	c		a			o	o				c

Appendix 8.B.2. Microscopic Examination of the Filter Films, January, 1976.

	Depth (mm)	Zoogleal Bacteria	Filamentous Bacteria	Fusarium-coarse	Fusarium - fine	Algae	Holotrichia	Peritrichia	Heterotrichida	Hypotrichida	Rotifera	Nematoda
Biopac 50	0 – 200	a	f		c		o					o
	200 – 600	a		c	c		o					o
	600 –1000	a		c	o			f				o
	1000 –1400	a		a	o			f				r
	1400 – 1800	a			c		f	f				c
Biopac 90	0 – 200	a			c	c	o					c
	200 – 600	c			f		a					f
	600 – 1000	c	o				c	o				f
	1000 – 1400	a			c		o	c				
	1400 – 1800	a			c		f					r
Flocor E	0 – 200	a	a		c	f						c
	600 – 800	a		c			a					o
	1200 – 1400	a		f			c	c				o
Flocor M	0 – 200	a			a							a
	600 – 800	a			c							c
	1200 – 1400	c	o		f		o					o

Appendix 8.B.2. Macroscopic Examination of the Filter Films, January, 1976.

(Individuals/m^3)

Depth (mm)		Volatile Solids (kg/m^3)	Psychoda alternata larvae ($\times 10^{-6}$)	Psychoda alternata pupae ($\times 10^{-6}$)	Enchytraeidae ($\times 10^{-6}$)	Chironomus dorsalis ($\times 10^{-6}$)	Achorutes subviaticus ($\times 10^{-6}$)	Eristalis tenax ($\times 10^{-6}$)	Unidentified dipteran ($\times 10^{-6}$)
125/75 mm Slag									
0	200	3.2	1.814	0.261	0.325				
200	600	3.3	2.864	1.050	0.851				
600	1000	6.5	2.643	1.733	0.735				
1000	1400	5.0	2.588	1.461	0.907				
1400	1800	5.2	2.172	1.098	0.533				
89/50 mm Slag									
0	200	18.5	3.132	11.050	1.959				
200	600	16.5	9.965	3.873	1.751				
600	1000	14.8	7.658	2.685	0.577				
1000	1400	12.0	2.440	6.216	0.802				
1400	1800	8.3	5.334	2.368	0.624				
125/75mm Granite									
0	200	9.0	2.381	1.477	0.535				
200	600	11.1	2.595	2.295	2.050				
600	1000	9.1	2.368	2.737	1.642				
1000	1400	9.2	1.648	2.767	0.801				
1400	1800	6.9	1.515	2.239	1.704				
89/50mm Granite									
0	200	14.0	9.524	2.220	0.812				
200	600	16.1	7.753	4.924	3.097				
600	1000	14.5	5.729	3.342	1.651				
1000	1400	7.5	2.286	1.324	1.117				
1400	1800	12.4	3.711	1.803	1.698				

Appendix 8.B.2 Macroscopic Examination of the Filter Films, January, 1976.

(Individuals/m^3)

Depth (mm)	Volatile Solids (kg/m^3)	Psychoda alternata larvae ($\times 10^{-6}$)	Psychoda alternata pupae ($\times 10^{-6}$)	Enchytraeidae ($\times 10^{-6}$)	Chironomus dorsalis ($\times 10^{-6}$)	Achorutes subviaticus ($\times 10^{-6}$)	Eristalis tenax ($\times 10^{-6}$)	Unidentified dipteran ($\times 10^{-6}$)
Biopac 50								
0 200	25.8	4.217	1.790	1.999				
200 600	26.3	6.569	5.567	0.955				
600 1000	19.5	4.491	2.814	4.815				
1000 1400	15.0	5.060	4.297	3.413				
1400 1800	7.9	2.502	2.272	0.947				
Biopac 90								
0 200	10.8	1.313	0.883	1.026				
200 600	11.2	2.296	2.689	0.848				
600 1000	13.7	2.559	3.017	0.439				
1000 1400	7.4	2.763	1.816	0.156				
1400 1800	4.3	2.253	1.279	0.070				
Flocor E								
0 200	2.1	0.119	0.199					
600 800	7.0	1.451	1.970	0.027				
1200 1400	1.7	0.302	0.299	0.017		0.012		
Flocor M								
0 200	4.4	0.616	1.086	0.021				
600 800	4.9	1.900	1.890	0.010				
1200 1400	5.0	1.503	2.164	0.007		0.016		

Appendix 8B.2

Species of protozoa noted in samples of effluent taken from the beds of different media in the two evaluation filters at Hereford on 29 January 1976 at 1530.

Protozoal species	Filter Bed no. and media.							
	Slag 89/50 A3,A7	Slag 125/75 A2,A6	Granite 89/50 A1,A5	Granite 125/75 A4,A8	Flocor E B3,B4	Flocor M B7,B8	Biopac 50 B1,B5	Biopac 90 B2,B6
Flagellates	+	+	+	+	+	+	+	+
Uronema nigricans	+	+	+	+	+	+	+	+
Aspidisca costata	+		+	+	+	+	+	
Opercularia microdiscum	+	+	+	+	+	+	+	+
Chilodonella uncinata			+	+	+	+	+	
Colpidium campylum		+		+			+	+
Tetrahymena pyriformis				+				
Cinetochilum margaritaceum	+							
Vorticella convallaria	+							
Euplotes moebiusi		+				+	+	
Litonotus carinatus							+	
Trachelophyllum pusillum					+	+	+	
Tachysoma pellionella							+	
Paramecium trichium					+		+	
Vorticella microstoma					+			
Litonotus fasciola					+			

Notes ; Filters dosed with screened sewage, unsettled from November until day before sampling. On day of sampling dosed sewage , settled in converted sludge digester. Vegetable processing waste present.

Appendix 8.B.3 Microscopic Examination of the Filter Films, April, 1976.

	Depth (mm)	Zoogleal Bacteria	Filamentous Bacteria	Fusarium-coarse	Fusarium-fine	Algae	Holotrichia	Peritrichia	Heterotrichida	Hypotrichida	Rotifera	Nematoda
125/75mm Slag	0 – 200	a	a		r							c
	200 – 600	a			a							o
	600 – 1000	a			c							f
	1000 – 1400	a	c		c							f
	1400 - 1800	a			c			f				f
89/50mm Slag	0 - 200	a	o		o					f		o
	200 - 600	a	f		c							
	600 - 1000	a	f		c			o				o
	1000 - 1400	a	f		c			o				
	1400 - 1800	a	o		c							c
125/75mm Granite	0 - 200	a	f		c							c
	200 – 600	a	f		f			o				f
	600 - 1000	c	o	c	o							
	1000 - 1400	c	o	c								
	1400 - 1800	c	c					c				c
89/50mm Granite	0 - 200											
	200 - 600											
	600 - 1000											
	1000 - 1400											
	1400 - 1800											

Appendix 8.B.3. Microscopic Examination of the Filter Films, April, 1976.

	Depth (mm)	Zoogleal Bacteria	Filamentous Bacteria	Fusarium-coarse	Fusarium-fine	Algae	Holotrichia	Peritrichia	Heterotrichida	Hypotrichida	Rotifera	Nematoda
Biopac 50	0 – 200	a			r					o		o
	200 – 600	a		o							r	r
	600 –1000	a	c	o	c							c
	1000 –1400	a	o	c				r				o
	1400 – 1800		f								r	c
Biopac 90	0 – 200	a	o	f	f			o				c
	200 – 600	c	o		o			r				f
	600 – 1000	a		f	f			r				f
	1000 – 1400	a	a	f				o				
	1400 – 1800	a		c				f				r
Flocor E	0 – 200	a	a		a			f				f
	600 – 800	c			a							f
	1200 – 1400	c			a			f				o
Flocor M	0 – 200	a	f		a	c				r		
	600 – 800	a			a							o
	1200 – 1400	a	r		a			o				c

Appendix 8.B.3 Macroscopic Examination of the Filter Films, April, 1976.

(Individuals/m^3)

Depth (mm)		Volatile Solids (kg/m^3)	Psychoda alternata larvae ($\times 10^{-6}$)	Psychoda alternata pupae ($\times 10^{-6}$)	Enchytraeidae ($\times 10^{-6}$)	Chironomus dorsalis ($\times 10^{-6}$)	Achorutes subviaticus ($\times 10^{-6}$)	Eristalis tenax ($\times 10^{-6}$)	Unidentified dipteran ($\times 10^{-6}$)
125/75 mm Slag									
0	200	15.9	15.977	2.292	5.092				
200	600	13.2	12.229	5.513	8.399				
600	1000	17.3	16.750	6.108	5.926				
1000	1400	13.1	10.983	2.110	5.465				
1400	1800	9.1	3.374	1.910	3.342				
89/50 mm Slag									
0	200	14.8	6.222	2.597	3.084				
200	600	13.7	9.310	5.668	11.626				
600	1000	19.9	10.695	9.574	5.909				
1000	1400	16.9	7.511	3.374	11.076				
1400	1800	16.9	8.103	2.117	6.410				
125/75mm Granite									
0	200	6.3	2.034	0.430	1.260				
200	600	8.7	7.893	2.164	8.180				
600	1000	18.3	28.472	7.276	9.567				
1000	1400	22.2	14.503	4.411	9.357				
1400	1800	13.3	5.829	2.941	3.781				
89/50mm Granite									
0	200	11.9	4.800	0.828	7.448				
200	600	14.8	14.054	2.393	7.638				
600	1000	21.0	0.611	2.215	0.611				
1000	1400	21.3	4.707	3.165	4.139				
1400	1800	17.8	6.525	2.784	1.432				

Appendix 8.B.3. Macroscopic Examination of the Filter Films, April, 1976.

(Individuals/m^3)

Depth (mm)	Volatile Solids (kg/m^3)	Psychoda alternata larvae ($\times 10^{-6}$)	Psychoda alternata pupae ($\times 10^{-6}$)	Enchytraeidae ($\times 10^{-6}$)	Chironomus dorsalis ($\times 10^{-6}$)	Achorutes subviaticus ($\times 10^{-6}$)	Eristalis tenax ($\times 10^{-6}$)	Unidentified dipteran ($\times 10^{-6}$)
Biopac 50								
0 200	30.0	1.000	2.800	0.733				
200 600	43.2	0.359	0.199					
600 1000	21.5	6.395	3.991	4.989				
1000 1400	9.6	4.593	0.549	14.347				
1400 1800	7.7	2.615	1.209	6.017				
Biopac 90								
0 200	4.0	0.858	9.942	0.0312				
200 600	33.8	30.935	18.660	0.0278				
600 1000	31.9	28.201	25.962	0.0533				
1000 1400	23.8	18.026	21.501	1.455				
1400 1800	11.8	6.872	5.573	1.650				
Flocor E								
0 200	3.5	4.059	1.511					
600 800	6.0	6.090	1.995	0.035				
1200 1400	2.8	1.739	1.892	0.014				
Flocor M								
0 200	7.0	12.684	2.716					
600 800	6.4	5.886	1.520	0.035				
1200 1400	7.8	6.899	3.111	3.061				

Species of protozoa noted in samples of effluent taken from the beds of different media in the two evaluation filters at Hereford on 26 May 1976 at 1600

Protozoa	Filter bed No. and media							
	Slag 89/50	Slag 125/75	Granite 89/50	Granite 125/75	Flocor E	Flocor M	Biopac 50	Biopac 90
	A3,7	A2,6	A1,5	A4,8	B3,4	B7,8	B1,5	B2,6
Flagellates	+	+	+	+	+	+	+	+
Uronema nigricans	+	+		+	+	+	+	+
Opercularia microdiscum	+	+		+	+	+	+	+
Colpidium colpoda				+	+	+	+	+
Paramecium trichium		+						
Paramecium candatum				+		+		
Opisthotricha similis	+							
Vorticella microstoma		+						
Opecularia coarctata		+						

Water Research Centre, Stevenage Laboratory and Welsh National WDA

Appendix 8.B.4 Microscopic Examination of the Filter Films, July, 1976.

	Depth (mm)	Zoogleal Bacteria	Filamentous Bacteria	Fusarium-coarse	Fusarium-fine	Algae	Holotrichia	Peritrichia	Heterotrichida	Hypotrichida	Rotifera	Nematoda
125/75mm Slag	0 – 200	a			a	c				o		f
	200 – 600	a			a					c		o
	600 – 1000	a			a					o		o
	1000 - 1400	a	c		a					f		
	1400 - 1800	a			a			o		c		o
89/50mm Slag	0 - 200	a			a	c						o
	200 - 600	a			a					f		o
	600 - 1000	a			a					f		o
	1000 - 1400	c	f		c					c		o
	1400 - 1800	c	o		c					c		
125/75mm Granite	0 - 200	c			a					f		o
	200 – 600	c			a					f		r
	600 - 1000	a	c							f		o
	1000 - 1400	c	c							o		r
	1400 - 1800	a	f		c					f		
89/50mm Granite	0 - 200		a	a	a	a		f				r
	200 - 600		a		a		o			f		o
	600 - 1000		a		a		o			f		o
	1000 - 1400		c		c					c		f
	1400 - 1800	f	c		c					f		o

Appendix8.B.4. Microscopic Examination of the Filter Films, July,1976.

	Depth (mm)	Zoogleal Bacteria	Filamentous Bacteria	Fusarium-coarse	Fusarium - fine	Algae	Holotrichia	Peritrichia	Heterotrichida	Hypotrichida	Rotifera	Nematoda
Biopac 50	0 – 200	a		c	a							c
	200 – 600	c		a				o				
	600 –1000	c		c	o			o				
	1000 –1400	a	f	c								o
	1400 – 1800	c		c				o		o		o
Biopac 90	0 – 200	a		a	c					r		f
	200 – 600		c	a	c					f		f
	600 – 1000	c	c	a				r				o
	1000 – 1400	c		a								o
	1400 – 1800	f		c						c		c
Flocor E	0 – 200	a		a						r		o
	600 – 800	a	o	a			o					f
	1200 - 1400	a		c				r		o		f
Flocor M	0 - 200	a		a						o		f
	600 – 800	a		a			r	o			r	f
	1200 – 1400	a	f	c						o		f

Appendix 8.B.4 Macroscopic Examination of the Filter Films, July, 1976.

(Individuals/m^3)

Depth (mm)		Volatile Solids (kg/m^3)	Psychoda alternata larvae ($\times 10^{-6}$)	Psychoda alternata pupae ($\times 10^{-6}$)	Enchytraeidae ($\times 10^{-6}$)	Chironomus dorsalis ($\times 10^{-6}$)	Achorutes subviaticus ($\times 10^{-6}$)	Eristalis tenax ($\times 10^{-6}$)	Unidentified dipteran ($\times 10^{-6}$)
125/75 mm Slag									
0	200	7.5	3.164	2.451	0.891				
200	600	8.0	4.074	1.687	0.414				0.064
600	1000	11.1	4.144	4.278	1.871				
1000	1400	10.0	2.368	1.108	0.802				0.076
1400	1800	7.7	2.751	1.693	2.449				0.242
89/50 mm Slag									
0	200	14.1	3.765	2.317					
200	600	10.7	4.675	2.193	0.083				0.041
600	1000	10.8	3.404	1.184	0.444				0.345
1000	1400	8.6	2.932	1.926	1.400				0.131
1400	1800	6.5	1.095	0.229	1.502				0.229
125/75 mm Granite									
0	200	7.9	1.680	1.260	0.315				
200	600	13.7	2.116	1.782	0.891				
600	1000	5.5	6.779	2.029	1.647				
1000	1400	7.8	10.995	2.105	2.473				0.033
1400	1800	7.4	3.273	1.515	7.602				
89/50 mm Granite									
0	200	9.1	3.972	1.448	0.290				0.124
200	600	14.4	2.062	1.776	0.057				
600	1000	8.9	2.013	1.940	2.196				0.183
1000	1400	10.6	1.413	1.757	2.559				0.382
1400	1800	6.8	1.380	1.168	2.759				0.325

Appendix 8.B.4 Macroscopic Examination of the Filter Films, July, 1976.

(Individuals/m^3)

Depth (mm)	Volatile Solids (kg/m^3)	Psychoda alternata larvae ($\times 10^{-6}$)	Psychoda alternata pupae ($\times 10^{-6}$)	Enchytraeidae ($\times 10^{-6}$)	Chironomus dorsalis ($\times 10^{-6}$)	Achorutes subviaticus ($\times 10^{-6}$)	Eristalis tenax ($\times 10^{-6}$)	Unidentified dipteran ($\times 10^{-6}$)
Biopac 50								
0 200	12.4	11.585	6.572					
200 600	11.8	11.448	3.624	0.137				
600 1000	17.4	9.330	4.763	6.394				
1000 1400	12.6	12.390	2.489	2.543				
1400 1800	9.1	4.612	1.139	1.354				
Biopac 90								
0 200	12.8	3.950	0.054	11.687				
200 600	18.3	14.634	7.982	0 .560				
600 1000	14.5	14.131	1.623	1.480				
1000 1400	9.6	6.564	2.904	3.222				
1400 1800	8.4	6.684	1.036	6.015				
Flocor E								
0 200	3.6	2.733	1.310					
600 800	7.1	7.406	2.957	0.035				
1200 1400	3.0	0.611	0.876	1.175	0.015			
Flocor M								
0 200	10.5	4.964	2.896	0.091				
600 800	8.8	6.187	2.253	0.437				
1200 1400	11.1	1.786	0.583	5.248				

Appendix 8.B.5 Microscopic Examinations of the Filter Films, October, 1976.

	Depth (mm)	Zoogleal Bacteria	Filamentous Bacteria	Fusarium-coarse	Fusarium-fine	Algae	Holotrichia	Peritrichia	Heterotrichida	Hypotrichida	Rotifera	Nematoda
125/75mm Slag	0 – 200	a			a	o	o					o
	200 – 600	a	c		a		f					o
	600 – 1000	a	f		f			r				
	1000 – 1400	a	f		f		c				o	
	1400 - 1800	a	o		f		o	f				
89/50mm Slag	0 - 200	a			a	r	f					o
	200 - 600	a	f		a		c	o			r	f
	600 - 1000	a	o		f		a	o				o
	1000 - 1400	a	o		f		c	c				o
	1400 - 1800	a	o		f		f	f			r	o
125/75mm Granite	0 - 200	a	o		a			r				f
	200 – 600	a	c		a		f	c				
	600 - 1000	a	f		a		a	r			r	
	1000 - 1400	a	f		a		a	r				o
	1400 - 1800	c	o		c		a	o				
89/50mm Granite	0 - 200	a	o		a	f	r					f
	200 - 600	c	f		a		o	r				o
	600 - 1000	a	f		a			o				f
	1000 - 1400	a			c		f	f				o
	1400 - 1800	a	c		c		r	r				r

Appendix 8.B.5 Microscopic Examinations of the Filter Films, October, 1976.

	Depth (mm)	Zoogleal Bacteria	Filamentous Bacteria	Fusarium-coarse	Fusarium - fine	Algae	Holotrichia	Peritrichia	Heterotrichida	Hypotrichida	Rotifera	Nematoda
Biopac 50	0 – 200	a	o		a			o				o
	200 – 600	a	o		a		f	o				
	600 –1000	a	f		a			f				
	1000 –1400	a			a		f	c				o
	1400 – 1800	a			a		c	f				o
Biopac 90	0 – 200	a	o		a	o	r					c
	200 – 600	a	o		a		f					o
	600 – 1000	a	o		a		f	f				o
	1000 – 1400	a	c		a		f	o				
	1400 – 1800	a	c		a		o	c				
Flocor E	0 – 200	a	f		a		c					
	600 – 800	a	o		a							
	1200 - 1400	a	o		a		c					
Flocor M	0 - 200	a	o		a							f
	600 – 800	a	o		a		o	r				r
	1200 – 1400	a	c		a		r	o				

Appendix 8.B.5 Macroscopic Examination of the Filter Films, October, 1976.

(. Individuals/m^3)

Depth (mm)		Volatile Solids (kg/m^3)	Psychoda alternata larvae ($\times 10^{-6}$)	Psychoda alternata pupae ($\times 10^{-6}$)	Enchytraeidae ($\times 10^{-6}$)	Chironomus dorsalis ($\times 10^{-6}$)	Achorutes subviaticus ($\times 10^{-6}$)	Eristalis tenax ($\times 10^{-6}$)	Unidentified dipteran ($\times 10^{-6}$)
125/75 mm Slag									
0	200	8.5	1.795	1.451	0.649				0.191
200	600	10.7	3.520	2.852	3.386				0.223
600	1000	7.5	3.335	1.528	1.146				0.255
1000	1400	8.2	2.721	2.635	2.922				0.344
1400	1800	6.4	0.538	0.703	6.682				0.766
89/50 mm Slag									
0	200	10.2	2.349	2.177	2.177				0.172
200	600	10.1	1.838	2.729	1.782				2.340
600	1000	8.9	0.512	1.135	1.244				3.111
1000	1400	8.4	0.151	0.181	4.566				3.931
1400	1800	5.6	0.269	0.476	2.524				2.358
125/75 mm Granite									
0	200	7.3	2.406	1.827	2.406				0.223
200	600	9.4	2.069	1.158	3.393				1.076
600	1000	8.7	1.645	2.311	8.017				0.630
1000	1400	7.5	1.690	0.544	5.872				1.060
1400	1800	6.6	1.158	1.593	6.082				0.455
89/50 mm Granite									
0	200	10.0	11.712	4.685	1.731				
200	600	11.4	10.507	7.412	3.886				2.679
600	1000	9.0	4.297	3.151	2.292				
1000	1400	6.4	2.116	1.493	2.250				0.245
1400	1800	6.9	1.217	1.122	5.538				0.142

Appendix 8.B.5 Macroscopic Examination of the Filter Films, October, 1976.

(Individuals/m^3)

Depth (mm)	Volatile Solids (kg/m^3)	Psychoda alternata larvae ($\times 10^{-6}$)	Psychoda alternata pupae ($\times 10^{-6}$)	Enchytraeidae ($\times 10^{-6}$)	Chironomus dorsalis ($\times 10^{-6}$)	Achorutes subviaticus ($\times 10^{-6}$)	Eristalis tenax ($\times 10^{-6}$)	Unidentified dipteran ($\times 10^{-6}$)
Biopac 50								
0 200	17.7	29.830	12.214	1.488				
200 600	17.2	9.558	5.934	2.206				0.158
600 1000	10.7	8.943	4.074	3.374	0.127			0.191
1000 1400	8.7	7.877	1.764	5.262				0.662
1400 1800	2.5	0.793	0.392	0.831				0.439
Biopac 90								
0 200	20.2	4.717	6.289	0.828				0.166
200 600	18.3	8.989	6.263	1.842				
600 1000	15.2	9.195	5.977	5.261				
1000 1400	16.4	15.046	4.368	6.552				
1400 1800	9.4	3.003	2.299	6.249				0.054
Flocor E								
0 200	3.8	1.753	1.884	1.858				
600 800	7.2	3.926	2.444	3.224				0.130
1200 1400	8.2	4.256	1.960	2.828	0.028			
Flocor M								
0 200	10.2	8.855	5.158	0.685				
600 800	9.6	8.349	5.255	0.671	0.261			
1200 1400	5.0	1.938	0.302	3.822				0.533

Appendix 8.B.6 Microscopic Examinations of the Filter Films, March, 1977.

	Depth (mm)	Zoogleal Bacteria	Filamentous Bacteria	Fusarium-coarse	Fusarium-fine	Algae	Holotrichia	Peritrichia	Heterotrichida	Hypotrichida	Rotifera	Nematoda
125/75mm Slag	0 – 200	a	o	o	o	o		r				c
	200 – 600	a	f	c	c							c
	600 – 1000	a		a				o				c
	1000 – 1400	c	o	c	o			r				a
	1400 - 1800	a		c	a			f				a
89/50mm Slag	0 - 200	a	o	o	f	o		o				f
	200 - 600	a		c	o							f
	600 - 1000	c	o	o	c			o				a
	1000 - 1400	a		r	a			r		r		c
	1400 - 1800	c		a	c							c
125/75mm Granite	0 - 200	a	o	o	c	c						f
	200 – 600	a	o	f								f
	600 - 1000	c		c	f							o
	1000 - 1400	c	f	a			o					o
	1400 - 1800	a	o	c	f							o
89/50mm Granite	0 - 200	a	o	o	a		o	o				f
	200 - 600	c	o	c	a		r					f
	600 - 1000	c	o	c	f							f
	1000 - 1400	f		a			a					f
	1400 - 1800	a		o	a			f				f

Appendix 8.B.6 Microscopic Examinations of the Filter Films, March, 1977.

Biopac 50

Depth (mm)	Zoogleal Bacteria	Filamentous Bacteria	Fusarium-coarse	Fusarium - fine	Algae	Holotrichia	Peritrichia	Heterotrichida	Hypotrichida	Rotifera	Nematoda
0 – 200	a			c							a
200 – 600	f		a								c
600 –1000	f		a								c
1000 –1400	c		a								r
1400 – 1800	c		c	o							c

Biopac 90

0 – 200	a	f		f							c
200 – 600	a	r		f							c
600 – 1000	f	o	a	o							c
1000 – 1400	f	o	a	f							f
1400 – 1800	c		a	o							o

Flocor E

0 – 200	a			c							o
600 – 800	a			c						r	f
1200 - 1400	a		c	c			o	f			f

Flocor M

0 - 200	a	o		c							o
600 – 800	a	o		c							f
1200 – 1400	a			c		o				r	f

Appendix 8.B.6 Macroscopic Examination of the Filter Films, March, 1977.

(. Individuals/m^3)

Depth (mm)	Volatile Solids (kg/m^3)	Psychoda alternata larvae ($\times 10^{-6}$)	Psychoda alternata pupae ($\times 10^{-6}$)	Enchytraeidae ($\times 10^{-6}$)	Chironomus dorsalis ($\times 10^{-6}$)	Achorutes subviaticus ($\times 10^{-6}$)	Eristalis tenax ($\times 10^{-6}$)	Unidentified dipteran ($\times 10^{-6}$)
125/75 mm Slag								
0 200	1.8	0.420	0.032	0.146				
200 600	16.3	15.787	9.829	1.019				
600 1000	10.7	8.689	8.588	0.836				0.167
1000 1400	4.2	7.002	3.552	0.318				0.025
1400 1800	3.0	9.357	1.862	0.411				0.076
89/50 mm Slag								
0 200	11.3	2.610	1.496	0.382				
200 600	10.6	13.969	3.840	0.575				
600 1000	5.7	5.567	4.394	0.280				
1000 1400	2.9	9.023	1.098	0.296				0.019
1400 1800	1.9	3.246	0.643	0.380				0.019
125/75 mm Granite								
0 200	9.2	2.559	0.115	0.497				0.076
200 600	15.4	8.689	0.668	1.392				0.056
600 1000	6.3	4.303	2.317	1.883				0.062
1000 1400	1.5	3.886	0.544	0.210				0.019
1400 1800	1.3	3.709	0.411	0.516				0.024
89/50 mm Granite								
0 200	3.8	0.334	0.016	0.048				
200 600	16.9	10.875	2.435	1.244				0.054
600 1000	5.0	9.120	0.385	0.630	0.035			0.018
1000 1400	4.2	3.523	0.473	3.208				0.014
1400 1800	2.8	2.015	0.287	1.556				0.115

Appendix E.B.6(cont) Macroscopic Examination of the Filter Films, March, 1977.

(Individuals/m^3)

Depth (mm)	Volatile Solids (kg/m^3)	Psychoda alternata larvae ($\times 10^{-6}$)	Psychoda alternata pupae ($\times 10^{-6}$)	Enchytraeidae ($\times 10^{-6}$)	Chironomus dorsalis ($\times 10^{-6}$)	Achorutes subviaticus ($\times 10^{-6}$)	Eristalis tenax ($\times 10^{-6}$)	Unidentified dipteran ($\times 10^{-6}$)
Biopac 50								
0 200	9.1	0.714	0.097					
200 600	20.2	4.812	1.289					
600 1000	12.8	6.512	1.677	0.296				
1000 1400	5.1	2.559	0.420	0.707				
1400 1800	1.7	0.855	2.532	0.589				0.068
Biopac 90								
0 200	9.7	0.805	1.318					
200 600	33.3	8.016	2.220	0.123				
600 1000	19.7	5.594	2.343					
1000 1400	6.6	9.982	1.096	0.049				
1400 1800	3.1	2.584	0.746					
Flocor E								
0 200	0.6	0.258	0.184	0.116				
600 800	2.0	2.508	0.833	0.083	0.017			
1200 1400	3.3	0.529	1.343	3.155				
Flocor M								
0 200	1.7	1.331	0.302	1.106				
600 800	3.6	1.876	1.566	0.078				
1200 1400	4.5	1.916	1.132	3.746				

Appendix 8.B.7 Microscopic Examinations of the Filter Films, May, 1977.

	Depth (mm)	Zoogleal Bacteria	Filamentous Bacteria	Fusarium-coarse	Fusarium-fine	Algae	Holotrichia	Peritrichia	Heterotrichida	Hypotrichida	Rotifera	Nematoda
125/75mm Slag	0 – 200	a	f		c	a				f		o
	200 – 600	c	f		a			o				r
	600 – 1000	a	f		a			f		o		f
	1000 - 1400	a	c	f	a							f
	1400 - 1800	a	c	c	a			f		c		
89/50mm Slag	0 - 200	a	f	c	a	r		r		o		o
	200 - 600	a	o		a			r		o		f
	600 - 1000	a	c		a			r		f.		o
	1000 - 1400	c	c		a			o		f		f
	1400 - 1800	f	f		a			f		o		r
125/75mm Granite	0 - 200	a	f	c	f							f
	200 – 600	a	f	c				f		r	o	
	600 - 1000	a	f	c	r		r	r				
	1000 - 1400	c	a	a	f			o		f	r	
	1400 - 1800	c		a				c				o
89/50mm Granite	0 - 200	a	f		a	o						f
	200 - 600	a	c	a				r		o		f
	600 - 1000	c	f	a						c		o
	1000 - 1400	a	c	a						c		
	1400 - 1800	a	c	a				f		o		r

Appendix 8.B.7. Microscopic Examinations of the Filter Films, May, 1977.

Biopac 50

Depth (mm)	Zoogleal Bacteria	Filamentous Bacteria	Fusarium-coarse	Fusarium-fine	Algae	Holotrichia	Peritrichia	Heterotrichida	Hypotrichida	Rotifera	Nemaioda
0 – 200	a	f		c	r						o
200 – 600	o	f		a			f				f
600 –1000	a			c			c				o
1000 –1400	a			a		o	f				r
1400 – 1800	a			a			c				o

Biopac 90

0 – 200	a	f		f	r		o		r		o
200 – 600	a	o	c				f		r		o
600 – 1000	a	o		c			f				f
1000 – 1400	a			a			c				
1400 – 1800	c			a			a		r		r

Flocor E

0 – 200	a		a	c			o		o	r	c
600 – 800	a	f		a			o		c		o
1200 – 1400	a			a		f	f			r	f

Flocor M

0 – 200	a			a					o		c
600 – 800	a	o		a			r		f		f
1200 – 1400	a	o		a		f	o		o		f

Appendix 8.B.7 Macroscopic Examinations of the Filter Films, May, 1977.

(Individuals/m^3)

Depth (mm)		Volatile Solids (kg/m^3)	Psychoda alternata larvae ($\times 10^{-6}$)	Psychoda alternata pupae ($\times 10^{-6}$)	Enchytraeidae ($\times 10^{-6}$)	Chironomus dorsalis ($\times 10^{-6}$)	Achorutes subviaticus ($\times 10^{-6}$)	Eristalis tenax ($\times 10^{-6}$)	Unidentified dipteran ($\times 10^{-6}$)
125/75 mm Slag									
0	200	7.5	2.673	2.801	0.331				
200	600	11.6	5.461	6.785	0.869				
600	1000	12.3	4.400	4.511	2.395		0.111		
1000	1400	14.1	6.808	3.651	3.108		0.148		
1400	1800	8.2	3.689	1.844	1.421	0.091	0.030		
89/50 mm Slag									
0	200	11.5	7.753	4.545	2.362				
200	600	12.8	12.341	10.293	1.628				
600	1000	15.8	6.168	7.680	2.177		0.068		
1000	1400	16.3	6.617	4.516	3.729		0.105		
1400	1800	19.5	8.254	5.275	5.399		0.124		
125/75 mm Granite									
0	200	6.7	1.044	1.400	1.069				
200	600	12.7	6.093	10.199	3.830				
600	1000	21.6	7.638	3.581	2.467				
1000	1400	16.3	5.789	5.032	4.274				
1400	1800	13.7	4.933	3.063	4.018				
89/50 mm Granite									
0	200	8.6	2.960	1.432	1.496				
200	600	14.2	5.829	7.510	3.939				0.053
600	1000	19.3	6.722	9.663	4.971				
1000	1400	10.3	5.614	3.552	9.319				
1400	1800	13.3	5.048	3.931	10.860				

Appendix 8.B.7 Macroscopic Examinations of the Filter Films, May, 1977.

(Individuals/m^3)

Depth (mm)	Volatile Solids (kg/m^3)	Psychoda alternata larvae ($\times 10^{-6}$)	Psychoda alternata pupae ($\times 10^{-6}$)	Enchytraeidae ($\times 10^{-6}$)	Chironomus dorsalis ($\times 10^{-6}$)	Achorutes subviaticus ($\times 10^{-6}$)	Eristalis tenax ($\times 10^{-6}$)	Unidentified dipteran ($\times 10^{-6}$)
Biopac 50								
0 200	12.5	4.495	2.052	0.195				
200 600	8.8	3.095	1.710	0.065				
600 1000	17.1	27.938	7.352					
1000 1400	13.4	24.706	6.273	0.644	0.215			
1400 1800	4.8	9.148	1.999	0.336	0.144			
Biopac 90								
0 200	5.5	2.269	0.644					
200 600	10.7	8.559	7.344					
600 1000	7.0	10.386	6.842					
1000 1400	7.1	10.602	5.798	0.055				
1400 1800	6.0	6.055	4.231	0.080	0.080			
Flocor E								
0 200	5.4	2.055	3.716	0.750				
600 800	7.1	1.332	3.117	0.113				
1200 1400	4.6	2.185	1.406	1.604				
Flocor M								
0 200	4.6	4.112	6.796	0.225				
600 800	7.9	2.688	5.740	0.504				
1200 1400	3.0	1.076	0.815	1.995				

Appendix 8.B.7

Species of protozoa noted in samples of effluent taken from the beds of different media in the two evaluation filters at Hereford on 24 May 1977.

protozoal species	Filter Bed No. and media.							
	Slag 89/50 A3,A7	Slag 125/75 A2,A6	Granite 89/50 A1,A5	Granite 125/75 A4,A8	Flocor E B3,B4	Flocor M B7,B8	Biopac 50 B1,B5	Biopac 90 B2,B6
Flagellates	+	+	+	+	+	+	+	+
Uronema nigricans	+	+	+	+	+	+	+	+
Opercularia microdiscum	+	+	+	+	+	+	+	+
Colpidium colpoda	+	+	+		+	+		
Paramecium trichium								+
Paramecium caudatum	+		+					
Opisthortricha similis							+	
Vorticella microstoma								+
Opercularia coarctata								+

Appendix 8.B.8. Microscopic Examinations of the Filter Films, August, 1977.

	Depth (mm)	Zoogleal Bacteria	Filamentous Bacteria	Fusarium-coarse	Fusarium-fine	Algae	Holotrichia	Peritrichia	Heterotrichida	Hypotrichida	Rotifera	Nematoda
125/75mm Slag	0 - 200	a	o		a	f	c	f				o
	200 - 600	a	f		a			f				o
	600 - 1000	a	c		a		r	f				f
	1000 - 1400	a	f		a		r	c				r
	1400 - 1800	a	o		a			f				f
89/50mm Slag	0 - 200	a	o		a			o		r		r
	200 - 600	a	o		a			o				f
	600 - 1000	a	c		a			f				f
	1000 - 1400	a	c		a			f				f
	1400 - 1800	a	f		a		r	c				o
125/75mm Granite	0 - 200	a	f		c							o
	200 - 600	a	c		a			f		r		o
	600 - 1000	a	f		a		o	f		r		f
	1000 - 1400	a	f		a			c				o
	1400 - 1800	a	f		a		o	o				o
89/50mm Granite	0 - 200	a	c		a		o					
	200 - 600	a	f		a			o		r		
	600 - 1000	a	c		a		r	o				o
	1000 - 1400	a	f		a			o				f
	1400 - 1800	a	f		a		f	o		o		f

Appendix 8.B.8. Microscopic Examination of the Filter Films, August, 1977.

	Depth (mm)	Zoogleal Bacteria	Filamentous Bacteria	Fusarium-coarse	Fusarium - fine	Algae	Holotrichia	Peritrichia	Heterotrichida	Hypotrichida	Rotifera	Nematoda
Biopac 50	0 – 200	a	o	a	a			o				o
	200 – 600	a	f		a			o				f
	600 –1000	a	c		a			o		r	r	c
	1000 –1400	a	f		a		r	f				f
	1400 – 1800	a	f		a		o	f				f
Biopac 90	0 – 200	a	f	o	c		r	o				o
	200 – 600	a	c		a		o	f				o
	600 – 1000	a	c		a		o	f				r
	1000 – 1400	a	f		c		f	o				o
	1400 – 1800	a	f		c		f	o		r		o
Flocor E	0 – 200	a			a	c				o		f
	600 – 800	a	o		a		o	f				f
	1200 - 1400	a	f		a		r	o		r		o
Flocor M	0 - 200	a	o		a	c	o			o		f
	600 – 800	a	f		a		o	f				c
	1200 – 1400	a	f		a		o	o				o

Appendix 8.B.7 Macroscopic Examinations of the Filter Films, August, 1977.

(Individuals/m^3)

Depth (mm)	Volatile Solids (kg/m^3)	Psychoda alternata larvae ($\times 10^{-6}$)	Psychoda alternata pupae ($\times 10^{-6}$)	Enchytraeidae ($\times 10^{-6}$)	Chironomus dorsalis ($\times 10^{-6}$)	Achorutes subviaticus ($\times 10^{-6}$)	Eristalis tenax ($\times 10^{-6}$)	Unidentified dipteran ($\times 10^{-6}$)
125/75 mm Slag								
0 200	6.9	3.119	3.632	2.562				
200 600	4.7	4.220	2.545	0.931				
600 1000	6.4	3.485	1.981	0.883				
1000 1400	1,8	1.184	0.716	1.088				
1400 1800	2.7	1.509	0.964	0.917				
89/50 mm Slag								
0 200	10.4	4.239	3.523	3.409				
200 600	6.5	2.495	3.310	1.731				
600 1000	8.3	3.490	2.922	2.787				
1000 1400	6.6	5.503	2.027	1.916				
1400 1800	5.3	3.711	1.453	1.820				
125/75 mm Granite								
0 200	8.5	2.339	1.582	7.753				
200 600	4.5	3.132	1.668	3.145				
600 1000	5.6	4.604	2.451	3.238				
1000 1400	7.7	6.588	5.037	2.339				
1400 1800	3.7	2.292	1.819	2.120				
89/50 mm Granite								
0 200	6.2	1.719	1.003	2.928				
200 600	6.4	3.549	1.862	0.382				
600 1000	8.7	5.538	3.199	0.286				
1000 1400	5.4	5.777	5.033	5.995				
1400 1800	3.6	0.824	1.036	5.591				

Appendix 8.B.8 Macroscopic Examinations of the Filter Films,

August, 1977.

(Individuals/m^3)

Depth (mm)	Volatile Solids (kg/m^3)	Psychoda alternata larvae ($\times 10^{-6}$)	Psychoda alternata pupae ($\times 10^{-6}$)	Enchytraeidae ($\times 10^{-6}$)	Chironomus dorsalis ($\times 10^{-6}$)	Achorutes subviaticus ($\times 10^{-6}$)	Eristalis tenax ($\times 10^{-6}$)	Unidentified dipteran ($\times 10^{-6}$)
Biopac 50								
0 200	3.9	6.769	2.971	0.714				
200 600	11.8	19.935	14.813	4.753				
600 1000	15.7	8.140	11.889	10.359				
1000 1400	13.1	4.297	3.620	12.491				
1400 1800	9.1	5.925	2.875	10.426				
Biopac 90								
0 200	4.1	8.400	2.871	1.777				
200 600	6.3	6.148	5.049	5.004				
600 1000	9.4	11.022	7.157	8.955				
1000 1400	14.4	8.938	10.466	9.632				
1400 1800	14.3	5.875	3.657	11.088				
Flocor E								
0 200	2.7	0.748	1.240	1.188				
600 800	4.4	1.777	3.451	1.378				
1200 1400	5.0	1.443	1.958	1.237				
Flocor M								
0 200	3.7	1.330	2.229	0.773				
600 800	5.7	3.799	2.355	1.837				
1200 1400	5.5	1.850	1.467	2.516			0.006	

Appendix 8.B8

Species of protozoa noted in samples of effluent taken from the beds of different media in the two evaluation filters at Hereford on 22 August 1977.

Protozoal species	Filter bed No. and media.							
	Slag 89/50 A3,A7	Slag 125/75 A2,A6	Granite 89/50 A1,A5	Granite 125/75 A4,A8	Flocor E B3,B4	Flocor M B7,B8	Biopac 50 B1,B5	Biopac 90 B2,B6
Flagellates	+	+	+	+	+	+	+	+
Epistylis rotans	+	+	+	+				
Pseudoglaucoma muscorum	+	+		+				+
Uronema nigricans	+			+				
Chilodonella uncinata	+							
Vorticella convallaria			+					
Vorticella alba						+		
Amoebae	+	+	+	+	+	+	+	+
Nematodes	+	+	+	+	+	+	+	+

Appendix 9.1 Weekly Averaged Flows to the Laboratory Scale Filters using High Rate Effluent (24.6.76 - 30.9.76)

($m^3/m^3/d$)

Week No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Feed A														
1A	.32	.20	.18	.21	.20	.21	.21	.23	.22	.22	.23	.22	.22	.22
2A	.36	.29	.38	.48	.41	.37	.38	.38	.38	.38	.39	.42	.41	.40
3A	.61	.60	.58	.61	.52	.53	.57	.66	.63	.63	.64	.59	.59	.56
4A	.32	.20	.25	.24	.21	.19	.19	.18	.18	.17	.18	.21	.20	.21
5A	.33	.25	.36	.47	.44	.42	.41	.40	.40	.41	.41	.34	.33	.32
6A	.61	.59	.61	.70	.57	.55	.59	.62	.63	.62	.62	.61	.58	.52
Feed B														
1B	.32	.15	.16	.19	.16	.14	.15	.19	.16	.17	.16	.16	.05	.06
2B	.45	.45	.42	.41	.41	.40	.44	.42	.43	.43	.40	.43	.44	.44
3B	.65	.63	.56	.52	.59	.63	.55	.64	.67	.62	.63	.66	.65	.63
4B	.33	.15	.14	.22	.21	.20	.21	.19	.10	.20	.19	.17	.19	.18
5B	.41	.38	.36	.43	.42	.42	.42	.37	.38	.38	.33	.34	.30	.30
6B	.65	.55	.59	.57	.58	.60	.58	.61	.65	.63	.55	.51	.60	.56

Appendix 9.1. cont. Weekly Averaged Flows to the Laboratory Scale Filters using High Rate Effluent (7.10.76 - 13.1.77)

($m^3/m^3/d$)

Week No.	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Feed A															
1A	.22	.22	.20	.18	.18	.21	.18	.18	.19	.19	.19	.22	.22	.22	.12
2A	.40	.36	.30	.37	.37	.33	.34	.34	.41	.41	.41	.41	.41	.41	.32
3A	.58	.59	.47	.54	.54	.36	.46	.49	.58	.58	.61	.63	.63	.63	.41
4A	.21	.20	.19	.17	.17	.18	.15	.20	.23	.23	.18	.18	.18	.18	.20
5A	.31	.32	.27	.32	.32	.24	.29	.29	.35	.35	.33	.31	.31	.31	.26
6A	.51	.52	.47	.53	.53	.60	.55	.53	.54	.54	.58	.54	.54	.54	.33
Feed B															
1B	.19	.20	.19	.18	.18	.17	.21	.17	.15	.15	.20	.21	.21	.21	.20
2B	.45	.46	.43	.41	.41	.47	.41	.41	.44	.44	.44	.42	.42	.42	.29
3B	.66	.66	.57	.60	.60	.61	.51	.47	.58	.58	.62	.59	.59	.59	.40
4B	.16	.07	.04	.20	.20	.22	.15	.21	.15	.15	.25	.23	.23	.23	.08
5B	.29	.34	.35	.35	.35	.48	.42	.45	.44	.44	.40	.37	.37	.37	.12
6B	.83	.61	.55	.60	.60	.65	.56	.41	.33	.33	.56	.56	.56	.56	.15

Appendix 9.1. cont. Weekly Averaged BOD Data for Laboratory Scale Filters using High Rate Effluent (7.10.76 - 13.1.77)

(mg/l)

Week No.	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Feed A	17	63.5			80		120.5	173	227.5	195	53.5	117	117	117	117
1A	3.5	12.5			9		6	7.5	7	7.5	1	3.5	3.5	3.5	3.5
2A	34	13			15		7.5	13.0	12.5	8	3.5	7.0	7.0	7.0	7.0
3A	7	13.5			9		2	7.5	5	6.5	1.5	3.0	3.0	3.0	3.0
4A	0	12.0			15		6.5	3.5	3.5	4.5	1.5	7.0	7.0	7.0	7.0
5A	22.5	25.0			12		7.5	5	5	5.5	3.5	4.0	4.0	4.0	4.0
6A	33.5	28.0			13		3	8.5	17.5	8	2.0	0.5	0.5	0.5	0.5
Feed B	12	57.5			70		136.5	171	321.5	249	63	64	64	64	64
1B	12.5	13.5			7		5.5	1	9.5	NS	2.5	0.5	0.5	0.5	0.5
2B	16	16.0			15		9	27.5	28.5	7	6	4.0	4.0	4.0	4.0
3B	11	22			31		25	51.5	72	7.5	1.5	1.5	1.5	1.5	1.5
4B	4	13.5			6		28.5	2	47	2	2	1.5	1.5	1.5	1.5
5B	14.5	17.5			18		16.5	34	113	7	3.5	3.5	3.5	3.5	3.5
6B	2	13.5			10		25.0	27	20.5	8	4	2.0	2.0	2.0	2.0

Appendix 9.1. cont. Weekly Averaged BOD Data for Laboratory Scale Filters using High Rate Effluent (24.6.76 - 30.9.76)

[mg/l]

Week No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Feed A	190	175	115								74	179		
1A	90	-	19								11	17		
2A	97	29	16								14	54		
3A	96	34	33								10	35		
4A	51	11	17								6	19		
5A	67	30	17								13	44		
6A	94	58	18								12	33		
Feed B	193	207	102								78	162		
1B	100	55	38								5	24		
2B	35	41	17								11	24		
3B	66	35	19								21	26		
4B	73	35	32								6	12		
5B	37	33	16								11	38		
6B	78	40	27								6	11		

Appendix 9.1. cont. Weekly Average Ammoniacal Nitrogen Data for the Laboratory Scale Filters using High Rate Effluent (24.6.76 - 30.9.76)

(mg N/l)

Week No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Feed A	18.7	15.7	14.4	17.7	15.3	17.3	14.4	14.2	18.4	20.4	14.7	18.7	13.7	13.8
1A	14.4	11.1	10.8	11.8	10.0	9.9	3.2	3.3	5.3	3.2	2.8	3.2	4.5	1.75
2A	13.9	11.1	12.6	14.6	13.0	13.8	6.3	3.0	3.4	5.1	2.8	6.2	10.0	1.75
3A	14.8	11.2	13.5	15.5	14.0	18.8	7.9	5.1	5.2	4.2	2.5	4.2	5.0	3.10
4A	11.5	9.4	10.8	10.7	10.7	5.3	2.7	5.9	3.1	2.4	5.7	3.4	5.1	1.7
5A	13.6	10.4	11.7	16.1	15.6	14.2	5.8	3.6	2.7	3.0	2.4	3.7	5.2	2.0
6A	14.3	10.7	13.7	15.5	16.4	17.0	7.5	7.1	7.4	4.6	4.7	5.4	5.9	3.0
Feed B	19.3	13.9	13.5	16.8	14.3	17.3	13.0	14.0	18.2	12.6	13.4	18.2	13.2	14.7
1B	11.7	8.2	10.0	10.0	8.5	6.2	2.7	3.2	4.3	5.4	1.9	4.0	4.4	1.65
2B	10.6	12.1	12.3	13.5	10.6	10.3	4.7	4.6	4.3	3.0	4.8	5.9	4.9	1.55
3B	12.6	11.3	17.1	16.5	11.1	14.8	7.2	6.5	5.5	3.0	2.6	3.7	4.0	3.0
4B	9.9	7.7	5.8	10.8	7.8	7.3	2.7	2.8	4.5	1.5	3.4	2.4	8.8	1.55
5B	11.2	9.8	12.8	14.9	12.5	12.1	10.0	4.8	2.8	3.0	2.9	3.3	3.9	1.65
6B	12.7	10.3	13.9	14.5	12.5	14.7	9.9	7.3	6.7	9.5	3.9	2.8	4.0	2.95

Appendix 9.1. cont. Weekly Average Ammoniacal Nitrogen Data for the Laboratory Scale Filters using High Rate Effluent (7.10.76 - 13.1.77)

(mg N/l)

Week No.	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Feed A	10.3	11.1	11.6	9.2	11.1	8.8	14.8	6.5	21.0	15.55	7.28	9.17	10.58	11.47	10.4
1A	3.35	1.80	1.5	1.2	1.2	1.2	1.1	1.3	3.0	2.8	3.0	0.37	0.95	<0.5	<0.5
2A	3.20	1.60	1.4	1.2	1.1	1.2	1.0	1.55	3.0	2.95	1.57	<0.5	0.70	<0.5	0.8
3A	3.50	1.50	1.3	2.4	1.7	1.2	0.9	1.15	3.0	2.75	1.58	<0.5	<0.5	<0.5	<0.5
4A	1.50	1.60	1.4	1.2	1.2	1.2	1.0	1.25	3.0	2.40	0.87	0.37	0.93	<0.5	1.25
5A	1.65	1.50	1.3	1.4	1.2	1.2	0.9	1.3	3.65	2.6	0.50	<0.5	<0.5	<0.5	0.45
6A	3.00	1.55	1.2	2.5	1.8	1.2	0.9	1.05	3.1	2.6	0.27	<0.5	<0.5	<0.5	<0.5
Feed B	10.4	10.8	8.0	9.5	11.4	11.5	13.4	13.15	21.0	15.55	7.85	12.97	10.1	10.87	11.5
1B	1.80	1.60	1.5	1.4	1.2	1.3	1.0	1.4	3.35	2.6	0.5	0.37	<0.5	0.27	0.45
2B	1.65	1.50	1.4	1.5	1.2	1.2	0.8	1.4	3.25	2.6	<0.5	0.27	<0.5	<0.5	<0.5
3B	2.30	1.60	1.4	2.4	1.2	1.2	0.8	1.65	7.25	4.1	0.4	0.23	<0.5	0.27	0.40
4B	1.60	1.55	2.2	2.1	1.2	1.2	0.7	1.3	2.50	2.5	0.4	<0.5	<0.5	<0.5	0.50
5B	1.55	1.45	1.4	1.5	1.2	1.2	0.7	1.5	4.15	2.65	0.43	<0.5	<0.5	<0.5	<0.5
6B	2.55	1.60	1.4	2.6	1.2	1.3	0.7	1.4	3.35	2.20	0.47	<0.5	<0.5	<0.5	<0.5

Appendix 9.1. cont. Weekly Averaged Oxidised Nitrogen Data for Laboratory Scale Filters using High Rate Effluent (24.6.76 - 30.9.76)

(mg N/l)

Week No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Feed A	<0.1	<0.1	<0.1	0	0	0.1	0.1	0.2	0.2	0.1	2.05	<0.1	0	0.1
1A	.27	.18	0.7	2.55	3.4	4.0	9.1	9.8	11.2	15.2	9.4	10.9	13.4	12.2
2A	.2	.22	0.43	0.63	1.1	1.9	6.2	9.6	12.8	24.0	12.9	11.0	10.3	11.8
3A	.1	.15	0.22	0.4	0.6	0.95	3.7	4.9	11.35	17.8	12.05	10.3	14.2	12.7
4A	.48	.67	2.48	3.98	6.95	7.00	9.6	10.2	11.2	14.0	8.2	9.9	16.3	15.2
5A	.22	.35	0.45	0.68	1.2	1.40	6.5	9.1	15.2	24.0	12.8	8.6	12.7	10.9
6A	.12	.13	0.18	0.33	0.6	0.75	5.15	4.35	9.05	18.6	10.8	11.9	12.4	12.8
Feed B	<0.1	<0.1	<0.1	0	.0	0.1	0.25	0.25	0.35	0.3	0.4	<0.1	0.1	0
1B	.33	1.2	1.8	2.8	6.5	6.3	9.4	9.8	11.7	15.2	9.1	9.5	20.7	22.7
2B	.27	0.42	0.7	1.4	3.25	4.5	5.95	6.9	13.3	11.0	15.8	11.9	11.4	11.0
3B	.18	0.18	0.42	0.83	1.1	1.85	3.55	4.25	15.0	21.6	15.1	14.6	13.9	12.2
4B	.38	0.7	2.5	2.65	4.6	4.35	8.1	9.6	6.4	14.8	8.8	10.7	17.5	15.2
5B	.22	0.3	0.53	1.00	2.3	2.1	5.2	6.6	17.2	24.0	16.6	13.9	14.3	10.4
6B	.15	0.25	0.48	0.78	0.95	0.95	3.25	3.75	10.6	10.6	15.35	14.6	13.8	12.4

Appendix 9.1. cont. Weekly Averaged Oxidised Nitrogen Data for Laboratory Scale Filters using High Rate Effluent (mgN/l) (7.10.76 - 13.1.77)

Week No.	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Feed A	0	0	0	1.2	0.1	0.1	0.1	0	0	0.1	0.1	<0.1	0	0	0.3
1A	9.0	8.5	5.8	7.0	6.4	6.4	8.1	6.4	4.4	13.2	6.9	7.1	6.8	8.9	6.0
2A	8.0	7.6	6.5	6.0	5.6	6.2	8.0	5.7	3.7	11.8	6.9	5.7	6.6	8.6	6.5
3A	8.9	8.1	7.6	7.0	5.7	7.4	7.7	4.9	3.4	11.7	6.7	5.3	6.3	8.0	6.9
4A	10.8	10.1	7.4	8.0	6.5	6.6	8.2	5.5	4.6	12.1	8.1	7.0	7.3	9.5	6.1
5A	7.6	6.8	5.9	6.8	6.0	6.9	7.7	6.0	4.4	11.7	7.0	5.4	6.7	8.4	6.75
6A	9.3	8.3	6.7	6.6	5.4	5.6	7.5	5.1	3.8	12.6	6.3	5.4	6.6	8.2	7.0
Feed B	0	0	0	0.5	<0.1	<0.1	<0.1	0	0	0.1	0.1	<0.1	0	0	0.35
1B	6.3	6.7	5.9	7.5	7.2	6.5	6.9	6.9	7.2	10.5	5.7	6.2	6.6	8.7	6.6
2B	7.4	7.3	5.8	5.6	5.9	6.1	6.8	5.9	4.4	9.5	7.2	5.6	6.8	8.5	7.3
3B	8.5	7.8	6.6	5.9	5.4	5.9	6.7	4.5	1.4	9.5	4.9	5.1	6.7	8.4	7.2
4B	6.1	10.5	-	-	5.9	5.9	7.3	4.1	6.6	9.3	4.9	6.3	6.6	8.7	7.0
5B	2.3	6.9	5.3	5.6	6.0	6.1	6.7	4.7	3.4	9.1	6.9	5.6	6.7	8.5	6.9
6B	7.6	7.1	6.6	4.4	5.9	6.0	6.6	6.1	6.4	10.0	5.5	5.0	6.8	8.5	6.9

Appendix 9.2. Weekly Averaged Flows to Laboratory Scale Filters using High Rate Effluent (31.3.77 - 21.7.77)

(m^3/m^2d)

Week No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Feed A																	
1A	.66	.66	.48	.58	.61	.64	.62	.65	.62	.58	.60	.60	.71	.64	.58	.64	.72
2A	.64	.70	.66	.62	.66	.70	.68	.66	.56	.68	.72	.63	.73	.71	.57	.65	.62
3A	.62	.64	.62	.60	.60	.60	.63	.69	.70	.62	.63	.62	.74	.69	.69	.65	.66
4A	.63	.68	.67	.64	.67	.71	.62	.69	.73	.68	.72	.67	.74	.65	.54	.61	.66
5A	.59	.62	.61	.52	.57	.59	.44	.68	.66	.61	.65	.66	.73	.67	.71	.59	.67
6A	.72	.55	.52	.71	.62	.60	.65	.68	.62	.27	.76	.76	.72	.66	.61	.69	.66
Feed B																	
1B	.72	.72	.74	.67	.70	.68	.62	.66	.58	.56	.67	.68	.73	.75	.74	.74	.72
2B	.62	.63	.61	.52	.65	.60	.60	.36	.58	.60	.53	.67	.70	.71	.68	.70	.64
3B	.77	.65	.67	.63	.69	.66	.69	.64	.51	.59	.52	.67	.69	.66	.64	.68	.66
4B	.60	.74	.71	.62	.69	.67	.65	.61	.52	.64	.58	.71	.77	.76	.70	.67	.64
5B	.61	.70	.68	.63	.65	.59	.59	.61	.50	.61	.55	.70	.74	.72	.67	.66	.65
6B	.65	.66	.67	.69	.62	.58	.56	.62	.49	.55	.53	.55	.68	.69	.68	.66	.65

Appendix 9.2. cont. Weekly Averaged BOD Data for Laboratory Scale Filters using High Rate Effluent (31.3.77 - 21.7.77)

(mg/l)

Week No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Feed A	24.5	15.1	210	133.8	151.8	69.3	18.9	57.0	18.1	38.1	81.9	5.2	52.5	33.7	99.2	54.6	119.2
1A	1.3	2.5	0.4	12.4	9.0	1.2	2.2	2.7	1.7	5.9	2.5	2.2	1.3	7.5	8.5	16.9	11.7
2A	2.7	1.3	2.7	5.4	2.8	0.7	1.8	2.4	0.4	7.4	1.7	0.8	1.2	3.9	7.5	16.0	6.5
3A	2.0	0.7	0.8	5.4	6.1	1.1	1.6	1.2	2.7	9.2	2.4	1.5	1.8	9.6	9.7	13.1	8.9
4A	1.8	1.3	2.0	4.6	5.6	0	0.5	3.2	0.3	6.1	1.1	1.0	0.1	4.9	4.6	9.7	4.2
5A	3.2	3.1	3.3	7.6	8.7	0	2.1	2.3	3.0	6.4	2.3	2.3	0.1	5.2	5.9	15.9	8.3
6A	3.6	0.7	2.1	4.4	7.0	0.5	0.7	2.6	4.7	8.5	2.7	2.5	1.1	7.3	5.2	14.2	4.4
Feed B	28.2	21.4	94.6	261.8	136.6	18.8	36.8	48.2	22.1	43.1	47.9	13.8	43.7	35.7	46.1	51.6	138.1
1B	2.8	3.0	3.9	6.8	3.0	1.1	0.5	1.7	0.6	4.4	1.8	2.3	1.8	3.5	2.0	4.7	1.8
2B	2.1	0.5	1.2	1.9	2.0	0.8	0.9	3.4	0	4.3	1.7	0.6	1.6	1.2	1.8	3.0	0.8
3B	0.7	1.7	0.9	1.6	3.0	0.6	0.9	1.0	0	2.9	0.2	0.1	1.2	1.8	1.2	3.0	0.6
4B	2.3	0.1	0.8	2.0	2.4	0.5	0.4	2.0	0.1	5.0	2.1	0.8	4.9	2.1	0.2	3.7	3.3
5B	3.3	0.9	1.7	5.9	6.1	0.1	1.2	1.1	1.5	3.5	0.3	0.5	0.6	1.5	0.8	3.7	2.5
6B	2.2	0.7	2.0	3.8	6.9	0.9	0.4	0.2	0	5.0	1.6	1.1	0.7	2.5	1.6	4.3	1.2

Appendix 9.2 cont. Weekly Averaged Ammoniacal Nitrogen Data for Laboratory Scale Filters using High Rate Effluent (31.3.77 - 21.7.77)

(mg N/l)

Week No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Feed A	6.2	9.6	15.6	26.5	13.3	11.0	16.05	13.45	7.20	11.30	11.15	10.75	8.50	7.55	5.70	16.0	14.65
1A	0.55	1.00	13.1	22.4	11.75	4.95	3.70	0.75	0.40	0.90	1.05	0.65	0.55	2.25	1.70	5.05	2.45
2A	0.30	0.65	4.0	18.3	5.80	1.45	1.40	0.40	0.25	0.50	0.70	0.55	0.50	2.60	2.05	6.05	1.45
3A	0.20	0.60	3.0	15.25	3.05	0.95	0.70	0.25	0.20	0.35	0.50	0.50	0.50	2.05	1.30	3.85	1.10
4A	0.20	0.70	7.3	23.70	15.15	10.9	6.55	0.45	0.20	0.45	0.45	0.50	0.45	2.10	1.35	2.60	0.70
5A	0.25	0.65	7.35	21.85	12.75	3.55	1.35	0.35	0.20	0.35	0.50	0.50	0.45	2.50	1.70	1.75	0.45
6A	0.20	0.50	3.10	17.75	4.10	1.35	0.65	0.35	0.20	0.35	0.50	0.55	0.50	2.65	1.85	4.65	0.50
Feed B	6.05	8.85	14.3	29.95	14.3	11.20	15.00	14.15	8.45	13.40	9.75	9.75	6.80	7.35	5.55	15.65	14.85
1B	0.40	0.80	1.70	0.80	0.45	0.25	1.10	0.45	0.40	0.55	0.70	0.60	0.45	0	0.05	0	0.20
2B	0.30	0.55	1.55	0.80	0.45	0.25	2.10	0.35	0.25	0.45	0.50	0.55	0.45	0	0.05	0	0.20
3B	0.25	0.50	1.35	0.75	0.35	0.25	0.85	0.25	0.20	0.30	0.40	0.50	0.45	0	0	0	1.00
4B	0.20	0.60	1.55	0.70	0.35	0.25	0.90	0.25	0.20	0.25	0.35	0.50	0.45	0	0	0	0.30
5B	0.20	0.50	1.40	0.90	0.30	0.25	0.75	0.30	0.25	0.25	0.35	0.45	0.45	0	0.05	0	0.20
6B	0.25	0.50	1.40	1.15	0.65	0.25	0.75	0.25	0.30	0.30	0.45	0.45	0.45	0	0	0	0.20

Appendix 9.2. cont. Weekly Averaged Oxidised Nitrogen Data for Laboratory Scale Filters using High Rate Effluent

(mgN/l) (31.3.77 - 21.7.77)

Week No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Feed A	0.10	0.03	0.08	0	0.17	0.08	0	0	0.03	0.08	0.13	1.55	0.10	0	0	0.03	0.03
1A	3.75	7.13	4.53	2.42	7.05	9.47	14.20	16.47	11.13	13.03	16.83	17.0	11.67	10.73	5.77	11.48	13.60
2A	4.05	7.83	8.32	6.30	18.50	14.90	20.90	22.60	11.50	12.93	17.40	18.27	11.43	9.95	4.63	8.03	13.87
3A	4.00	7.67	9.70	8.67	19.23	15.13	17.90	20.60	10.90	13.27	17.13	15.97	12.90	13.32	5.27	11.28	14.47
4A	4.00	7.90	9.10	2.27	5.35	8.58	15.83	20.23	10.47	12.67	17.70	16.57	12.13	11.70	6.05	13.43	14.67
5A	4.10	7.90	6.87	5.03	14.87	14.73	18.33	21.00	10.60	13.63	18.27	16.90	12.67	11.45	5.37	13.80	15.17
6A	4.25	8.10	10.10	8.73	23.83	14.20	15.97	19.23	9.57	12.37	14.00	15.57	12.37	12.55	4.63	8.98	13.13
Feed B	0.05	0.08	0.08	0.47	0.17	0.08	0	0	0.03	0.02	0.10	0.08	0	0	0	0.05	0.05
1B	4.00	5.87	12.23	22.50	15.07	9.47	11.10	12.70	8.17	13.60	13.47	16.17	10.77	11.77	7.75	17.03	14.87
2B	4.85	6.43	13.83	25.93	20.87	12.60	14.23	19.20	10.83	14.70	16.43	15.97	10.90	11.47	7.62	15.27	14.27
3B	4.35	6.42	13.67	25.17	19.90	13.17	15.20	18.57	11.80	13.70	16.70	16.23	10.07	10.53	6.65	14.10	14.33
4B	4.75	6.57	14.50	27.53	21.60	13.53	15.60	19.60	11.60	15.13	16.70	18.30	10.93	11.67	7.98	17.03	16.63
5B	4.80	6.62	14.90	26.60	21.07	13.40	15.70	19.03	11.47	14.03	15.93	16.77	10.60	11.30	7.70	14.90	13.93
6B	4.90	6.83	14.97	26.20	23.60	13.03	15.30	18.03	10.97	14.07	16.73	20.47	10.73	11.18	7.60	15.13	13.60

Appendix 9.3. Weekly Averaged Flows to Laboratory Scale Filters using High Rate Effluent (28.7.77 - 26.8.77)

($m^3/m^3/d$)

Week No.	1	2	3	4	5
Feed A					
1A	.74	.83	.87	.86	.59
2A	.74	.82	.87	.87	.70
3A	.75	.81	.84	.86	.76
4A	.69	.63	.61	.43	.70
5A	.65	.65	.66	.70	.35
6A	.72	.70	.72	.68	.54
Feed B					
1B	.71	.90	.81	.74	.76
2B	.64	.82	.96	.77	.78
3B	.69	.88	.66	.72	.72
4B	..63	.71	.77	.72	.68
5B	.66	.66	.64	.66	.60
6B	.67	.66	.66	.66	.61

Appendix 9.3 cont. Weekly Averaged BOD Data for Laboratory Scale Filters using High Rate Effluent (28.7.77 - 25.8.77)

(mg/l)

Week No.	1	2	3	4	5
Feed A	55.1	28.9	46.5	9.2	108.9
	55.1	44.1	55.6	50.8	115.4
1A	6.4	7.7	14.7	7.7	11.9
2A	4.5	5.5	7.5	5.0	8.2
3A	5.1	8.3	9.0	6.8	11.0
4A	2.6	4.9	5.1	2.4	3.9
5A	4.7	4.7	6.0	4.6	5.5
6A	3.9	4.4	7.1	3.2	5.5
Feed B	45.8	25.6	103.4	94.4	120.5
	45.8	36.5	101.6	127.2	120.5
1B	0.9	3.9	5.8	4.8	2.5
2B	0	3.3	20.4	3.8	2.6
3B	0.7	3.8	6.1	5.3	4.9
4B	1.0	1.9	3.6	2.6	3.5
5B	0	4.8	3.8	2.5	1.7
6B	0.2	3.7	3.6	1.0	1.6

Appendix 9.3. cont. Weekly Averaged Ammoniacal Nitrogen Data for Laboratory Scale Filters using High Rate Effluent

(mg N/l) (28.7.77 - 25.8.77)

Week No.	1	2	3	4	5
Feed A	19.05	13.90	22.15	19.35	24.40
		13.45	23.70	20.95	20.85
1A	2.65	1.25	1.55	2.20	7.00
2A	2.00	0.80	1.70	1.85	7.25
3A	1.60	0.85	1.30	1.90	6.50
4A	1.15	0.60	0.95	1.80	1.35
5A	0.90	0.60	0.80	1.95	1.25
6A	1.00	0.55	0.70	1.95	1.05
Feed B	19.80	13.40	21.45	18.15	23.55
		13.35	22.15	21.95	24.80
1B	0.75	1.30	0.80	1.10	2.55
2B	0.60	0.85	1.25	1.05	4.70
3B	0.55	1.75	1.80	1.05	4.45
4B	0.55	0.60	1.50	0.90	0.95
5B	0.45	0.50	0.85	0.95	0.75
6B	0.45	0.50	0.65	0.90	0.55

Appendix 9.3 cont. Weekly Averaged Oxidised Nitrogen Data for Laboratory Scale Filters using High Rate Effluent (28.7.77 - 25.8.77)

(mg N/l)

Week No.	1	2	3	4	5
Feed A	0.10	0.03	0.17	0.07	0.10
		0	0.07	0.03	0.10
1A	16.27	15.60	18.53	17.90	14.73
2A	16.17	15.23	16.30	16.47	13.63
3A	17.07	15.87	17.47	16.93	13.93
4A	18.53	15.67	17.60	18.73	19.83
5A	19.07	15.47	18.20	16.23	19.97
6A	16.47	13.90	15.60	14.63	18.80
Feed B	0.13	0	0	0.07	0.10
		0.03	0	0	0.08
1B	17.97	13.97	13.80	16.67	19.40
2B	17.40	13.60	11.07	16.47	16.87
3B	18.33	12.23	11.13	15.63	16.63
4B	19.37	15.43	12.80	18.47	19.47
5B	17.53	13.87	10.17	14.87	18.77
6B	16.87	12.87	11.17	13.87	17.23

Appendix 10.1 Weekly Averaged Flow Data for the Lab. Scale Filters using Synthetic Sewage ($m^3/m^3/d$). 1977

	19/5	26/5	2/6	9/6	16/6	23/6	30/6	7/7	14/7	21/7	28/7	5/8	11/8	18/8	26/8	2/9	8/9	15/9	22/9	29/9
A1	0.82	0.75	0.83	0.74	0.74	0.78	0.74	0.62	0.69	0.79	0.78	0.77	0.71	0.76	0.71	0.79	0.68	0.70	0.74	0.73
A2	0.72	0.73	0.73	0.78	0.77	0.72	0.72	0.58	0.67	0.77	0.76	0.77	0.77	0.80	0.78	0.90	0.71	0.68	0.71	0.73
B1	0.57	0.74	0.74	0.75	0.76	0.75	0.77	0.69	0.69	0.80	0.76	0.76	0.78	0.78	0.75	0.82	0.70	0.87	0.93	0.79
B2	0.75	0.79	0.78	0.78	0.78	0.80	0.81	0.69	0.74	0.85	0.85	0.82	0.79	0.86	0.79	0.92	0.73	0.69	0.70	0.68
C1	0.76	0.73	0.73	0.70	0.73	0.80	0.80	0.75	0.73	0.78	0.71	0.65	0.71	0.85	0.86	0.90	0.79	0.86	0.87	0.82
C2	0.70	0.67	0.72	0.71	0.74	0.72	0.74	0.63	0.69	0.79	0.72	0.72	0.74	0.77	0.65	0.84	0.74	0.63	0.73	0.80
D1	0.74	0.74	0.75	0.72	0.78	0.78	0.71	0.65	0.72	0.81	0.74	0.73	0.73	0.65	0.61	0.81	0.68	0.68	0.76	0.83
D2	0.73	0.70	0.66	0.60	0.65	0.73	0.70	0.67	0.73	0.80	0.77	0.72	0.78	0.74	0.77	0.92	0.78	0.75	0.82	0.76

Appendix 10.1(cont) Weekly Averaged BOD Data for The Lab Scale Filters using Synthetic Sewage, mg/l. (1977).

	19/5	26/5	2/6	9/6	16/6	23/6	30/6	7/7	14/7	21/7	28/7	4/8	11/8	18/8	25/8	2/9	8/9	15/9	22/9	29/9
Feed A	11.0	9.8	13.0	3.9	6.2	4.7	1.2	5.8	4.0	0.8	1.8	1.6	2.2	2.65	1.80	6.95	16.50	7.60	5.0	0.1
A1	1.8	0.9	7.4	1.2	0	1.4	1.7	3.9	6.9	5.8	5.3	4.5	5.7	3.35	3.60	3.50	6.50	4.20	1.30	2.85
A2	0.4	0.7	6.9	1.8	0.5	2.0	1.3	7.7	20.3	7.4	8.0	6.0	4.8	4.35	1.90	1.90	8.30	1.85	1.55	1.50
Feed B	34.5	25.6	28.7	29.7	24.5	31.3	23.5	25.0	23.0	26.5	24.7	24.7	12.6	31.45	22.20	26.3	27.3	19.20	26.4	35.75
B1	8.0	4.3	10.6	1.3	1.4	1.8	0.7	4.3	5.1	5.9	3.5	7.4	5.8	5.60	4.05	3.55	6.30	4.25	1.70	3.10
B2	3.3	4.7	9.2	2.5	0.9	2.4	1.9	4.2	6.7	3.5	0.6	2.5	7.3	3.60	2.70	4.05	11.10	9.50	1.10	0
Feed C	63.5	58.6	71.0	57.2	55.8	65.2	65.0	64.8	62.1	56.7	52.9	60.7	50.1	63.05	61.70	44.95	65.3	69.55	67.9	67.00
C1	9.9	9.6	9.1	1.4	1.3	2.5	4.6	8.3	6.9	4.1	3.7	2.4	5.3	7.15	4.35	4.70	6.30	5.85	2.85	2.45
C2	8.9	5.2	18.3	2.9	1.8	4.7	3.2	5.9	5.0	6.8	5.7	7.8	1.9	8.70	8.60	8.80	9.90	4.25	2.75	1.20
Feed D	104.5	89.1	70.1	60.8	92.6	101.5	110.2	92.9	90.8	95.1	92.0	89.2	79.0	89.35	89.20	82.15	92.50	96.40	86.5	75.70
D1	12.7	2.3	11.0	2.7	5.2	3.6	6.3	11.4	18.6	15.2	21.6	10.4	8.4	9.60	13.85	15.95	35.1	52.25	9.00	7.15
D2	7.4	14.8	10.8	5.5	2.9	3.6	4.4	9.1	19.1	18.2	18.3	14.7	8.5	10.95	22.1	15.15	25.0	16.85	20.50	22.50

Appendix 10.1 Weekly Averaged Ammonia Results for the Lab. Scale Filters using Synthetic Sewage,(mg N/1) 1977.

	19/5	26/5	2/6	9/6	16/6	23/6	30/6	7/7	14/7	21/7	28/7	4/8	11/8	18/8	25/8	1/9	8/9	15/9	22/9	29/9
Feed A	31.50	32.97	31.23	27.43	29.20	32.13	27.47	39.50	45.73	50.73	54.27	39.17	37.33	34.67	35.87	34.8	37.53	34.93	39.80	38.80
A1	1.65	1.60	0.95	0.60	0.90	1.80	6.75	18.35	12.95	22.20	16.00	6.15	8.38	2.00	0.55	1.58	1.48	1.05	0.93	1.05
A2	0.85	1.05	0.60	0.45	0.60	1.65	7.55	20.85	11.75	19.20	13.20	3.80	8.30	1.57	0.53	1.20	1.17	0.72	0.77	0.80
Feed B	44.20	36.55	32.45	31.35	33.40	35.35	31.15	36.35	40.85	39.45	40.85	39.60	38.07	41.07	42.53	38.80	40.93	38.80	40.93	40.40
B1	16.15	14.85	11.25	11.75	10.10	9.50	10.40	29.40	14.55	18.40	14.60	12.40	13.00	14.13	13.50	11.95	13.88	13.37	12.57	14.68
B2	16.75	14.35	13.10	14.05	12.25	12.55	11.85	25.65	20.65	24.25	23.25	22.75	14.42	15.43	14.83	13.70	16.71	12.73	13.52	14.62
Feed C	43.55	40.45	39.45	37.95	34.40	37.25	32.45	35.60	42.60	40.25	41.05	41.10	38.73	44.67	42.93	40.80	42.80	41.00	42.67	41.93
C1	14.70	13.35	11.15	12.50	11.55	13.45	13.45	26.25	18.85	17.55	14.25	12.00	12.07	17.13	12.53	13.45	12.33	12.97	12.83	11.53
C2	15.15	13.50	17.30	14.95	11.60	12.20	13.95	27.20	20.45	20.65	21.80	22.10	15.43	17.10	12.88	12.55	12.67	12.52	11.93	14.13
Feed D	37.75	36.80	41.65	38.40	38.45	36.25	35.40	37.60	42.55	42.45	41.85	41.75	40.13	43.33	39.87	41.60	43.60	41.93	42.27	42.73
D1	15.15	13.50	12.45	11.65	12.10	11.55	16.00	30.65	26.15	34.60	32.65	27.90	18.03	24.73	16.53	15.68	17.17	19.43	20.07	20.50
D2	13.00	14.40	15.75	9.40	9.00	11.20	9.00	32.55	30.95	35.45	32.35	28.45	17.53	23.07	19.87	19.83	23.93	21.87	21.20	21.47

Appendix 10.1(cont) Weekly Averaged Oxidised Nitrogen Data for the Lab. Scale Filters using Synthetic Sewage ,

(mg N/l , 1977)

	19/5	26/5	2/6	9/6	16/6	23/6	30/6	7/7	14/7	21/7	28/7	4/8	11/8	18/8	25/8	1/9	8/9	15/9	22/9	29/9
Feed A	0·05	0	0·02	0·02	0·02	0·02	0	0·03	0·02	0·02	0	0·02	0	0·53	0	0·08	0·03	0·05	0·15	0·03
A1	32·80	31·87	29·47	32·60	24·87	38·47	34·73	24·33	31·07	27·60	36·67	37·13	24·87	31·00	29·87	32·60	37·60	32·87	32·13	28·87
A2	40·33	30·80	28·20	38·93	30·87	38·53	33·73	21·80	33·07	30·93	40·13	41·60	26·53	33·20	29·60	33·40	37·07	32·67	32·13	28·73
Feed B	0·17	0·07	0·25	0	0	0	0	0	0	0	0·07	0	0·03	0·13	0·13	0·05	0·33	1·88	0·07	0·10
B1	40·07	32·13	29·47	31·47	31·53	32·47	27·80	14·80	24·80	27·07	29·33	34·00	23·07	28·67	28·67	30·60	32·80	29·13	29·33	25·03
B2	40·67	30·33	28·73	36·73	31·33	32·27	26·20	12·80	15·67	18·80	21·53	23·33	21·00	26·47	27·47	29·60	29·73	30·67	30·27	27·13
Feed C	0·03	0·02	0·05	0	0	0	0	0	0	0·07	0	0	0	0·07	0·07	0	0·13	0·20	0·10	0
C1	44·40	37·33	35·40	43·33	36·40	38·07	28·87	14·53	21·33	26·40	32·00	39·87	27·47	28·67	32·80	35·80	38·53	33·60	34·93	32·13
C2	46·27	38·67	28·60	39·53	38·47	40·40	29·80	14·33	21·87	22·60	25·60	29·13	25·53	29·80	32·40	38·00	38·53	36·00	36·93	30·90
Feed D	0·03	0·02	0·02	0	0	0	0	0	0	0	0	0	0·25	0	0·07	0·03	0·12	0	0	0
D1	43·20	37·20	38·13	46·67	39·80	41·73	27·87	13·93	15·00	10·53	15·00	21·20	21·77	23·60	29·87	34·40	34·40	27·00	27·00	23·60
D2	42·53	36·67	34·53	50·00	39·53	45·60	27·07	10·40	6·87	11·33	15·93	23·60	21·60	23·13	22·47	27·00	27·33	24·80	25·00	22·57

REFERENCES.

ANDREWS,L. (I964). Operational Experiences at Dunstable. J. Proc. Inst.Sew. Purif. -(5), 434-439.

ANON. (I963). Northampton Sewage Works. J. Proc. Inst. Sew. Purif. 259-26I.

ANON.(I973). Real Savings with Artificial Media. Survr. Local Govt. Technol. I42,Nos 4254/4255,4I.

ANON. (I973). Temporary additions to an overloaded sewage works. Water and Waste Treatment, I6(I2), 2I.

ASKEW,M.W.,(I966). Plastics in Waste Treatment (Part I.) Process Biochemistry. I, 483-486 &489.

ASKEW,M.W.(I967). Plastics in Waste Treatment.(Part 2). Process Biochemistry. 2, 3I-34.

ASKEW,M.W.(I969). Biofiltration Technology. Effl. Wat. Treat. J. 9, 547-552 & 6II-6I7.

BALAKRISHNAN,S. & ECKENFELDER,W.W. (I969). Nitrogen relationships in Biological Treatment Processes. II Nitrification in Trickling Filters. Wat. Res. 3, I67-I74.

BANKS,P.A.,HITCHCOCK,K.W.,& WRIGHT,D.A.,(I974). Studies of High-Rate Biological Treatment of Ipswich Sewage on Pilot Filters using Plastics Media. Paper presented to East Anglia Branch I.W.P.C. 27 Nov.I974.

BANKS,P.A.,HITCHCOCK,K.W.,& WRIGHT,D.A.(I976). Studies of High-Rate Biological Treatment of Ipswich Sewage on Pilot Filters using Plastics Media. Wat. Pollot. Control. 75, 40-46.

BARRACLOUGH,D.H. (1954). Biological Filtration of Sewage and Vacuum Filtration of Sludge.
J. Proc. Inst. Sew. Purif. (4), 361 -376.

BARRITT,N.W. (1933). The Nitrification in soils and biological filters.
Ann. Appl. Bol. 20, 165-184.

BAYLEY,R.W. & DOWNING,A.L. (1963). Temperature relationships in percolating filters.
Instn. Publ. Hlth. Engrs. 62, 303-332.

BAYLEY, R.W. (1970). Nitrogen and Phosphorous removal - methods and costs.
Wat. Trt. and Exam. 19, 294-319.

BECKMAN,W.J., AVENDT,R.J., MULLIGAN,T.J., & KEHRBERGER G.J. (1972) Combined carbon oxidation - nitrification.
J. Wat. Pollut. Control Fed. 44, 1916-31.

BEEDHAM,C.C. (1947). Some future problems in sewage purification at Bradford.
J. Proc. Inst. Sew. Purif. (2), 141-149.

BELL,J.P. & EELES,C.W.O. (1967). Neutron Random Counting Error in terms of soil moisture for non linear calibration curves.
Soil Sci. 103, 1-3.

BERGEY'S Manual of Determinative Bacteriology, 7th Edn. Breed,R.S., Murray,R.G.D.,& Smith N.R., Bailliere, Tindall & Cox Ltd., London. 1957.

BISHOP,D.F.,HEIDMAN,J.A., & STAMBERG,J.B. (1976). Single stage nitrification - denitrification.
J. Wat. Pollut. Control Fed. 48,(4) 520-532.

BREZONIK,P.L. (1977). Denitrification in natural waters.
Prog. Wat. Tech. 8, (4/5), 373-392.

BRITISH STANDARD. 1438. (1971). Specification for Media for Biological Percolating Filters.
British Standards Institution. 1-26.

BRUCE, A.M., TRUESDALE, G.A. & MANN, H.T. (1967). The comparative behaviour of replicate pilot-scale percolating filters.
Inst. Publ. Hlth. Engrs. J. 66, 151-175.

BRUCE,A.M. (1968). The significance of particle shape in relation to percolating filter media.
J. Brit. Granite Whinstone Fed.Aut. 8,(2), 1-15.

BRUCE,A.M. (1969). Percolating Filters.
Process Biochem. 4(4), 19-23.

BRUCE,A.M. & BOON,A.G. (1970).
Publ. Wks.& Munic Services Conf. 1970, Paper 17.

BRUCE,A.M. (1970). Some factors affecting the efficiency of high rate biological filters.
Proc. 5th Int.Conf.Wat. Pollut. Res. 11, 14/1 -14/8.

BRUCE,A.M. (1970). & MERKENS,J.C. Recent studies of high rate biological filtration.
Wat. Pollut. Control. 69, 113-148.

BRUCE,A.M., MERKENS,J.C.,& MACMILLAN,S.C. (1970). Research development in high rate filtration.
Instn. Publ. Hlth. Engrs. J. 49, 178-207.

BRUCE,A.M. & BOON,A.G.(1971). Aspect of high rate biological treatment of domestic and industrial waste waters.
Wat. Pollut. Conf. 70, 487-513.

BRUCE,A.M. & MERKENS,J.C. (1973). Further studies of partial treatment of sewage by high rate biological filtration.
Wat. Pollu. Control. Lond. 72, 499-527.

BRUCE,A.M. & MERKENS,J.C. (1973). Partial treatment of domestic sewage by high rate biological filtration. Progress in Water Technology Vol.3. Pergaman Press, Oxford. 221-237.

BRUCE,A.M.,MERKENS,J.C. & HAYNES,B.A.O. (1974)(1975), Pilot scale studies on the treatment of domestic sewage by two stage biological filtration - with special reference to nitrification.
Paper presented to the West Midlands Branch I.W.P.C. 23/Jan/74.
Wat. Pollut. Control. 74, 80-100.

BRYAN,E.H.& MOELLER,D.H. (1963). Aerobic biological oxidation using Dowpac.
Int. J. Air Wat. Pollut. 5, 341-346.

BURGESS,F.J.,GILMOUR,C.M.,MERRYFIELD,F. & CARSWELL J.K.(1961). Evaluation criteria for deep trickling filters.
J. Wat. Pollut. Control. Fed., 33, 787-799.

BURN,K.N. (1961). Design and calibration of a neutron moisture meter. Symposium on nuclear methods for measuring soil moisture.
A.S.T. Spec. Tech. Publ. No 293. p14-26.

BUSWELL,A.M.,SHIOTA,T., LAWRENCE,N. & METERI.V. (1954). Laboratory studies on the kinetics of the growth of nitrosomonas with relation to the nitrification phase of the BOD test.
Appl. Microbiol. 2, 21-25.

CALOW,P. (1972). A method of determining the surface areas of stones to enable quantitative density estimates of litteral stonedwelling organisms to be made.
Hydrobiologia. 40, 37-50.

CHAPMAN,B.,COOKE,G.H. & WHITEHEAD,R. (1967). Automated analysis. The determination of ammoniacal nitrous and nitric nitrogen in river waters, sewage effluents and trade effluents.
Wat. Pollut. Control. (2). 3-9.

CHIPPERFIELD, P.N.J. (1966). The use of plastic media in the biological treatment of sewage and industrial wastes.
Survr. Munic. Cty. Engr. (3846) 30-32 & 67.

CHRISTENSEN,M.H. & HARREMOES,P. (1977). Biological denitrification of sewage. A literature review.
Prog. Wat. Tech. 8, (4/5), 509-555.

COOKE,W.B. & HIRSCH. (1958). Continuous sampling of trickling filter populations.
Sew. Ind. Wastes. 30, 138-155.

COOKE,W.B. (1959). Trickling filter ecology.
Ecol. 40(2), 273-291.

CRAFT,T.F. & INGOLS,R.S. (1973). Flow through time in trickling filters.
Wat. Sewage Wks. 120 (1), 78-79.

CURDS,C.R. (1969). An illustrated key to the British freshwater ciliated protozoa commonly found in activated sludge.
Water Pollution Research Technical Paper No 12,
H.M.S.O., London.

CURDS,C.R. & COCKBURN,A. (1970). Protozoa in biological sewage treatment processes -1. Survey of the protozoan fauna of British percolating filters and activated sludge plants.
Wat. Res. 4 225-236.

CUTLER,D.W. & CRUMP,L.M. (1933). Some aspects of the physiology of certain nitrite forming bacteria. Ann. Appl. Biol. 20, 291-296.

DAVIES,W. (1973). An investigation of several factors affecting nitrification in pilot scale percolating filters treating domestic sewage. M.Sc., Theseis, The University of Aston, Birmingham.

DEKEMA,C.J. & KRIGE,P.R. (1949). Two stage filtration versus single stage. J. Proc. Inst. Sew. Purif. -(1), 91-97.

DEPARTMENT OF THE ENVIRONMENT. (1972). The analysis of raw, poyable and waste waters. H.M.S.O. 304pp.

DEPPE,K. & ENGEL,H. (1960). Untersuchen uber temperaturabhangigkeit der nitratbildung durch nitrobacter winogradski buch. bei ungehmmten und gehemmten wachstum. Zentbl Bakt Parasitkde 11, 113, 561-568.

DOXTADER,K.G. & ALEXANDER,M. (1966). Nitrification by heterotrophic soil micro organisms. Proc. Soil Sci. Soc. Am., 30, 331-355.

DUDDLES,G.A., RICHARDSON, S.E., BART. E.F. (1974). Plastic medium trickling filters for biological nitrogen control. J. WAt. Poll. Cont. Fed., 46(5), 937-946.

ECKENFELDER,W.W. & HOOD,J.W. (1950). The role of ammoniacal nitrogen in sewage treatment. Wat. and Sew, Works. 97, 246-250.

ECKENFELDER,W.W. (1961). Trickling filter design and performances. J. Sanit. Engn. Div. of Am. Soc. Civ. Engrs. 87,33-45.

EDEN,G.E. & MELBOURNE,K.V. (1960). Radioactive tracers for measuring retention periods in filter beds. Int. J. Appl. Radiation & Isotopes. 8, 172-178.

EDEN, G.E., BRENDISH,K.R. & HARVEY,B.R., (1964). Measurement and significance of retention in percolating filters. J. Proc. Inst. Sew. Purif. 513- 525.

EDEN,G.E., TRUESDALE,G.A.&MANN H.T. (1966). Biological filtration using a plastic filter medium. J. Proc. Inst, Sew. Purif. 562-575.

EDMONDSON,J.H. & GOODRIDH,S.R. (1947). Further experiments on nitrification and recirculation in percolating filters. J. Proc. Inst. Sew. Purif. (2), 17-52.

EYLAR,O.R. & SCHMIDT,E.L. (1959). A survey of heterotrophic micro-organisms from soil for ability to form nitrite and nitrate. J. Gen. Microbiol. 20, 473-481.

FISHER,T.,FISHER,E. & APPLEMAN,M.D. (1956). Nitrite production by heterotrophic bacteria. J. Gen. Microbiol. 14, 238-247.

FLAIGG,N.G. & REID,G.W. (1954). Effects of nitrogenous compounds on stream conditions. Sew, and Ind. Wastes. 26,1145-54.

FRESHWATER BIOLOGICAL ASSOCIATION. (1971). Scientific Publication No.22. - A guide for the identification of British aquatic oligochaeta. R.O.Brinkhurst, Freshwater Biological Assoc.

GERMAIN,J.E. (1966). Economic treatment of domestic waste by plastic medium trickling filter. J. Wat. Poll. Contr. Fed. 38, 192-203.

GOLDTHORPE,H.H. (1938). Experimental rapid filtration at Huddersfield. J. Proc. Inst. Sew. Purif. (1), 127-137.

GOLDTHORPE,H.H. & NIXON,J.(1942). A report upon the treatment of sewage on percolating filters at Huddersfield. J. Proc. Inst. Sew. Purif. 101-115.

GRANTHAM,G.R. (1951). Trickling filter performance at intermediate loading rates. Sew. Ind. Wastes. 23(10),1227-1234.

HAIGH JOHNSON,J.W. (1914). A contribution to the biology of sewage disposal. J. Econ. Biol. 9, 105-24, 127-64.

HALVORSON,H.O., SAVAGE,G.M. & PIRET,E.L. (1936). Some fundamental factors concerning the operation of trickling filters. Sewage Works J. 8, 888-903.

HARROD, J.J. & HALL,R.E. (1962). A method for determining the surface areas of various aquatic plants, Hydrobiologia 20, 173-178.

HARVEY,B.R. EDEN,G.E. &MITCHELL,N.T. (1963). Neutron Scattering : a technique for the direct determination of the amount of biological film in a percolating filter. J. Proc. Inst.Sew. Purif. 495-506.

HAWKES,H.A. (1952). Ecology of anisopus fenestralis in sewage bacteria beds. Ann. Appl. Biol. 39, 181-192.

HAWKES,H.A. & JENKINS,S.H. (1955). Comparison of four grades of sewage percolating filter media in relation to purification, film accumalation and fauna. J. Inst. Sew. Purif. (4), 352-357.

HAWKES,H.A. (1959). Effect of methods of sewage application on the ecology of bacteria beds. Ann. Appl. Biol. 47, 339-349.

HAWKES,H.A. (1961). An ecological approach to some bacteria bed problems. J. Inst. Sew. Purif. (2), 105-132.

HAWKES,H.A. (1963). The ecology of waste water treatment. Pergaman Press, Oxford.

HAWKES,H.A. & JENKINS,S.H. (1964). Comparison of double filtration and alternating double filtration of an industrial sewage using beds having controlled frequency of dosing. Scientific Papers from Inst. Che. Techn. Prague. Technology of Water. 8,(1), 87-122.

HAWKES,H.A. & SHEPARD,M.R.N. (1970). The seasonal accumalation of solids in percolating filters and attempted control at low frequency dosing. Proc. 5th Int. Water Pollution Res. Conf. Vol.II,11/1-11/8.

HAWKES,H.A. & SHEPARD M.R.N. (1972). The effect of dosing frequency on the seasonal fluctuations and vertical distribution of solids and grazing fauna in sewage percolating filters. Water Research. 6, 721-730.

HEMMING,M.L. (1971). Textile wastes treatment. International Dyer & Textile Printer. 414-419.

HEMMING,M.L. (1970). Experiences in the treatment of effluents from the manufacture of malt whisky using high rate biofiltration and plastic media. Paper presented to International Congress on Industrial Waste Water. Stockholm Nov. 2-6, 1970.

HEMMING, M.L. (1971). Plastics filter media in treating dairy and milk processing effluents. Environmental Pollution Control. 1, 24-28.

HEMMING, M.L. (1973). The flocor installation at Kingston Seymour. Surveyor. 4247, 14-16.

HEUKELUKIAN,H. (1942). The influence of nitrifying flora,oxygen and ammonia supply on nitrification of sewage. Sew. Works J. 14, 964-979.

HEUKELUKIAN,H. (1945). The relationship between accumulation, biochemical and biological characteristics of the film and purification capacity of a biofilter and a standard filter. Sewage Wks. J. 17(a)23-38(b)269-91(c) 516-24(d)743-69.

HEUKELUKIAN,H. (1947). The effect of carbonaceous materials on nitrification. Proc. 4th Int Cong. Microbiol. p460.

HOWLAND, W.E., POMLAND,F.G. & BLOODGOOD,D.E. (1963). Kinetics in trickling filters. Int. J. Air. Wat. Poll. 5, 233-248.

HURWITZ,E. & BARNET (1953). Nitrification and B.O.D. Sew. Wks. J. 19(6), 995-999.

INGRAM, (1959). An investigation into the mechanics of controlled filtration.
Sew. Ind. Wastes. 31, 1147-58.

JENKINS,S.H. (1931). The biological oxidation of carbohydrate solutions. 1. The oxidation of sucrose and ammonia in sectional percolating filters.
Biochem. J. 25, 147.

JENKS,H.N. (1937). The renaissance of the percolating filter.
J. Proc. Inst. Sew. Purif. (1), 26-44.

JENSEN,H.L. & GUNDERSEN,K. (1955). Biological decomposition of aromatic nitro compounds.
Nature, London. 175, 341.

JOHNSON,W.K. (1952). Ventilation of trickling filters.
Sew. & Ind. Wastes. 24,(2), 135-148.

JOHNSON,W.K. & SCHROEPFER,G.L. (1964). Nitrogen removal by nitrification and denitrification.
J. Wat. Poll. Contr. Fed. 36, 1015-1036.

JOLLY,D.R.P. (1972). Experience with winery waste treatment plant.
Int, Brewing and Distilling. 2(7), 12-15.

JOSLIN,J.R.,SIDWICK,T.M.,GREENE,G.,& SHEAPER,J.R. (1971). High rate Biological filtration - A comparative assessment.
Wat. Poll. Control. 70, 383-399.

KNEALE,C.R. (1974). An investigation into some factors influencing notification in pilot scale biological filters treating domestic sewage.
M.Sc. Thesis. The University of Aston in Birmingham.

KOLKWITZ,R. & MARSSON,M. (1908).
Oekologie der pflauzlichen saprobien.
Ber. Dtsch. Bot. Ges. 26a, 505-519.

KOLKWITZ,R. & MARSSON,M. (1909).
Oekologie der tierischen saprobien.
Int. Rev. Hydrobiol. 2, 126-52.

LANDINE,R.C. (1972). Plastic media biofilters - their application in Canada.
Wat. Pollut. Control. 110(11), 34-39.

LAUDELOUT,H. & VAN TICHELEN,L. (1960). Kinetics of the nitrate oxidation by nitrobacter winogradskyi.
J. Bact. 79, 39-42.

LEVINE,M., LUEBBERS,R., GALLIGAN,W.E. & VAUGHN,R. (1936).
Observations on ceramic filter media and high rates of filtration.
Sewage Wks. J. 8, 699-727.

LEVINE,M. (1940). The role of trickling filters in sewage purification.
Sewage Wks. J. 12, 1062-76.

LUMB,C & EASTWOOD, (1958). The recirculation principle in filtration of settled sewage - Some notes and comments on its applications.
J.Proc. Inst. Sew. Purif. (4), 380-398.

McDONALD,D.P. (1971). High-rate biofiltration tower prevents clogging by bios.
Munic. Engng. London. 148, 1009.

MARAIS,P.G. & SMIT,W.B.DeV. (1960). Laboratory calibration of the neutron moisture meter.
S. Afr. J. Agric. Sci. 3, 581-601.

MARSHALL,K.C. & ALEXANDER,M. (1962).
Nitrification by ASPERGILLUS FLAUUS.
J. Bact. 83, 572-578.

MELTZER,D. (1962). Investigation of the time factor in biological filtration.
J. Inst. Sew. Purif. (2), 169-175.

MOHLMANN,F.W. (1936). One year's operation of an experimental high rate trickling filter.
Sewage Wks. J. 8, 904-914.

MOHLMAN,K.W. (1938). Nitrification.
Sewage Wks. J. 10, 792-793.

MORTIER,P. & DE BOODT,M. (1956). Determination of soil moisture by neutron scattering.
Neth. J. Agr. Sci. 4, 111-113.

NELSON,D.H. (1931). Isolation and characterisation of nitrosomonas and nitrobactor.
Zentbl. Bakt. Parasitkde, Abt.11, 83, 280-311.

OLDROYD,R.S. (1952). Filtration Experiments at Dewsbury.
J. Proc. Inst. Sew. Purif. (2), 122-134.

NICOLSON,N.J. (1973). Ammonia Standards for Sewage effluents.
Surv. Local Govt. Technol. 142, (4233),48.

PAINTER,H.A. & JONES,K. (1963). The use of the wide-bore dropping mercury electrode for the determination of rates of oxygen uptake and of oxidation of ammonia by micro-organisms.
J. Appl. Bact. 26, 471-483.

PAINTER,H.A. (1970). A review of literature on inorganic nitrogen metabolism in micro-orgamisms.
Wat. Res. 4, 393-450.

PAINTER,H.A. (1977). Microbial transformations of inorganic nitrogen.
Progress in Water Technol. 8,(4/5), 3-29.

PEACH, J.D. (1957). Some percolating filter experiments at Cheltenham.
J. Proc. Inst. Sew. Purif. (2), 111-115.
AND - Discussion - J.Proc. Inst. Sew. Purif. (3),238-241.

PETRU, ING.A. (1958). Temperature and airflow in filters significance in trickling filter efficiency.
Contract Rec. 69, 15-21.

QUASTEL,J.H.,SCHOLEFIELD,P.G. & STEVENSON,J.W. (1950). Oxidation of pyruvic-oxime by soil organisms.
Nature, London. 166, 940-942.

REEVES, G.T. (1972). Nitrogen removal literature review.
J. Wat. Poll. Control Fed. 44,(10), 1895-1908.

REYNOLDSON,T.B. (1939). The role of macro-organisms in bacteria beds.
Inst. Sew. Purif. (1), 158-172.

REYNOLDSON,T.B. (1939). Enchytraeid worms and the bacteria bed method of sewage treatment.
Ann. Appl. Biol. 26, 138-172.

REYNOLDSON, T.B. (1941). The biology of the macro fauna of a high rate filtration plant at Huddersfield.
J. Proc. Inst. Sew. Purif. p109-128.

REYNOLDSON,T.B. (1942). Further studies on the biology of a double filtration plant at Huddersfield. J. Proc. Inst. Sew. Purif. 116-139.

RINKE, G. & WOLTERS,N. (1970). Technology of plastic medium trickling filters. Proc. 5th Int Conf. Wat. Poll, Res. 11, 15-1 -- 15-9.

SAWYER,C.N. & BRADNEY, L. (1946). Modernisation of the BOD test for determining the efficiency of sewage treatment processes. Sew. Wks. J. 18, 1113-1120.

SCHROEPFER,G.J. (1951). Effect of particle shape on porosity and sunface area of trickling filter media. Sew. Indust. Wastes. 23, 1356-1366.

SCHROEPFER,G.J., AL-HAKIM,M.B.,SEIDEL,H.F. & ZIEMKE,N.R.(1952). Temperature effects in trickling filters. Sew and Inds. Wastes. 24(6), 705-722.

SCHULZE,K.L. (1960). Load and efficiency of trickling filters. J. Wat. Pollut. Contr. Fed. 32, 245-261.

SHARMA,B. & AHLERT,R.C. (1977). Nitrification and nitrogen removal. Water Res. 11(10), 897-925.

SHINDALA, A. (1972). Nitrogen and phosphorous removal from waste waters. Wat. Sew. Wks. 119(6), 66-71.

SIDWICK,J.M. & MURRAY,J.E. (1976). A brief history of sewage treatment. I, Before the Royal Commission. Effluent & Water Treatment Journal. 16(2),65-66 & 69-71.

REYNOLDSON,T.B. (1942). Further studies on the biology of a double filtration plant at Huddersfield. J. Proc. Inst. Sew. Purif. 116-139.

RINKE, G. & WOLTERS,N. (1970). Technology of plastic medium trickling filters. Proc. 5th Int Conf. Wat. Poll, Res. 11, 15-1 -- 15-9.

SAWYER,C.N. & BRADNEY, L. (1946). Modernisation of the BOD test for determining the efficiency of sewage treatment processes. Sew. Wks. J. 18, 1113-1120.

SCHROEPFER,G.J. (1951). Effect of particle shape on porosity and sunface area of trickling filter media. Sew. Indust. Wastes. 23, 1356-1366.

SCHROEPFER,G.J., AL-HAKIM,M.B.,SEIDEL,H.F. & ZIEMKE,N.R.(1952). Temperature effects in trickling filters. Sew and Inds. Wastes. 24(6), 705-722.

SCHULZE,K.L. (1960). Load and efficiency of trickling filters. J. Wat. Pollut. Contr. Fed. 32, 245-261.

SHARMA,B. & AHLERT,R.C. (1977). Nitrification and nitrogen removal. Water Res. 11(10), 897-925.

SHINDALA, A. (1972). Nitrogen and phosphorous removal from waste waters. Wat. Sew. Wks. 119(6), 66-71.

SIDWICK,J.M. & MURRAY,J.E. (1976). A brief history of sewage treatment. I, Before the Royal Commission. Effluent & Water Treatment Journal. 16(2),65-66 & 69-71.

SIDWICK,J.M. & MURRAY,J.E. (1976). A brief history of sewage treatment II, The Royal Commission.
Effluent & Wat. Tre. J. 16(4), 193-195 & 197-199.

SIDWICK,J.M. & MURRAY,J.E. (1976). A brief history of sewage treatment 3. The turn of the century.
Effluent & Wat. Tre. J. 16(6), 295,298,299,301.

SIDWICK,J.M. & MURRAY,J.E. (1976). A brief history of sewage treatment 4. Between the wars.
Effluent & Wat. Tre. J. 16(8), 403-405, 407,409.

SIDWICK,J.M. & MURRAY,J.E. (1976). A brief history of sewage treatment 5. Since the war.
Effluent & Wat.Tre. J. 16(10), 515,517-520.

SIDWICK,J.M. & MURRAY,J.E. (1976). A brief history of sewage treatment. Conclusion.
Effluent & Wat. Tre. J. 16(12), 609-611, 614-616.

SOLBE,J.F.de L.G., WILLIAMS,N.V. & ROBERTS,H. (1967). The colonisation of a percolating filter by invertebrates, and their effect on settlement of humus solids.
Wat. Pollut. Control. 66, 423-448.

SOLBE,J.F. de L.G.,RIPLEY,P.G. & TOMLINSON,T.G. (1974), The effects of temperature on the performance of experimental percolating filters with and without mixed macro-invertebrate populations.
Wat. Res. 8, 557-573.

STANBRIDGE, (1954). The development of biological filtration.
Wat. Sanit. Engr. 4, 297-300.

STANBRIDGE,H.H. (1976). History of sewage treatment in Britain. 1 - Introduction of the water carriage system.
Inst. Wat. Pollut. Control. 55pp

STANBRIDGE,H.H. (1976). History of sewage treatment in Britain. 2 - Preliminary treatment and treatment of storm damage.
Inst. Wat. Pollut. Control. 55pp.

STANBRIDGE,H.H. (1976). History of sewage treatment in Britain. 3 - Chemical treatment.
Inst. Wat. Pollut. Control. 30pp.

STANBRIDGE,H.H. (1976). History of sewage treatment in Britain. 4 - Removal of suspended matter.
Inst. Wat. Pollut. Control. 73pp.

STANBRIDGE,H.H. (1976). History of sewage treatment in Britain. 5 - Land treatment.
Inst. Wat. Pollut. Control. 37pp.

STANBRIDGE,H.H. (1976). History of sewage treatment in Britain. 6 - Biological filtration.
Inst. Wat. Pollut. Control. 220pp

STANBRIDGE,H.H. (1976). History of sewage treatment in Britain. 7 - Activated sludge process.
Inst. Wat. Pollut. Control. 95pp.

STANBRIDGE,H.H. (1976). History of sewage treatment in Britain. 8 - Tertiary treatment.
Inst. Wat. Pollut. Control. 39pp

STANBRIDGE,H.H. (1976). History of sewage treatment in Britain. 9 - Anaerobic digestion.
Inst. Wat. Pollut. Control. 64pp.

STONES,T. (1974). The effect of acid concentration on the determination of dichranate value. Wat. Pollut. Control. London. 73, 121-124.

SUMMERS,T.H. (1972). Wastes from poultry processing - origins and treatment. Inst. Wat. Pollut. Manual. (Edition Fuller J.R.) Thunderbird Enterprises, Harrow. pp135-140.

TARIQ,M.N. (1975). Retention time in trickling filters. Progress in Water Technology. 7, 225-234.

TERRY,R.J. (1951). The behaviour and distribution of the larger worms in trickling filters. J. Inst. Sew. Purif. (1), 16-23.

THOMPSON,J.T. (1942). High rate dosing of gravel percolating beds. J. Proc. Inst. Sew. Purif. 140-151.

TIDSWELL,M.A. (1960). Experimental purification of sewage containing a large proportion of brewery wastes at Burton upon Trent. J. Proc. Inst. Sew. Purif. (2), 139-154.

TOMLINSON,T.G. (1942). The nitrifying activity of biological film from different depths of percolating filters treating sewage by the process of alternating double filtration and single filtration . Proc. Soc. Agric. Bact. (Abstr) 5.

TOMLINSON,T.G. (1946). Growth and distribution of film in percolating filters treating sewage by single and double filtration. J. Proc. Inst. Sew. Purif. 168-178.

TOMLINSON,T.G. (1946). Animal life in percolating filters.
Water Pollut. Research Technic. Paper No 9, H.M.S.O. Lond.

TOMLINSON,T.G. & HALL,H. (1950). Some factors in the
treatment of sewage in percolating filters.
J. Inst. Sew. Purif. (4), 338-355.
Also in Publ. Wks & Munic. Serv. Congr. 600-630.

TOMLINSON,T.G. & SNADDON,D.H.M. (1966). Biological
oxidation of sewage by films of micro organisms.
Int. J. Air. Wat. Pollut. 10, 865-881.

TRUESDALE,G.A., WILKINSON,R. & JONES,K. (1961).
A comparison of the behaviour of various media
in percolating filters.
Inst. Publ. Hlth. Engrs. J. 60, 273-287.
Also in J. Proc. Inst. Sew. Purif. 325-340.

TRUESDALE,G.A. & EDEN,G.E. (1963). Comparison of
media for percolating filters : some further observations.
Inst. Public. Hlth. Engrs. 62, 283-302.

TRUESDALE,G.A.,BIRKBECK,A.E. & SHAW,D. (1964).
A critical examination of some methods of further
treatment of effluent from percolating filters.
J. Inst. Sew. Purif. 81-101.

USINGER,R.L. & KELLEN,W.R. (1955). Role of insects in
sewage disposal beds.
Hilgardia. 23, 263-321.

WHEATLAND,A.B. & SMITH,R.G. (1955). The BOD test :
a note on variable res ults from the use of
stored standard dilution water.
Analyst. London. 80, 899-900.

WHEATLEY,A.D. & WILLIAMS,I.L. (1976). Pilot scale investigations into the use of random pack plastics filter media in the complete treatment of sewage. Water Pollution Control. 75(4), 468-486.

WUKASH,R.F. & BLOODGOOD,D.E. (1966). Trickling filter stone gradation and placement. J. Sanit. Engng. Div., Am. Soc. Civ. Engns. 92,59-66.

WATER POLLUTION RESEARCH. (1946). Animal life in percolating filters. W.P.R. Technical Paper No.9., H.M.S.O. London.

WATER POLLUTION RESEARCH. (1969). An illustrated key to the British Freshwater Ciliated Protozoa commonly in activated sludge. W.P.R. Technical Paper No.12. H.M.S.O., London.

WORLD HEALTH ORGANISATION. (1970). European Standards for drinking water. World Health Organisation. p2.