THE OPTIMISATION OF LEGACY WATER TREATMENT WORKS TO PRODUCE A MORE CONSISTENT FINAL WATER QUALITY.

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Thesis Summary.

The project was carried out as part of a Teaching Company Scheme between Wrexham Water and the University of Aston. The initial remit was to identify and remove bottlenecks in a recently constructed potable water treatment plant known as Legacy Water Treatment Works and to design and install an effective process control system. This remit soon changed and the project then concentrated on:- understanding and then optimising the chemical dosing throughout the plant to improve product quality and consistency; initiating and implementing a change in operating philosophy among Wrexham Water staff; and introducing new techniques and technologies to the treatment process.

The treatment process at several treatment works was observed and after preliminary trials a change was made to an alternative coagulant which resulted in coagulation costs being reduced by 15%. At one treatment works the investigation into the process revealed an overdosing of both coagulant and lime, the correction of which has resulted in a saving of £44,950 per annum.

A significant improvement in the performance of the instrumentation was achieved. The need for improvement and the areas to target were highlighted by a series of instrument audits. An 87% improvement has been realised.

Assessment of the performance of Legacy treatment works showed a bottleneck in the existing filter plant. Due to other operational considerations a new filter plant was procured; installation will be completed by August 1995.

Quantifiable cost savings from work undertaken as part of this research project amount to £109,450 per annum and one-off savings of £302,000. Many of the benefits of the work carried out are intangible and a monetary value is hard to place on them.

Introduction of the changes to the treatment plant has been accompanied by a significant and definite change in attitude of the Wrexham Water personnel to many of the work practices.

FIVE KEY PHRASES :-
Aluminium Sulphate, Coagulation, Instrumentation, pH, Chlorination.

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All the people at Wrexham Water for providing assistance and information, especially the Treatment Department and the Technical Services Department. Thanks to the Laboratory staff for conducting the tests required.

Teaching Company Scheme and Wrexham Water for providing funding and training during the project.

To the project students at Aston University for attempting to find solutions to parts of the still unanswered questions.

And to all those who listened to hours of meaningless talk during the harder parts of the work and who kept me working at the project.

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1.1 General Introduction.

The research project was carried out under a Teaching Company Scheme between Wrexham Water and the University of Aston in Birmingham. The initial remit was to identify and remove bottlenecks in a recently constructed potable water treatment plant known as Legacy Water Treatment Works and to design and install an effective process control system. (Ref. 2) While initially investigating these two subjects it became apparent that there was neither sufficient understanding of the chemical treatment process itself nor were reliable measuring instruments available to support a modern integrated control system. The project therefore concentrated on:- understanding and then optimising the chemical dosing throughout the plant to improve product quality and consistency; initiating and implementing a change in operating philosophy among Wrexham Water staff; and introducing new techniques and technologies to the treatment process.

1.2 Teaching Company Scheme.

The Teaching Company Scheme is concerned with bringing about industrial change through the implementation of technology. (Ref. 1) It is supported and financed by a number of government agencies including the Department of Trade and Industry. Its mission is to strengthen the competitiveness and wealth creation of the UK by the stimulation of innovation in industry through partnerships between academia and business. The main objective of the scheme is to facilitate the transfer of technology and the spread of technical management skills, and to encourage industrial investment in training, research and development.

1.3 Wrexham Water.

The Wrexham and East Denbighshire Water Company was set up in 1864 as a statutory water company to bring piped stream water into the town of Wrexham. (Ref. 3) The original works consisted of an abstraction reservoir, slow sand filters and a storage reservoir. The original works have been abandoned but some of the original distribution pipework is still in use.

As the town grew in size alternative water sources were needed and new reservoirs were built. In 1945 changes in the law allowed water companies to amalgamate and Wrexham Water acquired several nearby water companies and now serves an area covering 690 square kilometres and a population of 150,000. Water is served to properties at elevations from 10 metres above sea level to over 365 metres above sea level.

Raw water is taken from various sources such as upland reservoirs, bore holes and rivers. The Company has a total of 7 treatment works which jointly supply 45,000 cubic meters of treated water every day. The treated water is distributed through 1400 kilometres of mains and 120 kilometres of communication pipes. There are also 32 booster stations and 33 service reservoirs and treated water tanks in the distribution system.

Wrexham Water was the first water company in Europe to gain BS5750 accreditation in March 1992 for the collection, treatment, distribution and testing of potable water.

1.4 Programme of Work.

Legacy Water Treatment Works was commissioned in 1990 to produce 13·5 mega litres per day (MLD) of drinking water. There was an opinion at Wrexham Water that the plant should be capable of a maximum production rate of 18 mega litres per day. Therefore it was thought that there were production bottlenecks in the treatment process and it was the initial aim of the Teaching Company Programme project to identify and remove these bottlenecks and to design and install a process control system in order to improve product quality.

Two real bottlenecks were identified, together with a third factor that was a misunderstanding of the plant capability rather than a practical bottleneck.

The first restriction was found to be the filter plant at the end of the treatment process which can adequately treat 11·25 MLD but at 13·5 MLD the quality of the water produced deteriorates drastically due to breakthrough of the filter beds.

The second factor is the water tower through which the entire plant production must pass before leaving the works. This again can only cope with 11·25 MLD rather than the required 13·5 MLD.

The misconception over total potential capacity arose through the fact that the treatment plant consists of two parallel streams, each capable individually of producing 9 MLD, but due to common front and back ends to the process, they can together only produce a maximum 13·5 MLD. The plant was purposely designed in this way to minimise the impact of shutting down one of the parallel streams for maintenance.

The investigation into the production process highlighted a number of problems. There was a persistent failing of the existing instrumentation used to both monitor and control the treatment process. Part of the project therefore concentrated on the availability of the instrumentation and ways of improving reliability for both monitoring and control purposes.. Three key areas were closely examined. These were the floc formation process, the pH correction process and the disinfection process.

It was also found that there were serious deficiencies in the system providing water saturated with air to the flotation stage of the process. Modifications were designed, installed and commissioned to overcome the original shortcomings. In view of these difficulties arising through Wrexham Waters failure to specify adequately the final product quality and the preferred process for the Legacy Water Treatment Works, a proper specification procedure was introduced to deal with new capital projects. The procedure was implemented during preparation of documents for Legacy Rapid Gravity Filter project.

1.4 Programme of Work.

All the work undertaken as part of this project was either undertaken or driven by the author. Where specific tests and expertise were required, these were also arranged by the author. For example, section 3.1 was undertaken with assistance from staff from Laporte Inorganics Ltd. and members of Wrexham Water staff; section 3.6.3 was dependent on an input from Wrexham Water staff and from companies tendering for work on the rapid gravity filters.

2. BACKGROUND.

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2.1 Description of Legacy Water Treatment Works.

Raw water can be treated by a variety of physical and chemical methods to make it potable. The particular methods employed at each water treatment works depends on the type, quality and consistency of the raw water supply. At some treatment works the water is merely filtered to remove any debris, chlorinated to disinfect it and then put out to supply. At others it receives a more complex treatment and should be considered as a commercial chemical process.

At Legacy Water Treatment Works (WTW) the raw water goes through a series of treatment steps to produce potable water. Raw water was initially supplied to Legacy from three sources, Ty-Mawr, Minera and Talwrn and was consequently difficult to process because of its varying composition.

Ty-Mawr is a large upland raw water reservoir which collects and stores the water that runs off the surface of nearby hills. This water carries both colour and turbidity and has a high buffering capacity which makes it reasonably easy to treat. The Minera source is derived from an abandoned lead mine working. Due to the rock structure, rainfall from the area collects in the mine and water is taken from the upper levels of the mine where it is most suitable for treatment. This source supplies water that is normally low in both turbidity and colour with high alkalinity but low buffering capacity which makes it very difficult to treat. Talwrn water comes from a borehole. This source is high in manganese and is difficult to treat. It has recently been abandoned.

Further sources have been added during 1994 from the River Dee and Penycae Reservoirs. The current sources are shown in Figure 1. Water is abstracted from the River Dee at Sesswick and pumped up to Legacy via

Marchwiel Reservoir using the Conjunctive Use Scheme, see Appendix 4. River Dee water has a high buffering capacity and contains both colour and turbidity. It also can contain a number of man-made pollutants. Penycae is an upland reservoir system. The water from this source has a very high colour and little turbidity. Whilst this water has not been chemically treated previously, initial investigations suggest that it is suitable for chemical treatment.

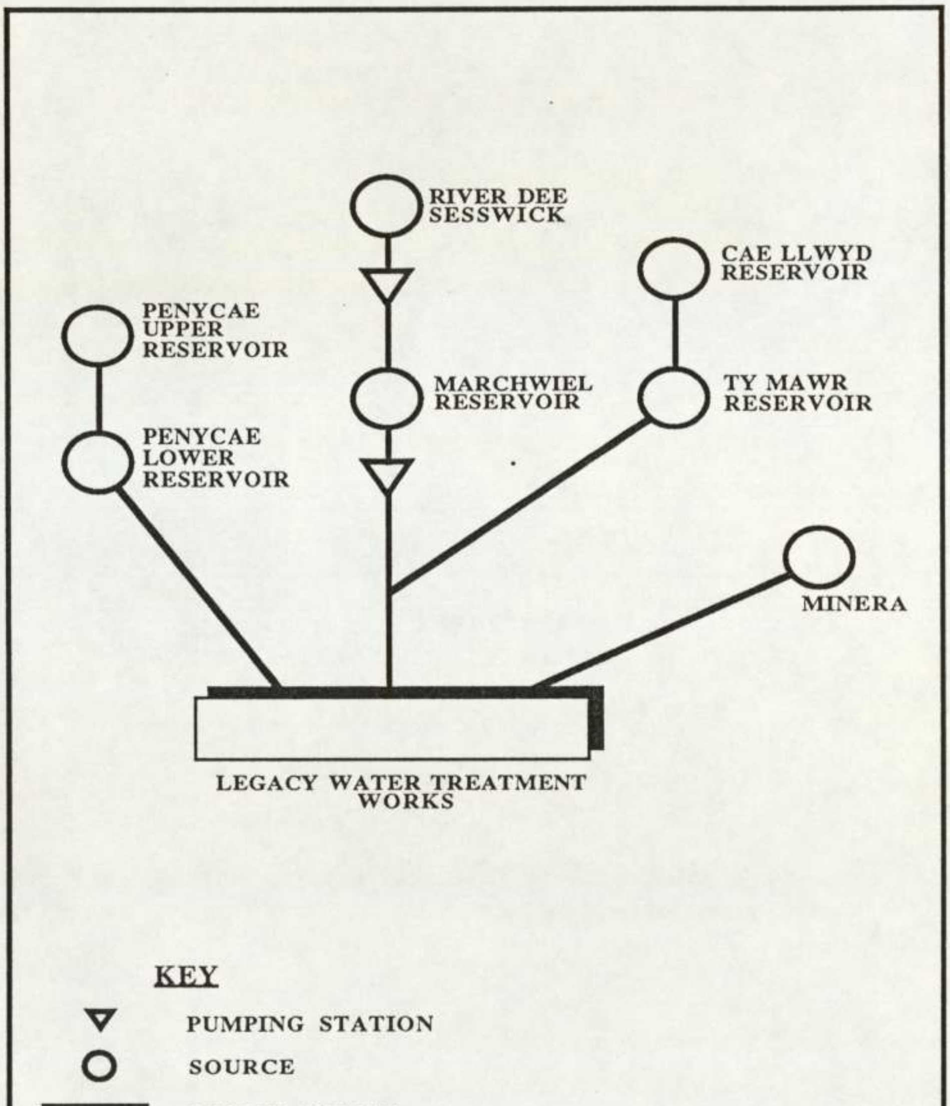

Figure 1 - Raw Water Sources at Legacy Water Treatment Works.

As the raw water leaves the source it passes through a coarse strainer to remove any large pieces of debris. Shortly before it enters the treatment works it passes through a second finer strainer to remove smaller entrained material.

The main water inlet valves to Legacy Water Treatment Works are each controlled individually by means of a corresponding 3-term controller, so the valve will modulate to control the water flow rate to that manually set at the controller. Should an automatic process shutdown occur, then all the main water inlet valves will close simultaneously. These valves are designed for slow closure to avoid water hammer or shocking of the mains.

The chemical treatment process at Legacy WTW itself can then be split into five main sections. These are coagulation, flocculation, flotation, filtration and disinfection. The sections themselves are now described and the theory is covered in section 2·2. A schematic of the plant is shown in Figure 2 and a site layout is given in Appendix 1.

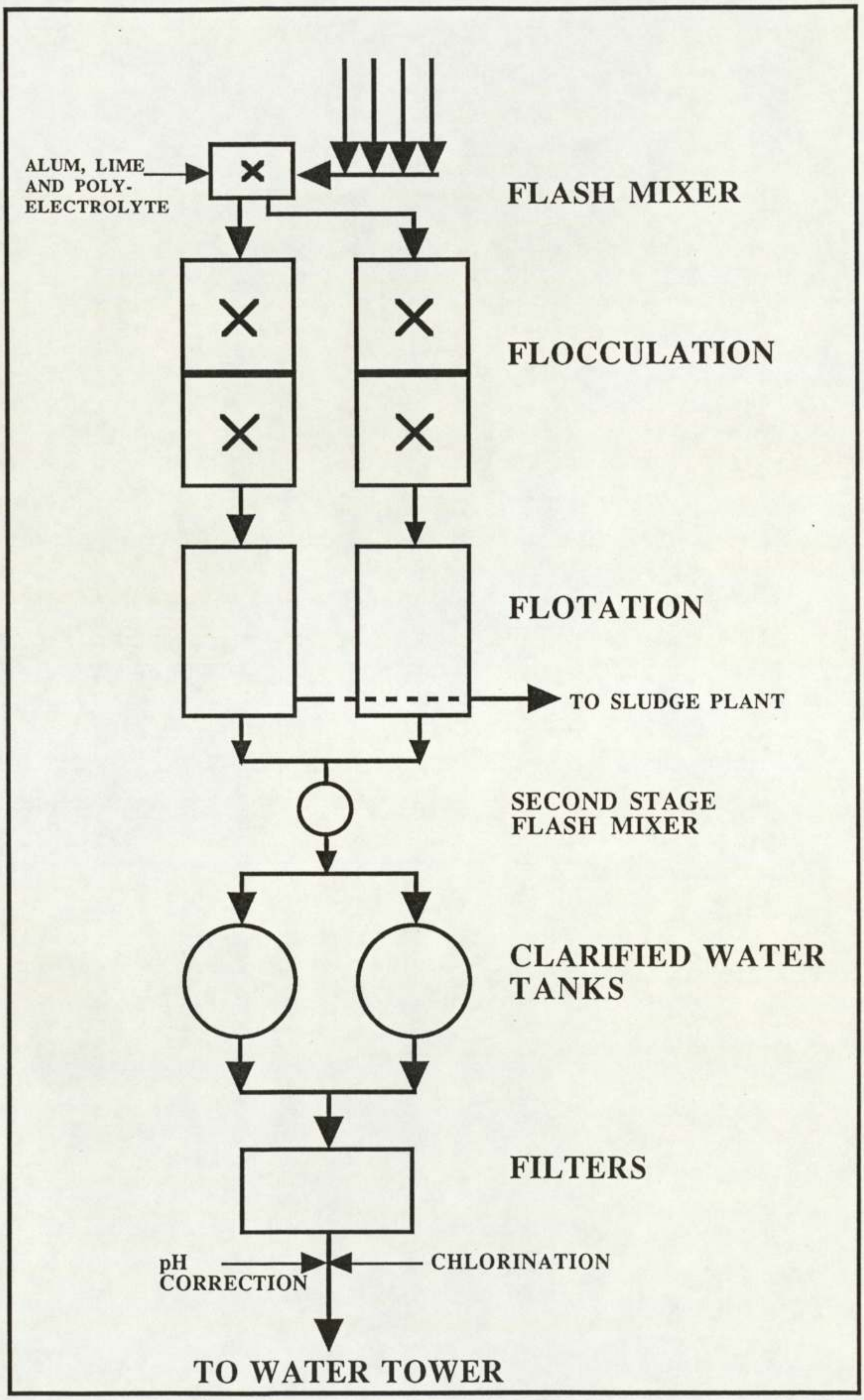

Figure 2 - General Schematic of Legacy Water Treatment Works.

2.1.1 Coagulation.

Coagulation is the destabilisation of colloidal particles brought about by the addition of a chemical reagent known as a coagulant. Chemicals are added to the water in the flash mixer to start the chemical treatment process and convert the 'dirt' in the water into a form that is suitable for removal.

At Legacy the primary coagulant used is aluminium sulphate solution, known more commonly, though incorrectly, as alum. This is delivered to the site by road tanker as a 7·5% aqueous solution and stored in a glass reinforced polypropylene tank.

The alum is dosed into a rapid mixing unit called a flash mixer by means of a variable speed diaphragm pump which is speed linked to the total flow of the plant. The metering of the alum is adjusted manually using stroke length by the treatment plant operators depending on the quality of the raw water. The flash mixer ensures thorough distribution of the chemicals throughout the water and also provides the energy needed for the coagulation process to take place. (Ref. 11)

Lime slurry and polyelectrolyte are also added in the flash mixer. The lime slurry is used to control the pH of the resultant solution to achieve optimum chemical treatment conditions, with pH being measured in a continuous sample removed from the flash mixer. The polyelectrolyte is a flocculation agent that helps bind the delicate floc particles together to give them a greater strength and size and so aid in subsequent treatment steps.

At full plant throughput the water has a residence time in the flash mixer of approximately one minute.

The flow is then split into two parallel streams having the same treatment stages, see Figure 2. First is flocculation, then flotation, after which the streams are re-combined. The streams are split in this way to aid cleaning and maintenance of the plant items. Flocculation and flotation are the two stages where floc is likely to sediment and accumulate to the extent that periodic equipment cleaning is necessary. The streams are sized such that when one side is shut down the other stream can handle two thirds of the full plant capacity, thus reducing the impact of maintenance on the overall production rate. However, since no flow measurement equipment has been installed it is probable that the residence time and thus the efficiency of the treatment process will be different in each stream.

2.1.2 Flocculation.

Flocculation consists of two stages, with a different degree of gentle agitation in each stage. The mixing in the second stage is more gentle than in the first. The water is stirred by means of a large gate agitator to promote ortho-kinetic flocculation. Flocculation causes the existing small floc particles to impact on each other and stick together forming larger particles which can be removed by downstream processes. After a residence time of approximately 20 minutes in the flocculators the water then passes on to the dissolved air flotation plant.

2.1.3 Dissolved Air Flotation.

Air is used to lift the floc particles to the surface of the tank for removal. As the water enters the flotation tank it meets a stream of pressurised water saturated with air from the saturator. The flow of the pressurised air saturated stream into the main water flow is controlled by needle valves, but is not measured. There are eight valves spaced across the incoming flocculated water flow, located immediately before the point at which the air saturated stream meets the main water flow. As the pressure is released from the saturated stream the dissolved air comes out of solution forming micro-bubbles which attach to the floc and lift it to the surface of the tank where it collects as a sludge blanket, Figure 3. A submerged baffle in the tank aids the process. The sludge blanket is periodically scraped off by a mechanical device and then transferred to the sludge treatment plant. The clarified water passes from the bottom of the flotation tank and on to the filters.

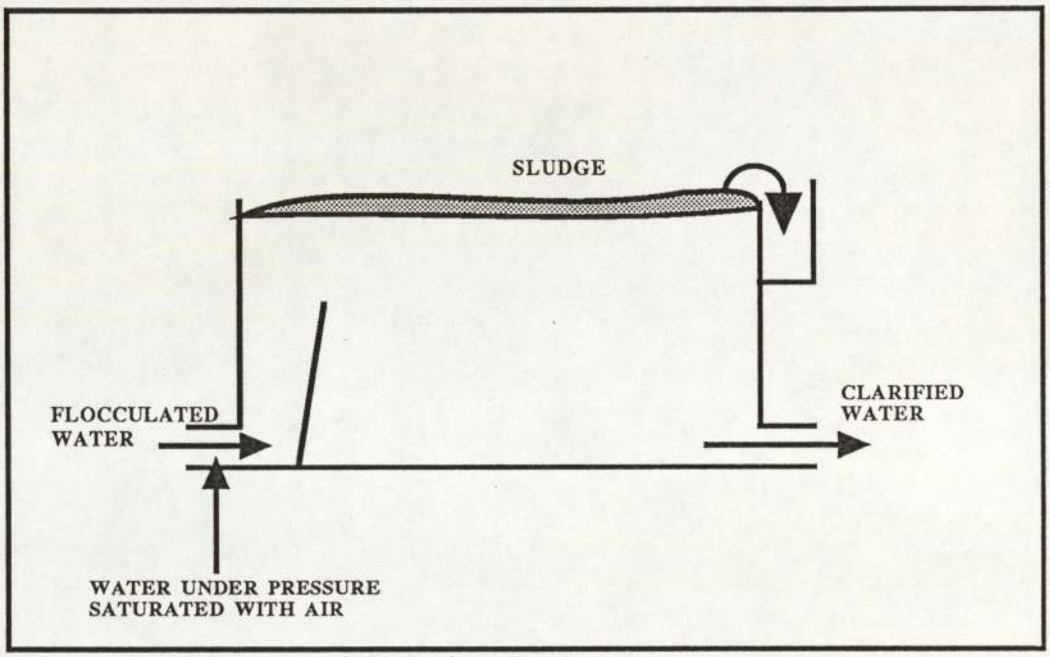

Figure 3 - Diagram of Flotation Tank.

The air-saturated water is generated local to the flotation plant by means of a vertical packed saturator, the layout of which is shown in Figure 4. The vessel is essentially a packed tower with a saturated water storage area at the bottom of its volume. Compressed air, at a pressure of approximately 6 bar, is supplied to the vessel. A supply of clarified water is taken from the outlet of the flotation tank and pumped to the top of the saturator. This is termed the recycle stream and normally constitutes 8% of the plant throughput.

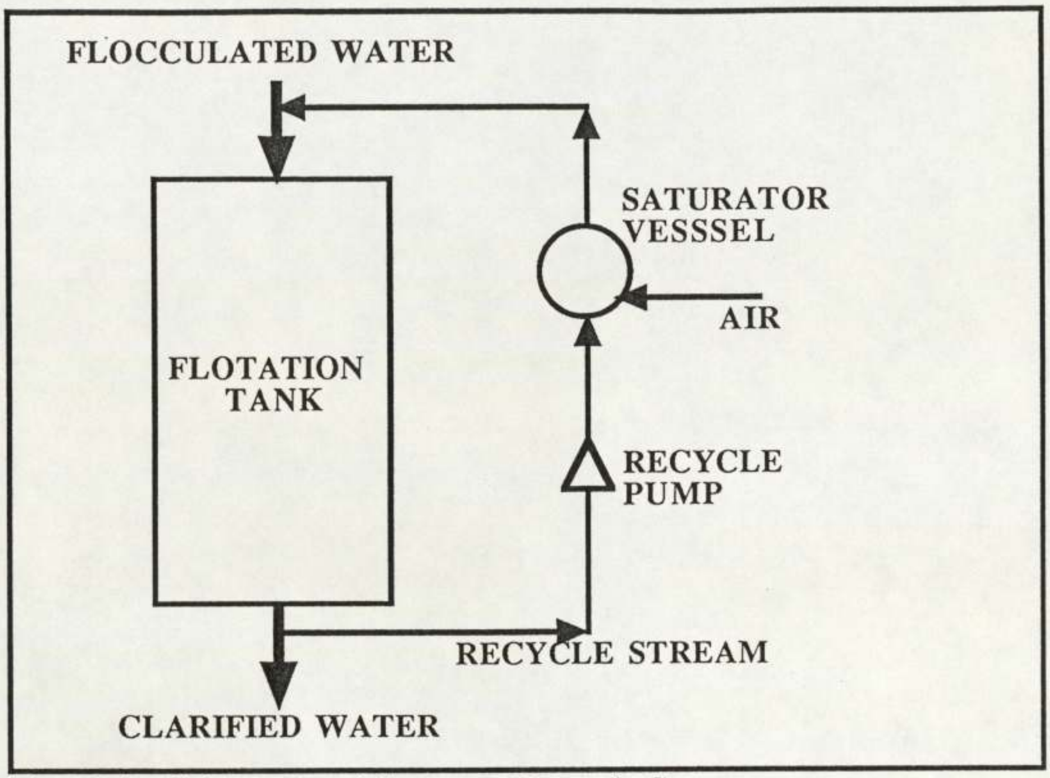

Figure 4 - Schematic of Saturator Recycle Stream.

2.1.4 Filtration.

After the treatment processes of coagulation, flocculation and flotation, there are still fine particles of floc in the water. These suspended solids are removed by filtration. The current method at Legacy WTW is pressure filtration using a sand medium.

There are twelve pressure filters at Legacy treatment works and each filter is automatically backwashed at least once each day to remove the accumulated dirt. The filter to be washed is isolated and partially drained. Air is first blown through the filter from the base to scour the bed and loosen any debris. The bed is then backwashed for a set period of time using filtered water. The filter is then returned to service. The dirty backwash water is collected and transferred to the sludge treatment plant.

2.1.5 Disinfection.

The final stage of the treatment process before the water goes into supply is disinfection.

Whilst the initial stages of the treatment process remove a large proportion of the micro-biological components, there is still a significant level of activity in the water. In order to bring this down to a safe level the water is disinfected. Disinfection destroys some organisms and inhibits the growth of others so that the water is safe to drink. Most of the pathogenic organisms and a further percentage of the microbial content are rendered non-viable, but again the process is not 100% efficient. The water is not sterilised since sterilisation implies that all the microbes have been destroyed and there is no attempt to achieve this situation in the commercial potable water treatment process, but the water still complies with all relevant legislation.

2.1.6 Sludge Treatment.

Solids are removed from the plant effluent by the on-site sludge treatment plant. There are three stages to the sludge treatment process, namely thickening, storage and centrifuging; a schematic is shown in Figure 5. The dirty backwash water from the filters contains very little solids, the actual content depends on the state of the filters when washed, but is normally in the range 0·005% to 0·01%. This needs to be thickened to around 1% solids to enable the centrifuge to operate effectively. This is achieved using a Water Research centre (WRc) Patent Sludge Thickener. The dirty water is mixed with polyelectrolyte to aid the thickening process and is then fed into the thickener via a central feed well. Flocculation takes place and a sludge layer is formed in the base of the tank. Clear water flows out from the top of the tank over a radial launder and is discharged to a nearby watercourse. The thickened sludge is transferred to a stirred holding tank by means of progressive cavity pumps.

The sludge from the flotation plant already contains 3% solids and so is sent directly to the holding tank without any pre-treatment. When sufficient sludge has accumulated in the tank a centrifuging cycle is initiated. By this method the sludge is further concentrated to give a final solids content of 16%. This final solid product is collected in skips and removed to a suitable landfill site. The centrate is returned to the sludge thickener.

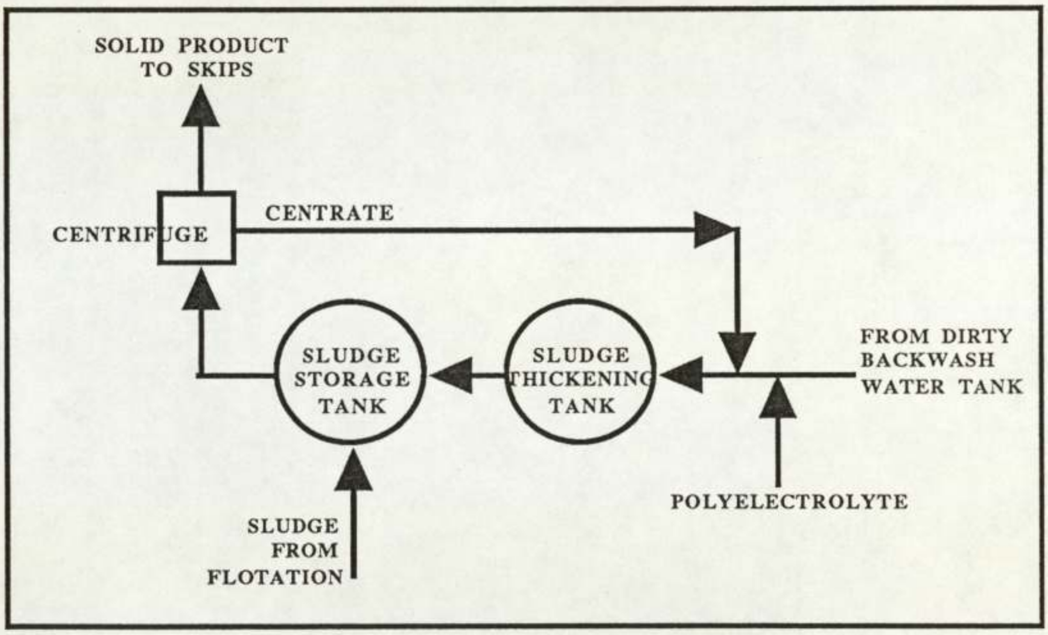

Figure 5 - Schematic of Sludge Plant.

2.1.7 Telemetry System.

The operating status of many items of plant at each treatment works is monitored continuously via a telemetry system, which collects both analogue and digital data from the treatment works and displays it on a central unit at Wrexham Water's control room. Data are available on the state and operation of larger and more critical pumps, reservoir levels, pH readings, chlorine readings and turbidity readings. A list of available parameters from Legacy Water Treatment Works is shown in Appendix 2.1. Through the central computer, single point readings and graphs of the data can be displayed; examples are shown in Appendices 2.2 and 2.3. The Control Room Officer monitors these on a 24 hour basis. Alarms are generated if any parameter exceeds pre-set levels. The Control Room Officer can then display further data to establish the cause and the urgency of the alarm.

2.1.8 Alterations to Legacy WTW.

In addition to the changes in raw water sources described hitherto there have been several major changes to the treatment works which are a direct result of this project. These changes are now outlined in flow order.

The primary coagulant has been changed from aluminium sulphate to a new water treatment product from Laporte Inorganics, Ferral 2060. This, a mixture of aluminium sulphate and ferric sulphate, gives a more stable floc at substantially lower cost and was introduced to the process during July 1994. See Section 3.1.

Initially there was only one air saturation vessel installed at Legacy Treatment Works, which is expected to be on line 365 days per year. This made it impossible to maintain the plant or conduct inspection tests, in spite of having two parallel flotation streams. A second vessel has been procured, installed and commissioned with updated pipelines and dedicated pumps to provide two separate recycle streams that can be operated in a more flexible manner.

In 1995, the pressure filters will be replaced by two continuously washing rapid gravity filters with a medium of granular activated carbon as described in Section 3.6.3. This will enable the plant to work at full throughput and still maintain the required water quality. The detailed specifications for the equipment were drawn up with the assistance of Wrexham Water staff, put out to tender, checked, compared and a preferred solution recommended to Wrexham Water for implementation.

2.1.9 Alterations to Wrexham Water.

Significant changes to the operating philosophy and attitude of the Wrexham Water staff have been brought about as a direct result of this project. Staff are now more prepared to consider new techniques and new technology, co-operate more effectively with other Wrexham Water departments, contribute to the decision making process involved in new capital projects, and accept the cost implications arising from the decision making process. Staff are more attentive to the performance of the water treatment plant and are now more likely to identify faults and suggest realistic improvements.

2.2 Theory of Water Treatment.

2.2.1 Coagulation.

Published information on coagulation and the chemistry of the water treatment process is both sparse and vague. Much of the available reference material is written by American authors and thus refers to American standards and water types. There is little literature published by researchers in Britain. Most of the references are written from the civil engineering viewpoint and so the detail devoted to the chemical processes involved tends to be somewhat basic.

Coagulation and flocculation are essential pre-treatment steps for the removal of finely divided particulate matter which, due to its small size, will not settle out of suspension by gravity in an economical time frame. (Ref. 11) Aggregation of fine particulate matter into larger particulates by the use of coagulation and flocculation facilities permits cost effective removal in subsequent solids separation processes.

Particulates of inorganic origin, such as clay, silt and mineral oxides usually enter the raw water through natural erosion processes and can decrease the clarity of the water to an unacceptable level. Organic particulates, such as colloidal humic and fulvic acids, are a product of decay and leaching of the organic debris that has fallen into the raw water source. These particulates impart a colour to the water which in some extreme cases can be nearly opaque. Removal of these particulate contaminants is required for both aesthetic and health concerns.

Organic matter (Ref. 5) covers a wide range of compounds which feature differing physical and chemical properties. Each stage of the water treatment process contributes to the removal of a certain part of the organic matter. The higher the organic matter content in the water, the greater the probable diversity of organic substances; hence a greater number of treatment stages may be required. Many water sources in Britain are currently relatively clean and require only one or two stage treatment. Some sources however may need as many as five stages of treatment.

Removal of the particulate contaminants may also assist in the removal of toxic contaminants, such as heavy metals, pesticides and viruses, known to be associated with inorganic and organic particulate matter in the water. Removal of colloidal organic particles that produce colour has gained increased attention because of the discovery that these particulates, although posing no known health hazards to consumers, will react with chemical oxidants used in water treatment, such as chlorine or ozone, to form organic by-products with known or potential health hazards for consumers.

Coagulation is the first main step in the chemical treatment process. Coagulants are added to the raw water to facilitate the removal of contaminants in the water. Primary coagulants are generally metal sulphates or chlorides; ferric and aluminium salts are normally used as they have limited toxicity, the final product has low solubility and the positive triple valency of the cation is crucial to the coagulation process. The Schulze-Hardy theory indicates that a trivalent ion is at least ten times more effective than a divalent ion (Ref. 5) and 700 to 1000 times more effective than a monovalent ion.

The coagulant is added to the raw water where it is rapidly and thoroughly mixed in a unit called a flash mixer. The design of the flash mixer can be a turbulent channel, a static mixer in a pipe or a mechanical device such as a Rushton Turbine. Mechanical devices are most common in the developed world. Static devices are more prevalent in third world countries where power sources are not so readily available. Electrically driven agitators are most favoured in developed countries as they are more flexible and occupy less area.

Coagulation is suitable for raw waters (Ref. 5) having one or more of the following characteristics :-

- suspended solids at a level higher than 20 to 40 g/m^3 for all or part of the year
- colour level greater than 30 mg/l on the Co/Pt colour scale
- high level of organic matter
- heavy metal content above the maximum recommended limit
- high plankton content.

To render waters with only moderate turbidity potable, it is generally sufficient to undertake coagulation, flocculation and single stage settling or flotation.

Use of a flocculant aid is nearly always beneficial (Ref. 5) not only to increase the rate of separation, but also to obtain better clarified water. Experience shows that, in general, no additive will allow reductions in the dosage of coagulant without adversely affecting the treated water quality.

The actual chemistry of what is happening in the flash mixer is relatively unknown. The reactions taking place depend upon the conditions in the flash mixer, contaminants in the water, flow patterns in the mixer and many other factors. Figure 6 shows the seasonal effect of temperature on the aluminium residual, just one of the parameters in the flash mixer, when all other physical parameters are kept constant. Data have been collected and analysed over three month periods, i.e. quarters, starting with quarter one showing data from April to June.

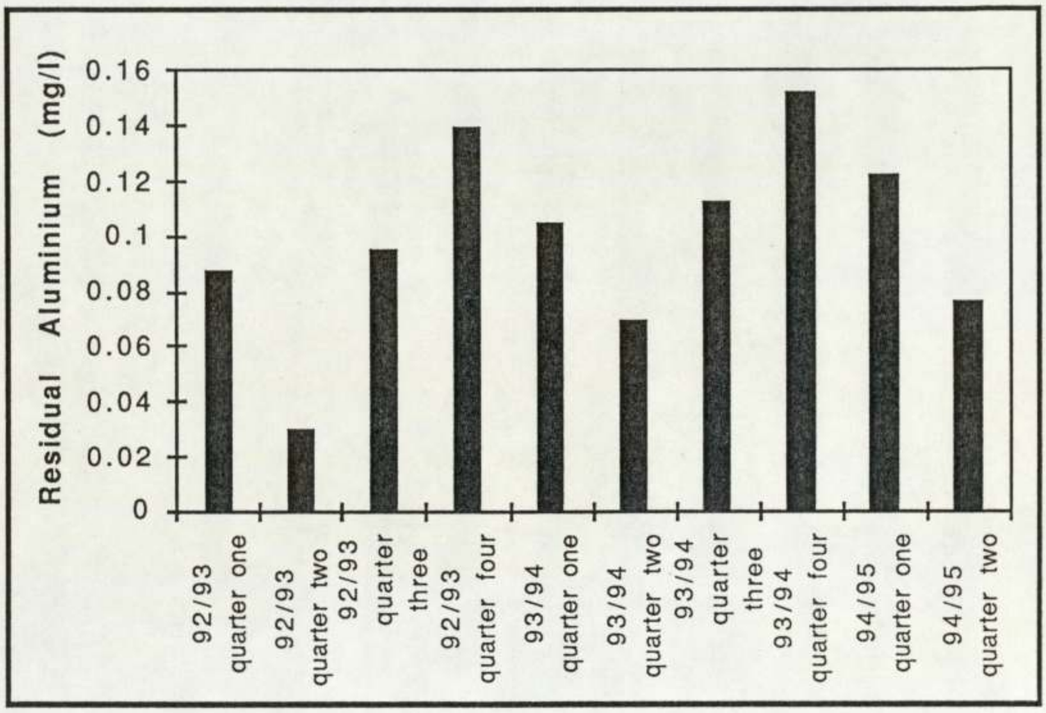

Figure 6 - Legacy Residual Aluminium, Quarterly Mean Values.

The dose rate of each of the chemicals is still determined by operator experience on a qualitative basis and remains very much a 'black art'. A statement (Ref. 12) from Laporte Inorganics, the major British supplier, reads: "There is no way of calculating the amount of alum to dose nor its optimum pH for flocculation; this can only be determined for each individual situation by a jar test."

The chemistry of the coagulation stage is extremely complex. On a simplistic basis a chemical reaction takes place in the flash mixer between the coagulant and the alkalinity in the water to produce small particles of aluminium hydroxide.

$$Al_2(SO_4)_3 + 3Ca(HCO_3)_2 = 2Al(OH)_3 + 3CaSO_4 + 6CO_2$$

This is far removed from the actual situation where the hydrolysis products of aluminium are very complex and can include compounds of the form $\left[Al(H_2O)_5OH\right]^{2+}$ and $\left[Al_6(OH)_{15}\right]^{3+}$ and sulphate complexes may also appear. As a result the actual reactions taking place are difficult to specify. (Ref. 18)

Initially this micro-aggregate of aluminium complexes is so small that it cannot be visually identified. The floc particles have a high surface area and a high positive surface electrostatic charge. Dissolved impurities in the water generally possess a negative surface electrostatic charge. They are attracted to the positively charged floc particles and the charges neutralise each other at a molecular level. (Ref. 5)

Although the precise nature of the reactions taking place is not known, the general principles of the reaction have been postulated. Dr. A Grohmann (Ref. 4) suggested that there are three processes taking place in the flash mixer. First is "flash mixing" itself which distributes the coagulant through the water and starts the diffusion process of the coagulant to the impurities. Second is destabilisation where the chemical reaction starts to take place between the metal cations of the coagulant and the surface of the impurities. Third is micro-aggregation when the particles aggregate to form micro-floccules. The time taken for these three processes can be less than 1 second or as much as 30 seconds depending on circumstances, such as the constituents and quantities of natural chemicals in the raw water, initial pH and temperature.

Many theories are available for the mechanisms involved in coagulation though these theories are very hypothetical and do not always apply to the real situation where there are many uncontrollable factors influencing the reaction. The Schulze-Hardy theory (Ref. 19) is generally accepted as a fair basis for understanding the process and it suggests that destabilisation of the colloids in the water occurs by the presence of oppositely charged ions compressing the diffuse ionic layer surrounding colloidal particles. Destabilisation is achieved by the introduction of coagulation chemicals into the flash mixer which reduces the inter-particulate forces. The inter-particulate forces can be reduced by several methods :-

- charge neutralisation by specifically absorbed charged species
- surface precipitation and formation of inter-particle bridges
- coagulant precipitation and entrapment of particulates
- compression of double charge layer.

The predominant mechanisms will change with the chemical composition and physical elements of the water.

2.2.2 Flocculation.

The next stage in the process is flocculation. The water passes out of the flash mixer and into the flocculators which are large, slowly agitated tanks. The particles formed by coagulation, although increased in size from the original particles, are still too small to be removed efficiently by a physical process. In order to increase the particle size further the semi-treated water is slowly stirred by use of large gate type stirrers to promote flocculation. As the water is stirred the floc particles collide with each other, with colloids and other suspended solids. The particles agglomerate, forming larger floc particles. Gentle agitation is required to cause collisions between the particles at a reasonable rate while avoiding breakdown of the aggregates already formed; this is known as ortho-kinetic flocculation. Collisions will occur naturally by Brownian motion, peri-kinetic flocculation, but this is totally insufficient for an economical process.

The residence time in the flocculators and the degree of agitation, amongst other factors, determines the floc size. Under normal circumstances the particles leaving the flocculators are within a preferred size range, since particle size is important to the efficiency of the flotation process.

The effectiveness of the flocculation process can be mathematically defined (Ref. 11) as

$$\frac{dN}{dt} = -KG\phi N_T$$

where dN/dt is the instantaneous rate of change of the total particle concentration, G is the root-mean-square velocity gradient, N_T is the total particle concentration and ϕ is the volume fraction of dispersed phase. As is normal for such cases the correction factor K has to be empirically determined.

2.2.3 Disinfection.

Disinfection can be carried out by a number of methods. Ozonation, chlorination, chlorine dioxide, chloramination and ultra-violet radiation are the most often used in Britain, but iodine, bromine and silver may also be used in some circumstances.

The disinfectant has two purposes. First there is the initial disinfection of the water, and secondly the maintenance of a residual bacteriostatic action in the final treated water. This stops the degradation of the water quality between the production plant and the point of use, thus ensuring that the water is wholesome when it reaches the consumer.

Disinfection works by (Ref. 11),

"i) the destruction or impairment of cellular structural organisation

ii) interference with energy yielding metabolism,

and iii) interference with bio-synthesis and growth."

In order to achieve these actions in the water-borne organisms the disinfecting agent has to be able to :-

"i) oxidise or rupture the cell wall with consequent cellular disintegration,

and ii) diffuse into the cell and interfere with cellular activity."

Chlorine is by far the most common disinfectant used in Britain. It has the benefit of being widely available, more effective than many other chemical agents and can maintain an effective residual in the final water.

At Legacy WTW the water is chlorinated as it is transferred to the water tower. The tower at Legacy acts as both a contact tank and a service reservoir. As the water enters the tower, dissolved chlorine gas is added to it to disinfect it before it goes out into the distribution system. Depending on the nature of the water it is either super-chlorinated and then de-chlorinated, or it is marginally chlorinated.

The level of chlorine at the point of use depends on both the distribution system and the distance from the treatment works. The free residual chlorine content is depleted as the water flows through the distribution system and its rate of depletion is dependent on the quality of the distribution system. This in turn depends on the quality of the water and the type of material used for the pipes. Distribution systems made from cast iron have the greatest chlorine demand. Asbestos cement and

PVC systems generally have a much lower chlorine consumption. The farther away from the treatment works, the lower the chlorine residual.

When chlorine is added to water it hydrolyses to form hydrochloric acid and hypochlorous acid,

$$Cl_2 + H_2O = HCl + HOCl$$

The hypochlorous acid can then dissociate to give hydrogen ions and hypochlorite ions,

$$HOCl = H^+ + OCl^-$$

The balance of molecular chlorine, hypochlorous acid and hypochlorite is determined by the pH of the water as shown in Figure 7. In acidic conditions below pH 7 but above 2·5, over 80% of the free chlorine is available as hypochlorous acid. As the pH rises this rapidly becomes less and at a pH of 8·5 only 20% of the free chlorine is hypochlorous acid, the rest being hypochlorite ions. This effect of pH is very important as it severely alters the effectiveness of the disinfection process.

Hypochlorous acid is the most effective of all chlorine residual fractions species as its structure is similar to that of water and it can thus easily penetrate cell walls. It is over 80 times more powerful as a bactericide than the hypochlorite ion. (Ref. 16)

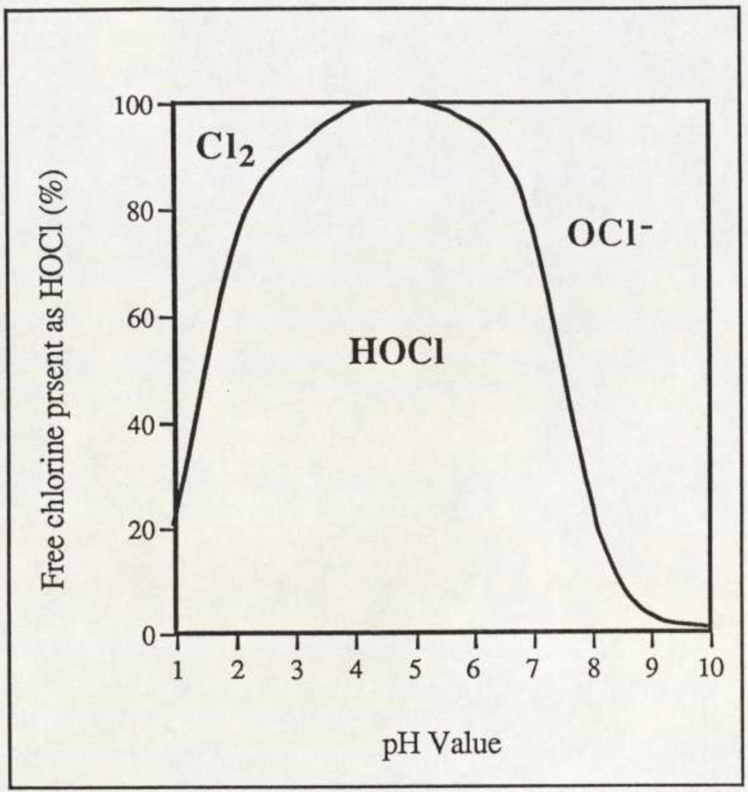

Figure 7 - Effect of pH on the Form of Free Available Chlorine in Water.

2.2.4 Interferences.

Although the description of the water treatment process given earlier appears to be quite simple, it is in fact very complex. A great number of factors interact to influence the treatment processes. These include temperature, pH, amount of coagulant dosed, various constituent chemicals in the raw water, colour, turbidity, and the hydraulics of the treatment plant itself. This list is by no means exhaustive. The affect of many of the factors has not been quantified. Further complications can arise in that the optimum conditions for coagulation will not necessarily be the same as those for flocculation and a balance has to be made between the needs of the two processes. Many attempts have been made to automate the water treatment process, but no attempts have previously been made to treat the process as a commercial chemical process. Some sections of the process have been successfully automated but the most important part of the process, i.e. coagulation and flocculation, remains manually controlled. The setting of the plant is still a skilled manual job, which requires experience of many qualitative parameters in order to be performed effectively.

3. WATER TREATMENT - FLOC FORMATION AND REMOVAL.

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3.1 Coagulation.

Coagulation is the most critical part of the water treatment process as the effective operation of all the other process steps is dependent on the quality of the floc produced. If coagulation is ineffective then flocculation is also ineffective and the filters cannot remove small suspended particles or dissolved matter. Furthermore, disinfection is ineffectual as agglomerates can shield pathogens and is inefficient as the total amount of organic carbon bears a relationship to the chlorine demand of the water. The compound effect of poor operation of all these processes means that the water is coloured, dirty, turbid, unwholesome and unpalatable. The level of many contaminants may well exceed safe limits. The addition of alum under unsuitable conditions also increases the residual aluminium level in the water far in excess of the permissible concentration. Of all of the process stages coagulation bears the highest operating cost; coagulation chemicals account for 12% of the total running costs of Legacy water treatment works. These items make the correct operation of the coagulation process one of the most important factors in a water treatment works.

In setting up the chemical dose rates to achieve coagulation several factors have to be borne in mind. The actual chemistry of the coagulation process is extremely complex and involves a great number of parameters. It is stated in reference 11, page 122 that "selection of the type and dose of coagulant depends on the characteristics of the coagulant, the particulates and the water quality." It is also dependent on temperature, degree of mixing and other physical parameters in the plant. The reference continues "the interdependence between these three elements is understood qualitatively; however the prediction of the optimum coagulant combination from characteristics of the particulates and the water quality is not yet possible. As a consequence, each coagulation problem must be solved empirically." The accepted method for selecting the coagulant, the dose and the reaction conditions is a 'jar test' as described in Section 3.2.

Coagulation, flocculation and flotation remove some of the organic matter. Certain compounds can be either adsorbed or precipitated with the floc. These compounds include such natural compounds as humic or fulvic acids. When coagulation and flocculation are used with flotation the organic matter removal rate is normally in the region of 40% - 60%.

Historically at Wrexham Water the primary coagulant has been aluminium sulphate. Ferric coagulants have been tried at various locations within the Company but were not successful in treating the water. Wrexham Water has an extensive distribution mains rehabilitation programme, that has been in place for some years, to reline all iron mains with a non-ferric compound, usually epoxy resin, concrete or PVC in an attempt to improve the water quality. This is one of the reasons that ferric coagulants have not been used. Following the introduction to the market of a new product by Laporte Inorganics and successful trials at the water treatment works all Wrexham Water's treatment plants now use Ferral 2060 instead of alum. This is a solution containing 6% aluminium sulphate and 1·5% ferric sulphate which gives a much more stable floc due to the interaction of the different metal compounds. The same quantity of coagulant is used but the product itself is 15% cheaper than alum giving a cost saving of £12,300 per annum for the Company. Savings have also been made as a consequence of this change in sludge treatment costs as the sludge produced is less voluminous. The residual iron content of the water is higher than that obtained using alum but is not significant as far as water quality is concerned.

At one treatment works, investigation into the coagulant use identified that the coagulant was being overdosed by more than 50%. Amending this error has promoted savings at Llwyn Onn treatment works of £3,750 per month. A breakdown of this figure is shown in Figure 8.

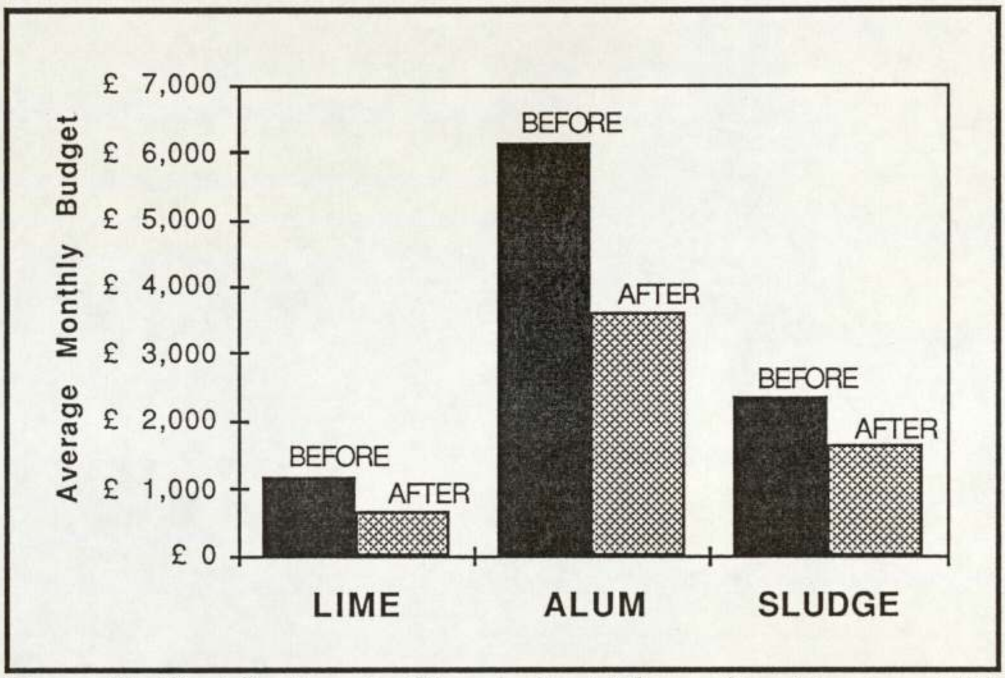

Figure 8 - Cost Savings in Chemicals at Llwyn Onn Treatment Works.

3.1.2 Coagulation pH.

The pH of the water is adjusted in the flash mixer for two reasons, one is to bring the raw water pH to a suitable level for coagulation and the other is to counteract the effect of adding the acidic coagulant. In some cases the raw water may have sufficient natural alkalinity and buffering capacity that pH control is not needed. When the water contains a high degree of colour, the optimum pH for coagulation is different to that needed for high turbidity levels.

When altering the pH in the flash mixer, account must be taken of the fact that although different pHs are needed for optimum coagulation and flocculation, the pH is only adjusted in one place and so a balance has to be made between the two requirements.

At Legacy WTW the control band for coagulation is very narrow as the variance of 0·2 pH units causes the final water quality to be outside the permissible range. Shown below in Figure 9 (Ref. 21) is a general indication of the sensitivity of the coagulation process to pH. To meet legal requirements the residual aluminium in the final water must not exceed 0·2 mg/l on a yearly average.

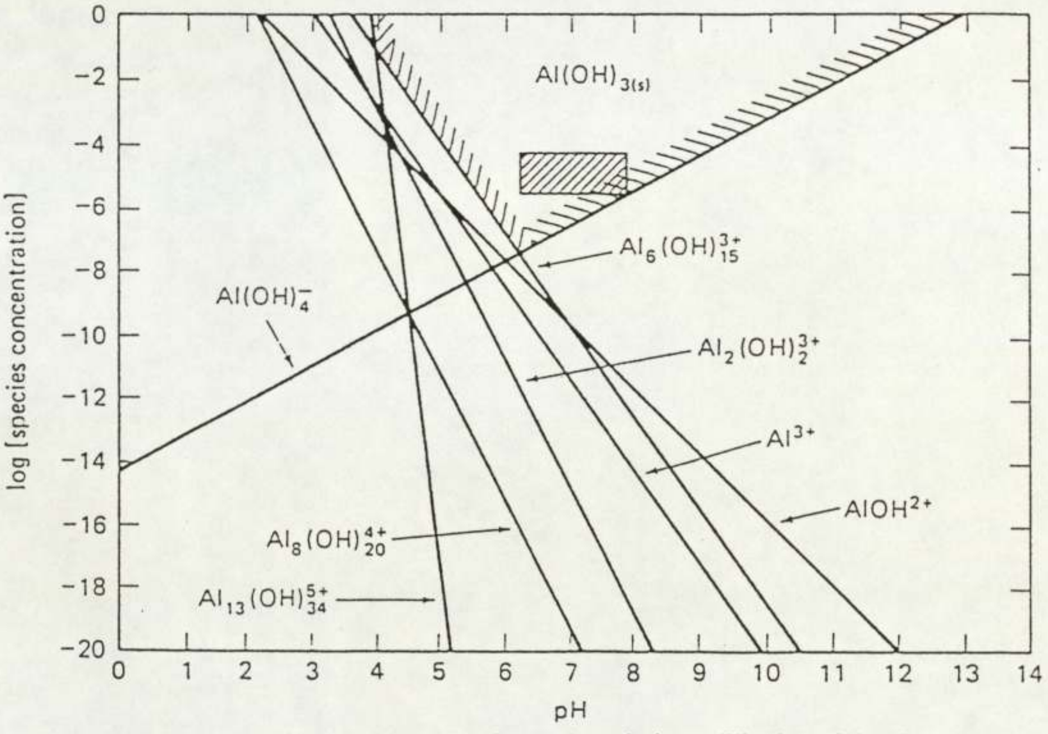

Figure 9 - Solubility Diagram for Aluminium Hydroxide Complexes.

3.2 Jar Tests.

Jar tests are the water industry's standard method for testing the suitability of the water under test for a particular set of treatment conditions. They are used to indicate the chemical dosing on existing treatment plant, to investigate any treatment difficulties and as a basis for design of new works. A jar test is a crude laboratory scale test of general suitability which does not take into account hydraulic conditions, time, temperature or the effects of continuous processing.

The method is basic. Normally six jar tests are carried out simultaneously. The apparatus consists of six variable speed simple paddles, all driven from the same mechanism and six 1 litre beakers. A measured amount of water is put into each beaker and measured doses of coagulant, pH adjuster (acid or alkali, depending on conditions) and polyelectrolyte are added. This solution is then mixed rapidly for a period of time, normally one minute. The rate of mixing is then greatly reduced and agitation continued for twenty minutes to promote flocculation. During this period the water is observed for the first appearance of floc. At the end of the period the stirrers are turned off and any floc produced is graded by comparison to a chart. The resultant mixture is then allowed to settle or is filtered through a coarse filter paper. Tests are conducted on the filtrate for residual coagulant concentration, residual pH and turbidity.

This batch test is taken as a good representation of the full scale continuous plant performance. No account is taken of the effect of continuous process dynamics, the effect of continuous processing or of physical dimensions of plant or the degree of agitation. Temperature and time are both disregarded. These factors, and many others, can be crucial to the way in which the physico-chemical reactions take place, thus altering the effectiveness of the treatment process.

While jar test do have limited use in predicting the dose rates of the various chemicals added they cannot be considered as an on-line measure of the optimum chemical dose as the tests can take several hours to complete and the raw water conditions can change in a far shorter time. The only information that they provide is a rough guess as to what the optimum chemical dose may have been for the raw water that was entering the plant when the water sample was taken. This therefore involves a large time lag.

Jar tests have no value at all as a method of automating a treatment works as they are slow and inaccurate. They are only good as an historic record of what might have been achieved on a treatment works at a single point in time.

3.3 Acid Dosing.

Due to the relatively alkaline nature of the Minera water an excess of alum has to be added purely for pH control purposes. It would be more economical to use an acid for this purpose rather than the coagulant. There are two main options to consider:-

1) Carbon Dioxide
2) Sulphuric Acid

Other primary acids, such as nitric or hydrochloric acid, are less suitable than sulphuric acid due to contaminants and possible interference with later stages in the water treatment process. They are also less cost effective.

Carbon dioxide is not very efficient over the pH range of 8 to 6 which is required at Legacy WTW. A large amount of carbon dioxide would be needed to depress the pH (Ref. 23). In this instance sulphuric acid is more efficient as is shown in Figure 10.

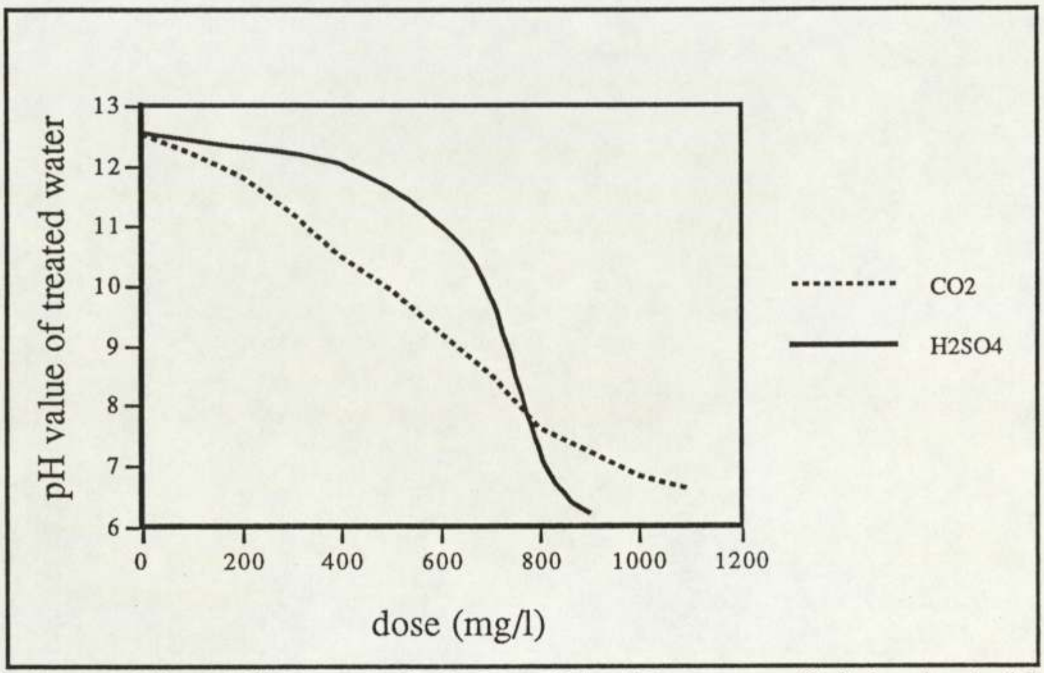

Figure 10 - Efficiency of Carbon Dioxide versus Sulphuric Acid in Adjusting the pH of Water.

Due to the low buffer capacity of Minera water only a small amount of acid is needed. However the capital cost of the plant and its control system outweigh the cost benefits of reducing the alum dose.

New products are being designed by coagulant manufacturers that combine a greater acidity with the coagulant to try and offset this cost problem while achieving better coagulation and flocculation.

3.4 Alternative Coagulants.

There are many coagulants available for the water treatment process. Metal based coagulants include aluminium sulphate, ferric sulphate, ferric chloride, aluminium chloride and polyaluminium chloride. Non-metallic coagulants are generally either polyelectrolytes or clays.

3.4.1 Metallic Coagulants.

Metallic coagulants are based on compounds of multi-valent metals. A trivalent metal ion is over 10 times more effective as a coagulant than a divalent ion. (Ref. 5)

Iron compounds exhibit several problems that are not found with aluminium salts. They can give rise to coloured compounds in the water by reaction with detritus in the distribution system. Iron coagulants often contain much higher levels of heavy metal contaminants, e.g. chromium, cadmium and manganese, due to their source. Iron salts coagulate at a much lower pH level than aluminium salts and so more coagulant is needed to depress the pH for coagulation. Acid addition may also be necessary. As a consequence of this low coagulation pH, more alkali is also needed at the end of the treatment process to elevate the pH of the water to the required final level (approximately pH 8·5) before it leaves the treatment works. Ferric salts also produce greater quantities of sludge than aluminium salts which then incur greater costs for treatment and disposal. On top of all these factors the ferric salt also has to be suitable for the type of water being treated. Jar tests and plant trials show that not all the waters to be treated at Wrexham Water can be coagulated using ferric salts.

Ferric salts do have some benefits. The cost per tonne is generally less than that of alum. It is more effective at low temperatures and there are as yet no suspected health problems with ferric salts.

Lime can be used on its own (Ref. 11) as a coagulant under certain circumstances. In waters with a very high magnesium content the addition of lime to elevate the pH to greater than 10 can be sufficient to cause the magnesium to hydrolyse, forming an insoluble precipitate.

3.4.2 Non-Metallic Coagulants.

Polyelectrolytes can be used as coagulants. More often they are used as coagulant or flocculant aids but this is not always the case. There are three main groups of polyelectrolytes which can be used as coagulants. They are all cationic and are melamine formaldehyde, epichlorhydrin dimethylamine and polydiallyldimethylammonium chloride (polyDADMAC). (Ref. 5) In England and Wales the only permissible polyelectrolyte coagulants are those based on polyacrylamide, polyamide, and polyDADMAC. In contrast to aluminium and ferric ions, polymers do not produce voluminous quantities of floc. (Ref. 11) Although polymers have significant potential in water treatment their use has been restricted due to high cost and uncertainties regarding chemicals associated with polymer synthesis.

Ozone and chlorine can be used as primary coagulants to oxidise matter in the water and cause its precipitation. This is seldom carried out due to high costs and the possible formation of harmful by-products. Other products are based on starch, tannin and alginate.

3.5 Monitoring.

The effectiveness of the coagulation process is monitored using a number of parameters. The three major ones are colour, turbidity and residual aluminium. Where there is a particular problem with the raw water, for example nitrate or iron, this may also be monitored. Colour and turbidity results show how effective the coagulation has been at removing dissolved and suspended matter respectively from the water. Residual aluminium is monitored to check that the combination of dose rates of each of the chemicals in the flash mixer is correct.

3.5.1 Spectrophotometer.

Water samples are taken from the start, middle and end of the treatment works and tested for various parameters using a portable spectrophotometer. The photometer used by Wrexham Water allows all the chemical analysis necessary in the water treatment process, apart from pH, to be made on a single instrument. In total, seven parameters are measured using the photometer, these are alkalinity, turbidity, colour, aluminium, iron, manganese and chlorine. By the addition of precise doses of colour generating reagents the concentration of the variable under investigation can be measured. The reagents used are provided in a tablet form as they are easy to transport and contain a measured chemical dose. Dissolving the tablet can be problematical, especially in cold water and this can lead to inaccuracies in the test being undertaken. Colour and turbidity can be read directly using the photometer without the need for reagent addition. Aluminium concentration is measured by the addition of a series of chemicals which results in a coloured complex, the strength of which can then be measured. The previous method for doing this included six different chemicals, namely 1,10-phenanthroline, pyrocatechol violet, hexamine/ammonia buffer, hydrochloric acid, ammonium hydroxide, and nitric acid, several of which are now known to be harmful. The photometer method uses eriochrome cyanine R to create a coloured complex in a slightly acidic solution. Ascorbic acid eliminates interference from iron and manganese. (Ref. 15) The strength of the colour is then measured directly by the photometer using percentage of applied light transmitted. This is converted to a concentration reading either manually by using a chart, or automatically by the photometer's electronics.

3.5.2 Continuous Measurement.

Spot checks on sixteen parameters at Legacy Water Treatment Works are made at least once per day. Seven of these are also covered by continuous on-line monitors and the signals are recorded via the telemetry system. These parameters are raw water turbidity, flash mixer pH, pre-service reservoir free chlorine residual, pre-service reservoir pH, final water free chlorine residual, filtered water turbidity and flow from the station. Clarified water turbidity is also continuously monitored on site and should this exceed locally set parameters an alarm will be generated via the telemetry system. From these parameters, judgements can be made as to the effectiveness of each of the treatment stages. Coagulation and flocculation are monitored using flash mixer pH and clarified water turbidity. If the flash mixer pH goes outside a set range then the treatment operators can predict, from experience, that there is likely to be a problem with the process. From the clarified water turbidity the treatment operator can tell that there has been a problem with the coagulation, flocculation or flotation processes and that downstream processes are likely to be affected. These methods are all either predictive or indicative of problems. None of them is a direct measurement of the more sensitive parameters such as residual aluminium, nitrate, sulphate, iron or other trace elements. pH and turbidity are important measurements to make and the levels attained in modern treatment works are normally well within the guidelines. Residual aluminium however may vary without a dramatic accompanying change in either pH or turbidity. This fact, in addition to concern over the medical effects of long term exposure to dissolved aluminium, warrants the installation of a continuous on-line residual aluminium instrument to monitor the clarified water. This will give a greater confidence that the coagulation, flocculation and flotation processes are all working correctly.

3.5.3 Coagulant Control Systems.

In addition to continuously monitoring the residual aluminium, it would be beneficial to automatically alter the coagulant dose to rectify any variations in the process and thus maintain a good quality water. A method is needed to automatically detect changes in the raw water conditions and then to react to these changes.

Jar tests are the traditional method for testing water but they can satisfy neither of these criteria. Jar tests are operator instigated, manually conducted tests that are time consuming, tedious and often bear no relation to the full size plant whatsoever. Automating the jar test method to achieve a continuous sampling system is possible, but is an expensive, unwieldy and slow method, and still relies on operator intervention to judge whether the floc size is correct.

A system is available from Aztec Environmental Control Ltd. that measures several parameters in the raw water on a continuous basis and then predicts a suitable dose rate of coagulant. This system has to run in a monitoring mode for an extensive period of time before sufficient data are available for the algorithm to be fine tuned to the particular application. In some cases the algorithm and the predictive system have proved to be unsuitable.

Streaming current detectors can be used as part of a coagulant control system. A unit from Lasertrim Ltd. has been tried at both Legacy and at

Llwyn Onn treatment works and subsequently installed at Llwyn Onn WTW to automatically control the coagulant dose; details are given in Appendix 3. The instrument measures the capability of the chemically dosed water to flocculate. The method does not depend on any other measurements for effective operation. It works on a feed-back rather than a feed-forward loop and so control is generally good. The streaming current detector methods are still very qualitative but are far more sensitive to process changes and provide a rapid response that is an on-line, continuous measurement of the coagulation/flocculation conditions.

Streaming current is a method of determination of zeta potential. Zeta potential is a measure of the capability of the individual particles to adhere to each other. It has been used with great success in the paints industry to greatly reduce the settling of emulsions. By keeping a high zeta potential, the likelihood of particles in the paint adhering to each other is minimised. The use of zeta potential within the water industry is to achieve the opposite affect, i.e. to encourage the particles to adhere so that colloids and fine particles can be removed from the water.

The apparatus involves forcing the water sample through a chamber containing a piston. As the piston shears through the water it disturbs the electron field around the micro-floc molecules which creates an electrostatic charge. This charge is measured and related back to the zeta potential of the particle.

None of the methods described provides an analysis of either the precise water contents or which parameters are affecting the stability of the floc. The methods merely suggest the better conditions for coagulation and flocculation to take place. It is thought that each of the many parameters in the water contribute in varying degrees to the stability and rate of formation of the floc. To measure each of these parameters, a continuous on-line measurement of raw water quality and conditions is needed. This is an extremely expensive option as sensitive analytical instrumentation is required and it is hard to justify from a cost basis as the treatment process is currently controlled within the legal parameters using existing qualitative techniques.

The quality of the raw water at Legacy WTW, especially the Minera source, can change in a very short time with little warning. Local weather conditions, i.e. temperature, rain, sunshine, can have a great effect on the water. Water quality is assumed to be constant in normal conditions but as a full chemical analysis is not carried out all that can be reasonably said is that the water quality does not change in a manner that affects the coagulation or flocculation processes.

It is not known precisely how each contaminant in the water affects the coagulation and flocculation processes, nor how the contaminants interact.

3.6 Removal of Floc.

The floc formed in the coagulation and flocculation processes has to be removed before disinfection. This is achieved by two methods. Firstly the flocculated water passes through a flotation unit which removes approximately 95 to 98% of the floc. (Ref. 11) The water is then relatively clear and is termed clarified water. However there is still a significant proportion of the floc remaining in the water which will later be removed by filtration.

3.6.1 Primary Removal of Floc by Flotation.

The primary method of floc removal at Legacy Water Treatment Works is by dissolved air flotation. The floc particles are lifted to the surface of the flotation tanks by minute air bubbles and form a blanket of sludge, which is then removed by a mechanical scraper as described in Section 2.1.3. Essential to the flotation process is the generation of pressurised water saturated with air. Initially at Legacy there was only one saturation vessel. This meant that maintenance and inspection tests could not be carried out without shutting the entire water treatment plant for up to two days. The only way to solve this problem was to install a second saturator vessel. While the new vessel was being installed an opportunity was taken to inspect the interior of the existing vessel. Problems had been experienced over the previous months in maintaining an effective dispersion in the flotation tanks. While this was caused partly by pipework which was demonstrated to be undersized, a second reason was found. On removing the top of the saturator vessel it was noted that the packing in the bed appeared to be discoloured. This prompted removal of a portion of the bed at which point it was discovered that the bulk of the packing was totally blocked with entrapped floc material rendering the packing virtually useless. This had led to the pressurised water only being partially saturated with air and thus being ineffectual in the flotation process. The packing was removed and cleaned with a water jet. Detergents are not used for cleaning any part of the equipment that may come into contact with the water as traces of detergents can adversely affect the delicate balance of the treatment process and also contaminate the potable water. After cleaning, the performance of the saturator was vastly improved. Figure 11 shows the effect of resizing the pipework and cleaning the saturator.

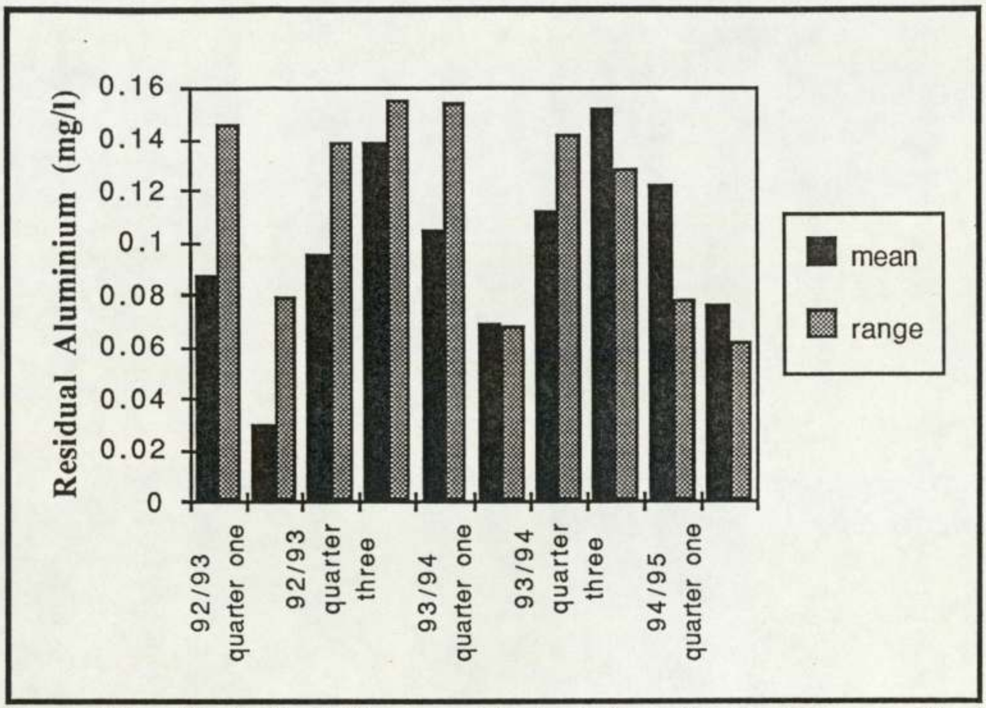

Figure 11 - Statistical Process Control Results for Legacy Residual Aluminium.

The column marked "range" is a measure of the variability of the measured aluminium residual and demonstrates the poor control of the process. The range in the data shown is calculated from the previous three months data. The pipework was altered and the saturator cleaned in March 1993. The results were collected during quarter four, April to June 1993, and the change is seen in 93/94 quarter one. Both the mean and range vary seasonally with the water temperature as control is inferior during periods of cold weather. When the range is greater than the average, the control is very poor.

3.6.2 Secondary Removal of Floc by Filtration.

Following flotation the clarified water still contains fine particles of floc which need to be removed before disinfection as the floc can shield bacteria from the disinfectant and allow contamination of the distribution system. A number of filter designs are available employing a variety of media. The filter medium can be any material that does not adversely affect the filtered water quality and which allows the passage of water through the bed. This generally means any insoluble, granular material, though availability, cost, durability and lifetime of the material also have to be considered. For practical reasons, sand or granular activated carbon are the most common.

While primary filtration is the main purpose of the filter medium the further removal of dissolved and suspended matter can be achieved by employing an adsorbent such as granular activated carbon (GAC) for the filter medium. Activated carbon produced from a carbonaceous base is particularly effective in removing organic matter that has a high molecular weight and a low polarity, for example :-

- phenols
- surfactants
- saturated hydrocarbons with relatively insoluble molecules that are not easily attacked by ozone
- pesticides.

Adsorption is less effective against polar solvents and organochlorinated compounds with low molecular weights, which is why filtration on granular activated carbon alone is not enough to remove haloform compounds satisfactorily. The nature of the carbon also has a bearing on its effectiveness. Carbonaceous based carbons are more effective at removal of a wide range of contaminants than coconut based activated carbons and also have a better long term life and better regeneration properties. (Ref. 14)

Removal of organic matter by GAC is normally between 5% and 15% of the initial content of the raw water. The removal process is due partly to the diffusion of organic compounds inside the pores of the carbon, and partly to the biological activity of micro-organisms inside the filter bed. While the filter bed is suitable for supporting these micro-organisms it is also ideal for the support of other organisms, such as pathogenic bacteria. These organisms are normally rendered non-viable by the disinfection process but should they become dislodged from the filter bed along with an amount of floc then they are likely to pass through the disinfection process unharmed; thus potentially causing health problems.

Filtration on sand contributes little to the removal of organic matter when located after flotation as it acts merely as a physical filter. Where there is a high quantity of carry-over from the flotation and a high organic content in the clarified water, two stage filtration is necessary. This normally consists of a first stage sand filter to remove the floc material followed by a second stage GAC adsorber. GAC is not normally used as a primary filter when there is heavy carry-over from the flotation as the carbon becomes impregnated with aluminium which greatly reduces its efficiency and also its regeneration ability.

The most common filter designs are either pressure filters or rapid gravity filters. Pressure filters occupy less space than rapid gravity filters but are more energy intensive and therefore costly to run. Rapid gravity filters are better suited to the water at Legacy WTW as the floc produced is very delicate. The water flows onto the rapid gravity filters rather than being pumped which preserves more of the floc in a suitable form for filtration. The floc should not be broken up by the filtration process as this can release entrapped particles which are too small to be effectively filtered out by themselves.

3.6.3 Rapid Gravity Filters.

Wrexham Water has a policy of using GAC filters wherever river water is treated. At Legacy WTW the raw water sources have historically been upland reservoir sources, but now these are supplemented with water from the River Dee via the 'Conjunctive Use Scheme' as detailed in Appendix 4. As a consequence the existing sand medium at Legacy is to be replaced by GAC. The existing pressure filters are not able to take GAC as a medium, so they are to be replaced with rapid gravity filters.

As part of this research project, the requirements of the filters were agreed with the relevant personnel and departments within Wrexham Water and the specification was then written. Due to the dearth of chemical process designers at Wrexham Water the invitation to tender was based on a performance contract using the IChemE "Red Book", which puts the responsibility for the design on the contractor. While this method seems straightforward it involved a distinct change of policy at Wrexham Water. Previous contracts had always been run from a civil engineering point of view with little attention to process detail. The change to dealing with the water treatment works as a chemical process involved a significant change of philosophy within the Company.

Several companies were selected to give presentations at Wrexham Water to pre-qualify for the work and of these five were invited to tender. Two companies withdrew during the tender period leaving three, Purac Rosewater Ltd., Mantec Environmental Engineering Ltd. and Biwater Treatment Ltd., to compete for the contract. Biwater submitted a variation on the specification which gave both capital cost and operating cost savings. This bid also had the significant advantage that it avoided the need to demolish the existing chlorine drum storage and dosing building, which gave a further financial saving of £130,000 capital plus £25,000 operating cost per year. These savings gave the Biwater bid a significant advantage over the other tenders but involved a totally new processing concept as far as Wrexham Water was concerned.

The preferred design offered by Biwater uses a continuously washing principle rather than the traditional rapid gravity filter design. It is a proprietary design initially patented in Switzerland, though the rights now rest with Biwater Europe Ltd. Each filter unit is divided into subsections and each section is washed in turn by back flow of water through a travelling hood. Detailed filter design is given in Appendix 5.

The change from rapid gravity filters to a continuously washing filter is a significant process change from that previously operated at Wrexham Water. The design of the new plant and potential problems caused considerable discussion of the tender but after viewing the units in operation and considering the benefits of the system the proposal was accepted by Wrexham personnel.

3.6.4 Reclamation of Sludge.

The waste product of the water treatment process from the flotation and filtration stages is a sludge, the nature of which depends upon the chemicals used in the flash mixer. At Legacy WTW this sludge is primarily dirt in, or on, aluminium complexes. Currently this is disposed of to landfill. There are potential uses for the sludge which are not currently financially feasible, but will become more viable as environmental concerns increase. The sludge produced by the centrifuge contains approximately 85% water. The remainder is mostly aluminium complexes. There are several opportunities to recycle this waste product.

One idea is to return it to the original coagulant supplier for inclusion in low grade aluminium based products; it would need excessive refining to be included in water grade products as it is contaminated with particulates from the raw water. Alternatively it could be dried and used as a construction material, or packaging. Similar uses have been demonstrated in Japan using sewage sludge wastes.

3.7 Chapter Summary.

Although the actual chemistry of coagulation is not fully understood the process can be controlled by using qualitative techniques, though these rely on operator expertise for effective operation. Techniques are slowly developing to automatically control the treatment process and at the moment streaming current potential seems to be the most promising method, though there is much progress yet to be made.

Through alterations in the coagulation process, the water treatment process has been improved and significant cost savings have been made in the use of chemicals which total, to date, £57,250 per annum and also have associated cost savings. There are further changes that could be made to the treatment process at Legacy WTW, e.g. acid dosing, which currently do not give sufficient cost benefits to warrant the alterations but which may be of importance in the future.

The current monitoring of the coagulation, flocculation and flotation processes are more than adequate for legal purposes and the water meets all national requirements. However, the installation of further monitoring equipment, especially residual coagulant, could greatly benefit the Treatment, Distribution and Technical Services Departments by adding valuable information to the existing data base.

The floc removal processes have been reviewed and the combination of changes made to the flotation plant in the initial stages of the project and programmed work on the filters will enable the plant to run at full capacity while maintaining the desired water quality. Furthermore these changes will also allow maintenance work to be undertaken without shutting down the entire water treatment plant. The work on the new filter plant has involved distinct and major changes in tendering techniques at Wrexham Water and in the consideration of new ideas and processes by Wrexham Water staff.

4. WATER TREATMENT - DISINFECTION.

4. WATER TREATMENT - DISINFECTION

4.1 Instrument Audit and Assessment.

Each instrument operated by Wrexham Water has a unique asset number. Information on the performance of each instrument is collected by the telemetry alarm record sheets, by defect sheets filled out by treatment operators and by the maintenance record, as described in Section 4.1.1. Instrument audits were carried out throughout the entire company. The audits were not restricted to Legacy WTW because there are relatively few instruments at Legacy; extensive problems were encountered in other parts of the Company and the larger data base gives a greater statistical confidence in the results.

The first instrument audit carried out on data collected from 7 October 1992 to 31 December 1992 used the record of telemetry alarm sheets. This audit showed that 75% of the recorded alarms were generated from chlorine instruments and, of these, 75% were recorded as the instrument required recalibration; in other words 60% of all instrument alarms were due to drifting calibration of chlorine instruments. One third of all chlorine alarms came from Berwyn WTW. The summary data collated for the initial audit are shown in Table 1. Full data are shown in Appendix 6.1.

CAUSE OF TELEMETRY ALARM	TOTAL
Cl_2 REQUIRES RECALIBRATION	28
Cl_2 REQUIRES MENDING	9
TURBIDITY, REQUIRES CLEANING	3
pH NOT CONTROLLING	2
pH REQUIRES RECALIBRATION	6
FILTER PROGRAMME LOCKED UP	1
TOTAL	49

Table 1 - Summary of Initial Instrument Audit Based on Telemetry Alarm Sheet.

Following this initial investigation, another audit was carried out using the maintenance record sheets, which revealed a more detailed picture of events. These data had never been put together in a logical format before and the results provided a large incentive to carry out an organised reassessment of parts of the instrumentation. This audit showed that contrary to popular belief, pH instruments were not the most problematical. For the six month period from 2 July 1992 to 17 January 1993 there was a total of 288 recalls (unplanned visits) to instruments within the Company. Of these, half were purely to reset readings that had drifted out of calibration, with the majority of these, 58%, being for final chlorine indicators, controllers and cells. Of the nineteen instruments covered in the maintenance audit 53% were pH instruments and despite their poor reputation within the Company they incurred only 12·5% of the recalls. Chlorine instruments made up 47% of the total, yet incurred 87·5% of recalls. Full details of this assessment are given in Appendix 6.2; a summary is shown in Table 2. Reliable chlorine measurement is extremely important for health reasons as the wholesomeness of the water is dependant on the disinfection process above all others. The numerical data from the audit were important for two reasons; i) they provided information necessary to promote action to solve the problem, and ii) they disproved one of the traditional 'old wives tales'. This created some interest in tackling long standing process faults and led to a welcome change in the working philosophy of Wrexham Water staff in that new techniques and technologies were no longer immediately dismissed but were given serious consideration.

	Recalls	%age of total	Resets	%age of category
Chlorine	252	87·5%	132	52%
pH	36	12·5%	9	25%
Total	288		141	49%

Table 2 - Summary of Maintenance Data on Recalls 2/7/92 to 17/1/93.

In a subsequent audit of six months maintenance data from 1 May 1994 to 31 October 1994, a marked improvement in performance was shown although some areas are still causing problems as detailed in Section 4.1.6. Summary details are shown in Table 3 and full data in Appendix 6.3. The total number of recalls has been reduced by 58%. Chlorine instruments still cause the vast majority of recalls though the installation of the Hach Cl17 chlorine residual meters (see Section 4.1.3), has greatly reduced this. Of the ten chlorine instruments, one is essentially out of service, four are Hach Cl17 and five are Wallace and Tiernan. Figures show that on average the amperometric cells have twice the number of recalls than the colorimetric cells. All instances when the only remedial action required was recalibration of the instrument can be attributed to Wallace and Tiernan cells. There are two main reasons for the number of recalls to the Hach instruments; the first is due to power dips or failures which cause a system error light to appear on the display although the chlorine reading is seldom affected, and the second is at Berwyn WTW where the flocculated material deposits on the inside of the glass photometer cell whenever there is a problem with the water treatment process. Recalls due to power dips and cuts can be overcome by the installation of an uninterruptible power supply (UPS).

	Recalls	%age of total	Resets	%age of category
Chlorine	114	93%	59	52%
pH	8	7%	8	100%
Total	122		67	55%

Table 3 - Summary of Maintenance Data on Recalls 1/5/94 to 31/10/94.

For the six months prior to the start of this research project there were on average 30 category B (see Section 4.1.1) telemetry alarms per month. Implementation of the recommendations arising from this research project reduced this figure to a monthly average of 4. Few alarms were noted in the category C area and they were due mainly to Legacy clarified water turbidity. This was thought to be caused by large particles of floc being released from the sludge blanket during scraping and being carried through the turbidity meter. This problem was avoided by installing a timer on the trigger so that if the turbidity reading was high for less than one minute the alarm was not generated. Most of the category A alarms, i.e. those due to genuine process faults, are due to changes in the raw water quality. These still cannot be dealt with automatically though some progress has been made at Llwyn Onn WTW in using the coagulant control system as described in Section 3.5.3.

4.1.1 Alarm Records and Maintenance Records.

Telemetry alarms are generated whenever a parameter goes outside a predetermined level. When this happens an alarm is transmitted to the control room. Based on the nature of the instrument, its duty and the distance of the alarm outside its control band the Control Room Officer can take one of three courses of action :

i) he can monitor the situation before further action,
ii) he can request a treatment operator to correct the fault, or
iii) if the station is unmanned he can call out a treatment operator.

Whenever the third scenario is actioned, a record sheet is used to log details of the event; an example is given in Appendix 7.1. Each alarm is categorised according to the treatment operator's findings when he arrived on site. Category A alarms are those generated by a genuine treatment problem, Category B alarms are due to an instrument fault and Category C alarms are spurious alarms for which no reason can be found. By this system, problem areas can be targeted for remedial work. At the end of each month the relevant records are condensed and entered into a spreadsheet to provide a summary of the months problems.

Defect sheets are filled out by the treatment operators when the value given by the process instrument does not agree with the operator's off-line reference check, as shown in Appendix 7.2. A set of guidelines for designating an instrument out of calibration has been set up by Wrexham Water as part of their BS5750 system and a sample from Legacy WTW is given in Appendix 7.3.

The maintenance record contains data collected by the Technical Services Department whenever any maintenance on an instrument is carried out, either planned or breakdown. Details are included of the reason that maintenance was initiated and what remedial work, if any, was carried out. See Appendix 7.4.

4.1.2 Problem Identification - Residual Chlorine Instrumentation.

Following the instrument audits, the reason for the high number of residual chlorine alarms was investigated. The amperometric type cell in use at Wrexham Water is prone to drifting. This is an inherent design fault. The readings can drift for a number of reasons. This type of cell works by measuring tiny differentials in current between a platinum and a copper electrode. It is easily affected by a change in the conductivity of the water being sampled, for example a change in pH or in water quality can alter the reading significantly. The cell is continuously cleaned by suspended sand grains in the sample flow; should these grains be carried out of the system then the cell's performance is affected. If the electrodes are partially corroded by contaminants in the water then, again, the reading is affected. The amperometric cell also requires the addition of a buffer to the water, which is supplied via a peristaltic pump. The particular device used in the instruments at Wrexham Water has a fault in the buffer pump which causes excessive wear on the tubing, as was demonstrated by the maintenance record audit, see Appendix 6.2.

The effects of drifting can be overcome by triple validation, see Section 5.2.2, but this is a costly alternative to choosing a reliable instrument at the outset.

4.1.3 Alternative In-line Chlorine Meter.

Alternative in-line chlorine meters were sought to replace existing amperometric ones in order to improve instrument reliability. The type of in-line meter chosen to replace the amperometric cells traditionally used had been previously identified by the Technical Services Department but little attempt had been made to introduce it. The meter identified was the Hach Cl17, which operates on a batch basis using the diethyl-p-phenylene diamine (DPD) colorimetric method. The meter takes a sample every 2·5 minutes. The instrument flushes the measuring cell, takes a background colour reading of the sample, doses a precise amount of colour forming chemicals into the sample, waits exactly two minutes and takes a reading using an internal spectrophotometer. The cycle is then repeated.

The Hach instrument was tried first in one location at Pendinas Treatment Works. Its performance was particularly impressive and three more units were installed at other sites. Currently all locations where the chlorine residual is monitored have now been fitted with the Hach Cl17. Where the chlorine residual is automatically controlled, the amperometric cells are still used because the controllers are currently configured to operate from a continuous signal. However when a new chlorine plant is installed at Legacy treatment works next year both monitoring and control functions will employ a Hach Cl17 instrument.

In addition to its good design qualities and impressive on-line performance the Hach chlorine residual instrument also has the benefit of using the same techniques as the portable off-line reference method. In this way any discrepancies between methods were eliminated. As a by-product of the increased reliability of the instrument it also has a greatly reduced cost of ownership.

4.1.4 Change of Control Parameters.

The improved reliability of the chlorine instruments has meant that there is a greater confidence in the readings given and in the alarms generated. This in turn has allowed a tighter control to be exercised on the residual chlorine. In some cases the control band has been narrowed considerably in the past two years due directly to this improvement in reliability. The control band for residual chlorine for Nant-Y-Ffrith Water Treatment Works has been reduced by 20% and for Oerog Springs Water Treatment Works by 40%. In other cases the control bands have not been changed but fewer alarms are generated as the chlorine residual is now controlled well within the required parameters, which obviously gives a greater confidence in the quality of the water.

4.1.5 Effect on Water Quality.

The increased reliability of the instruments has had two effects on water quality; one is a better control over the production process and the other is a greater certainty that what is happening is being accurately monitored and recorded. On occasions, the chlorine demand of the water appeared to be varying in association with unknown water quality parameters and the chlorine dose rate was altered accordingly. An example is the pre-service reservoir chlorine at Legacy WTW, as shown in Appendix 8. The change from the amperometric method to the Hach Cl17 has shown that this was not the case. The variation was due entirely to random drifting of the instrument.

The increased control of the chlorine residual gives fewer incidents where the water quality is outside the desirable parameters which in turn incurs far less paperwork and reporting activities (which under the BS5750 system are quite substantial). The improved control also gives a lower risk where health factors are concerned and allows any problems which do occur to be quickly identified and acted upon rather than being obscured by excessive variability in the system or by false data.

Having a consistent and reliable chlorine residual in the water also reduces the potential for problems in the distribution system. A constant residual is far more effective at controlling bacteriological problems than a sporadic high/low residual. If the chlorine residual is prone to variation then this allows periods where the bacteria can grow in the distribution mains. As they establish themselves on the inside of the mains they cause pitting and corrosion of the surface that then harbours bacterial colonies and effectively shields them from the chlorine in the water.

4.1.6 Remaining Areas for Improvement.

Although the operating situation has been greatly improved, there are still several faults in the existing disinfection systems. These are generally design problems with the treatment plant that are difficult to overcome without incurring major infrastructure costs and capital expenditure.

At Berwyn Treatment Works the final residual chlorine control has been greatly improved as demonstrated in Appendix 9. However the main factor in its operation is the flow rate from the station. In the winter the water is supplied only to the local area and the variation in flow can exceed 450% in a matter of minutes. The automatic controller has difficulty in responding to this wide change in flow while, at the same time, maintaining a stable response to other process changes. During the summer, when water resources are short in other parts of the supply area, two booster pumps are used to transfer the water to areas of high demand. This has the impact of giving a smaller variation in the flow from the station so the automatic controller does not have to respond to such wildly varying flows and a more constant residual is achieved. The only way to overcome the problems experienced during highly variable flowrates is to build a large service reservoir downstream from the contact tank to absorb these fluctuations, so that a steady flow can be achieved where dosing takes place.

The installation of the Hach Cl17 residual chlorine instrument at some locations has had a distinct impact on the number of alarms, the number of problems and on the stability of the reading. These instruments are not yet used at all possible locations as they are used only for monitoring purposes and not in any control capacity. Further reductions in the number of call-outs could be made if Hach Cl17, with UPS, were used for all in-line chlorine residual measurements. If current data are extrapolated, it seems probable that a 90% improvement on the situation that existed in 1992 could be achieved.

As mentioned in Section 2.2.3, pH has a large impact on the effectiveness of chlorine as a disinfectant. In most of Wrexham Water's treatment works including Legacy the final pH adjustment is made at the same point as the disinfectant is added. This means that the effectiveness and the efficiency of the disinfection process is hampered. At Legacy WTW the water before disinfection has a pH of 6·6 but during the disinfection has a pH of 8·5, which reduces the effectiveness of the process by over 66%. This is simply due to poor design. By making the final pH correction after the chlorine contact tank rather than before, the whole situation could be avoided.

Another problem with the layout and design of the distribution system is that in some cases the water has to travel a long distance before use. Water in the Wrexham area takes on average approximately 2 days between source and use. In some cases the water is used within an hour of leaving the treatment works and in other extreme cases it may not be used for several days. During this time the water has to remain wholesome and this is achieved by adding a free chlorine residual at the treatment works as described in Section 2.2.3.

The chlorine residual of the water leaving the treatment works can not be excessively high as the nearest customers would complain of an unacceptable chlorine taste and a strong odour from the water. Due to the layout of the distribution system this also means that the initial chlorine residual does not reach the far ends of the distribution system and the water quality there is more likely to deteriorate to an unsafe level. Chlorine booster stations are therefore required at strategic locations within the system. In many locations the installation of a chlorine gas unit is not acceptable, either due to the proximity of residential accommodation or the duty required does not warrant the high capital cost of the chlorine gas dosing plant. In these cases a booster unit using Chloros is more suitable.

4.1.7 Chloros Booster.

Penypalment Service Reservoir is located near the end of the distribution system. Water is supplied from Llwyn Onn treatment works 20 kilometres away and travels via Higher Berse and Tan-Y-Fron Service Reservoirs before reaching Penypalment Service Reservoir. Water leaving Llwyn Onn Water Treatment Works has a free chlorine residual of 0·22 mg/l but the residual level leaving Higher Berse Service Reservoir is normally 0·02 mg/l. There are very few micro-biological failures of the reservoirs in the distribution system and in 1993/94 Wrexham Water was one of the top five Water Supply Companies for water quality, achieving a sample compliance rate of 99·8%. However, during the summer months failure of reservoirs is more probable due to elevated temperatures and with the first heavy rain in autumn there is likely to be ingress of water to the service reservoir which carries with it biological contamination. In order to reduce the effect of these factors, reservoirs which traditionally have had problems are regularly chlorinated by manually adding Chloros to the water. This method suppresses the symptoms but does not solve the source of the problem.

Penypalment service reservoir has some structural problems that need attention but until the scheduled remedial work can be carried out a more effective method of suppression was needed as the manual chlorination was not efficient. Due to the reservoir design the manually added Chloros was not being mixed throughout the total water volume and was effectively slug dosing. Continuous dosing of the Chloros is more effective at controlling bacteriological growth than periodic overdosing. An automatic Chloros dosing unit was designed (see Appendix 10).

The unit was designed to dose Chloros into the pumping main on the way to Penypalment Service Reservoir and was located at the site of Tan-Y-Fron Service Reservoir as this provided an existing secure, temperature controlled building and a power source to drive the unit. It was possible to dose the Chloros at this location as there are no domestic service pipes from this pumping main.

Figure 12 shows the chlorine residual leaving Penypalment Service Reservoir as measured by the laboratory. Prior to the installation and commissioning of the unit on 16 August 1994, free chlorine residuals were normally below 0·02 mg/l and total chlorine (free plus combined) was below 0·05 mg/l. These samples are taken and measured at the service reservoir.

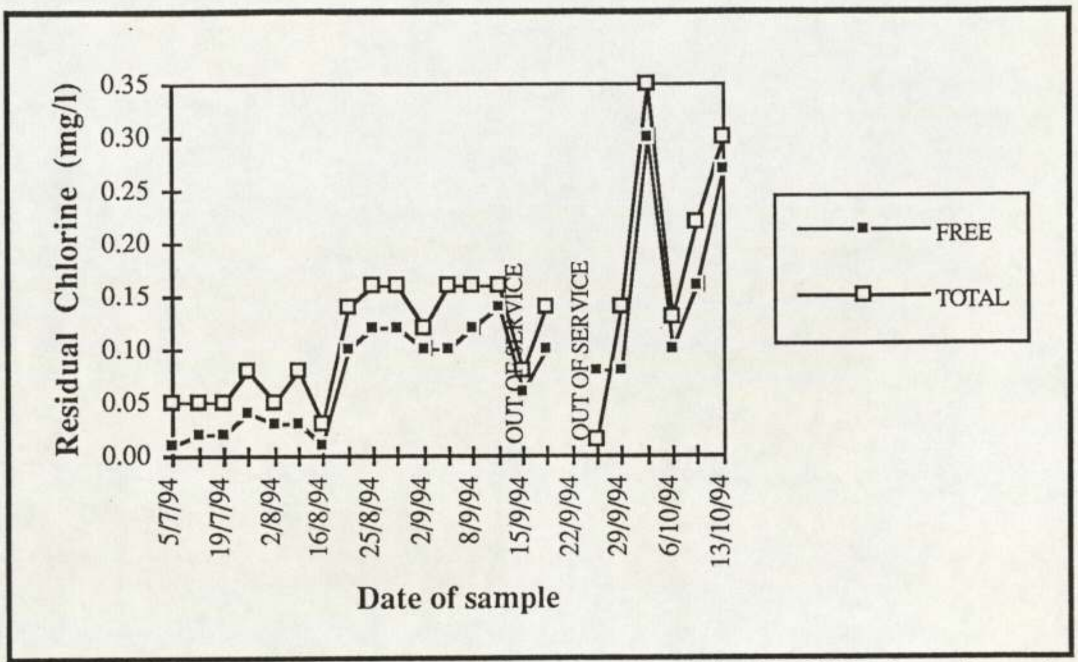

Figure 12 - Laboratory Results for Residual Chlorine Leaving Penypalment Service Reservoir.

4.2 Chlorination Facilities at Legacy WTW.

During the initial phases of the rapid gravity filter project, it appeared that the existing chlorine house would have to be demolished to provide the ground space necessary for the filter area required for traditional plant. Initially the plan was to move the existing facility to a new location but during enquiries it became apparent that this could not be done due to the Health and Safety Executive guideline HSG/40, (Ref. 22) which recommends that for new installations the distance between the outside of the containment building and site boundary should be at least 20 metres. The site at Legacy treatment works measures only 30 meters at its widest point, so alternative sources of disinfection had to be considered.

The main alternatives to chlorine employed in Britain are ozone, ultra-violet, chlorine dioxide and sodium hypochlorite. Of these, ozone and ultra-violet do not maintain a residual and so have to be used in conjunction with another disinfectant. Of chlorine dioxide and sodium hypochlorite the latter is more common for financial reasons, so a new installation at Legacy WTW was designed for the use of sodium hypochlorite.

4.2.1 Chloros.

Sodium hypochlorite is supplied in solution as it is highly unstable as a solid. Even as a solution it degrades fairly quickly and so stabilisers are added to reduce the rate of degradation. As it is added to the water the stabilisers have to be of low toxicity and in low concentration and the product has to be approved in accordance with Regulation 25 of The Water Supply (Water Quality) Regulations 1989. For these reasons "Chloros", a proprietary product of ICI, is widely used.

By choosing Chloros as a disinfectant there would be no adverse affects to the water quality. The addition of Chloros to the water will also have an impact on the total amount of several contaminants in the water. Legal limits are put on many parameters in the water as detailed in Appendix 11 and the addition of the Chloros must not increase any of these levels to such an extent that the parameters are exceeded. Sodium and chloride are the main concerns as these are the major by-products of the use of Chloros.

4.2.2 Legacy Chloros Dosing Plant.

In connection with the decision to use Chloros instead of chlorine gas for disinfection purposes, a change was also made to use sodium bisulphite solution instead of sulphur dioxide gas for dechlorination purposes. The Chloros and sodium bisulphite plant were designed to fit inside the water tower to avoid adding any further buildings to the site. It was decided to have duty and standby storage tanks to reduce any degradation of the chemicals and to allow maintenance on the tanks. Pipe-runs were kept to a minimum and flexibility of operation was built into the design. Wherever possible essential items were duplicated and provided with the means to be totally isolated from the working system for easy maintenance. The pumps were to be 'plug in' units to facilitate a quick replacement by a unit from the stores and maintenance could then be carried out on the faulty pump after the plant was returned to working order. The plant operation would be controlled automatically in every function by a programmable logic controller. All materials were checked for compatibility and the plant design was thoroughly inspected by all parties involved.

4.2.3 Design of New Chlorine Installation.

After the Biwater tender for the filter work had been accepted the Chloros dosing plant was no longer necessary as the existing chlorine facility could remain in place. In view of the increased strategic importance of Legacy WTW, the location of the new filters and the guidelines given in the HSG/40 document (Ref. 22) it was deemed necessary to upgrade the existing chlorine installation. It was decided to install dual gas dosing units for chlorination and de-chlorination. If possible, the units are to be installed using a baseload and trim arrangement, rather than a true duty/standby system as the chlorine gas will attack and corrode the gas dosing unit whether it is operating or not. When the standby is needed quickly, immediate operation could not be guaranteed with a standby unit as the moving parts have a tendency to stick when not in use. If the standby unit is continuously providing a base load this situation should not arise.

Further monitoring of the free chlorine residual will be added to the plant. Currently the residual is measured after chlorination before the water enters the service reservoir and after dechlorination as the water is leaving the plant. Another measurement will be taken after the water leaves the service reservoir but before it is dechlorinated. This will allow a continuous record to be kept of the chlorine demand of the water and will help to identify any micro-biological problems in the tower. It will also allow calculations to be made of the theoretical chlorine contact time should there be a problem with the final water.

An automatic drum closure system will be installed at Legacy WTW to improve safety aspects of the chlorine installation. The unit is a proprietary product from ICI that closes the drum valve should any chlorine or sulphur dioxide gas be detected or if an emergency button is pressed. By operating on the drum valve the unit isolates the drum from the rest of the system and thus covers all leaks from the delivery pipework or gas dosing units. The trigger levels for the unit need to be carefully considered because although the unit will increase the security of the chlorine installation it could reduce the security of the rest of the water treatment works by causing unnecessary station shutdowns, which themselves have an adverse impact on final water quality.

Investigations will also have to be made into the need for pre-treatment chlorine for algae control. This has not been necessary in the past at Legacy Water Treatment Works, but with the addition of River Dee water algal growth could become a problem. Alternatives to chlorine for this purpose will also be considered.

4.3 Chapter Summary.

The instrument audits have contributed to greater awareness of the importance to, and impact on the Company of reliable instrumentation. The improvements in instrument performance over the duration of this project have been exceptional, with an overall reduction in category B alarms of 87%. This progress has been largely due to the change in residual chlorine monitoring devices from an amperometric cell type to a colorimetric one. The reliability and accuracy of the new instruments are far superior to the amperometric ones and the cost of ownership is substantially lower. Quantifiable cost savings associated with improved instrument performance are £27,200 per annum, though many aspects of the ease of use of the new type instruments do not have quantifiable savings. Problems with the disinfection processes which remain to be solved have two main sources, either i) a physical problem which is costly to overcome, or ii) a greater perceived risk than perceived benefits from the change. The installation of a Chloros booster unit for Penypalment Service Reservoir is an attempt to limit potential water quality problems caused by a large physical problem while avoiding excessive capital expenditure.

Assessment of the impact on Legacy WTW of the new filters at the proposals stage gave rise to an in-depth study of the disinfection facility. Although the initial reason which necessitated the study has been resolved, the study has highlighted deficiencies in the system that should be rectified. This work will be undertaken after the filter work has been completed, and will significantly improve the security of the disinfection facility and thus the water treatment works.

5. WATER TREATMENT - pH MEASUREMENT AND CORRECTION.

5. WATER TREATMENT - pH MEASUREMENT AND CORRECTION.

5.1 Assessment of Historical Data.

From the initial instrument audit carried out on all instruments, as described in Section 4.1, it was apparent that pH measurement caused a considerable amount of problems. From the summary given in Table 1 it can be calculated that 16% of telemetry alarms due to instrumentation were caused by pH instruments. These alarms were generally caused by one of three reasons; i) the drifting of the instrument out of calibration, ii) the adherence of matter to the electrode, or iii) a problem with the lime dosing. Of these faults the third is the most time consuming and therefore costly to correct. Lime causes problems as it is dosed as a slurry, due to its low solubility, and because it is problematical to pump. The lime comes out of solution in the mixer, the pumps and the dosing lines either as a soft sludge or a hard scale, or both. Despite regular maintenance and flushing, blockages can occur.

The pipe itself may become blocked especially at bends or fittings where pressure differences increase the likelihood of deposits.

Where the lime is dosed into the water under pressure it is injected into the water main via a 'corporation cock', which is essentially a specially designed tube inserted into the main. This may become gradually blocked as the lime precipitates onto the inside edge of the tube or may be suddenly blocked by a dislodged flake of scale. This again causes severe process problems and due to the nature of the scale is difficult and time consuming to remove.

Due to the abrasive and alkaline nature of the slurry and the precise dosing needed, diaphragm pumps are used to dose the slurry. Variation in the lime dose causes problems with the treatment process as the pH is dramatically affected and the coagulation process may deteriorate, or the final water product may not be within the required specification.

As well as causing the final water product to be out of specification, problems with the lime dosing also have financial consequences. Each time a problem occurs, a treatment attendant is required on site to assess the situation. If the problem cannot be rectified by flushing the system through with water then the offending part has to be stripped down and cleaned by a member of the Technical Services Department, which can incur an additional call-out fee and overtime.

5.2 Methods of Measuring pH.

Following the success in reducing the number of problems and call-outs from chlorine residual instruments by employing the same reliable methodology for both in-line and portable reference, a similar approach was attempted with pH measurement.

The pH is measured in-line using a Kent pH meter of the type which is widely used throughout the water industry; details are given in Appendix 12. The manual reference method used at Wrexham Water is a Nessleriser, see Section 5.2.1, a type of comparator which uses a colorimetric method. In order to bring consistency to the two measurements, a portable electrode pH meter was required. A survey of the market revealed that the design of the glass electrodes is generally fairly standardised. There are however a few manufacturers that are attempting to overcome problems inherent in the design. Some manufacturers are looking to design out faults in the existing equipment whilst others are attempting to use new technologies such as optical methods and ion sensitive field effect transistors (ISFET). (Ref. 17)

The manual reference should use the same type of technology as the in-line method to ensure that no errors are introduced through discrepancies in the technique. This means that the method chosen must be suitable for automation. It is required that the new system be more accurate and reliable and be less problematical than the existing one. From a combination of the above factors the Hach One pH meter was chosen for trials. The performance was found to be very poor despite initial promising results, see Section 5.2.3, and the meters were returned to the manufacturer. Instruments were also examined from other manufacturers for example Radiometer, Russell, and ATI Unicam. None of these was found to be capable of giving a reliable reading during an initial demonstration and so were not tested for a prolonged period. Other instrument suppliers and manufacturers were approached but declined to give a site demonstration. An ISFET meter, as detailed in Section 5.2.4, has been identified and was able to give a reasonable reading during the initial demonstration and this is currently on trial at Wrexham Water. However, later results are proving to be less reliable.

5.2.1 Nessleriser.

The Nessleriser is a simple device used for the visual comparison of the colour of a dosed sample against a blank sample. Two 50 ml samples are taken in special glass tubes. One sample is placed straight into the Nessleriser unit and the other is dosed with a colour indicator. The indicator depends on the parameter under investigation. The Nessleriser is used for two main purposes in Wrexham Water, one is pH measurement and the other is to measure residual chlorine. Several pH indicators are used to cover the range expected in the water treatment process. Bromocresol purple for the range 5·2 to 6·8, bromothymol blue for the range 6·0 to 7·6, thymol blue for the range 1·2 to 2·8 and the range

8·0 to 9·6, m-cresol purple for the range 1·0 to 2·6 and 7·6 to 9·2 and methyl red for the range 4·4 to 6·0. pH on the treatment works is measured using an electrically powered Nessleriser. Each of the above mentioned indicators must be accurately measured into the sample at a concentration of 0·2ml in a 50ml sample. Great reliance is placed on the manufacturers of the indicators and while their product is generally of a high quality there is no claim made as to their traceability. Some of the pH indicators used by Wrexham Water overlap and confusion can occur as two different results are often obtained when different indicators are employed. The reason for this discrepancy has not been investigated and the result which most closely matches the expected result is taken as the correct one. This is an obvious failing in the monitoring regime. There are five reasons apart from manipulative errors that can lead to discrepancies in the readings obtained. "They are (Ref. 20) :

i) introduced by the dissociation of the indicator as either an acid or a base in supplying hydrogen ions to the test solution. This is termed 'acid error'.

ii) due to the action of neutral salts present in the solution upon the colour and the incidence of the colour change, termed 'salt error'.

iii) caused by the interaction of the indicator with ampholytic bodies such as proteins and colloids, termed 'protein error'.

iv) due to the effect of temperature on the dissociation of the indicator

v) due to the presence of alcohols in the sample."

The readings using the Nessleriser are only accurate to plus or minus the graduations in the scale, normally ±0·2 pH units. Although the dosed sample is compared to a blank sample, turbidity can effect the readings as some of the colour indicator can be absorbed by the suspended particles and if the sample has a colour of its own this may also interfere with the visual appearance of the dye. The amount of indicator added can affect the results by either under- or over-reacting with the parameter under investigation. The eyesight of the operator can play a large part in the accuracy of the reading. People can see colours differently and so get different readings. Colour blindness is an obvious failing.

Residual chlorine indicators for the Nessleriser are provided in tablet form and utilise the DPD method, as do the portable spectrophotometers and the in-line Hach Cl17 meters. Residual chlorine is normally measured at the service reservoir or treatment works using a daylight Nessleriser. This has additional problems to the electrical version as the strength of daylight and any shadow on the instrument can greatly affect the readings. Rain drops or dirt on the reflective surface can make the reading difficult to make and can cause a false reading to be made.

5.2.2 Triple Validation.

Due to the problems with pH meters generally and the high reliance on them to indicate process faults, a method has been developed to overcome the inherent faults in pH monitoring. This method is called triple validation and it is simply the installation of three pH monitors in parallel. Since the most common faults in pH meters are unpredictable drifting of the calibration and the adherence of small particles on the surface of the electrode, then the installation of three meters for the same duty aims to eliminate alarms due to faults, either by an averaging system or by a voting system. In the averaging system, alarm trigger levels are set to allow a degree of variation in the average reading before a warning is generated. In the elective system the average reading is still used as the alarm trigger; the three readings are compared to each other and if any one reading exceeds an allowable offset, the reading is disregarded by the system and the other two remain on line. If these two meters then differ greater than the allowable offset the system is isolated and immediate attention by a technician is called for.

While this method does allow more reliance to be put in the pH control system and allows remedial work to be carried out next day rather than on an emergency basis, it does not solve the basic problem with the meters themselves. A lot of effort has to be expended to maintain the instruments in correct working order and by installing three meters with the same inherent problems the cost and time of maintenance are also tripled.

5.2.3 Hach One Portable pH Meter.

The Hach One portable pH meter was identified as having been designed to overcome the main problem areas in traditional electrodes. The source of drifting and ageing problems in standard electrodes can generally be attributed to blocking of the reference junction. The Hach One electrode aimed to remove this problem by using a free flowing reference junction, as detailed in Appendix 12.2. By this means the stability of the reference electrode is guaranteed, and any problems with the reading can be attributed to the glass electrode.

Site trials with a demonstration meter over two weeks gave good results. On this basis five of the meters were bought for use throughout the Company. Initial results were confusing and this was ascribed to operator's unfamiliarity with the instrument and with electronic pH technology. However, after a period of two weeks the problems had not been solved. The suppliers of the meters were contacted, but on visiting the site, could find nothing amiss. They suggested small changes in the storage and operating techniques, but stated that these minor faults should not cause such large errors in the results. After a further period of time, the results were still very poor and this was ascribed to a manufacturing fault in the electrode. New electrodes were acquired from a more recent product batch but though the response was slightly improved the problems were still not resolved. Despite following all the supplier's instructions the performance of the meters after six months was still not acceptable, with forty-five percent of the results taking over three minutes to stabilise. The instruments were returned to the supplier and a full refund received. The range of response times are shown in Table 4. Full details of the trials, results and actions taken with the Hach One pH meters are given in Appendix 12.3.

TIME TAKEN FOR STABLE READING	NUMBER OF READINGS	PERCENTAGE OF READINGS
MORE THAN 1 MINUTE	271	78%
MORE THAN 2 MINUTES	197	56%
MORE THAN 3 MINUTES	158	45%
MORE THAN 5 MINUTES	111	32%
MORE THAN 10 MINUTES	71	20%
MORE THAN 20 MINUTES	46	13%

Table 4 - Response Times of Hach One pH Meter.

5.2.4 Sentron Portable pH Meter.

A further pH meter has been identified that works on a totally different principle to all the others tried so far. It does not make use of a glass electrode at all but employs an ISFET instead. The manufacturers of the meter are Sentron, an American Company and the instrument is sold in this country by Orme Scientific of Manchester; details of the meter are given in Appendix 12.4. The meter is currently on trial at the treatment works and results are shown in Appendix 12.5. As with the Hach pH meter, initial results were promising but during further testing the performance of the instrument deteriorated. The worst results are given on the final water samples which contain a free chlorine residual. The reason for this effect or for the general deterioration is not known.

5.3 Effect of Lime on the Distribution System.

When plumbosolvency was first identified as a problem in the late nineteenth century, the initial solution was to increase the pH of the water to such an extent that the lead no longer dissolved in significant quantities. Nowadays there are very few lead distribution mains or service pipes. However the final pH of the water is still adjusted to achieve relatively high values as a high number of communication pipes, which were installed prior to 1970 when the use of lead was discontinued, remain in use. The high pH level is also maintained as the type and rate of corrosion in the water mains under these conditions is fairly well known, but should the water quality be changed the corrosion also could be affected in an unpredictable and possibly expensive manner.

Another reason for adding lime to the final water is purported to be to supply calcium to reduce the degradation of the iron distribution mains. As the water passes through the distribution mains the calcium in the water is supposed to deposit on any exposed, iron surfaces and form an impervious layer that increases the pipes resistance to infestation and colonisation by micro-organisms and thus reduces pitting, corrosion and tuberculation. The ability of the main to take up calcium is termed the 'calcium demand'. There are remarkably few texts on this subject. Reference 13 gives an outline of the process but notes that only under very precise conditions does this particular reaction take place and that the hydrodynamics of the system often play a larger part in the process than the chemical constituents in the water.

5.3.1 Alternatives to Hydrated Lime.

The main alternative to hydrated lime is sodium hydroxide, which is more commonly referred to as caustic soda within the water industry. While this is perfectly adequate for pH control it cannot meet the 'calcium demand' of the system. Sodium hydroxide does not have any of the handling problems of lime but does have its own problems. It is more alkaline than lime slurry and so is more corrosive to equipment and potentially more harmful to personnel. Plants using caustic soda have corrosion problems in transfer and dosing pipes. In unfortunate cases this has led to operators being sprayed or splashed with caustic soda which can lead to permanent eye damage, burns and irritation of the skin and respiratory tract.

As caustic soda is a liquid rather than a slurry it reacts more quickly than lime and so can give a shorter process control time and thus better plant control. However, some concern is expressed over the strength of the particles generated, especially where the current lime aided floc is known to be very delicate.

Caustic soda is significantly more expensive than hydrated lime and the operational benefits do not outweigh the additional costs and risks.

5.4 Improvements in Lime Dosing Equipment.

Lime is widely used in the water industry for pH correction as it is relatively pure, comparatively cheap, relatively low risk and is thought to give benefits in the distribution system. For these reasons there is much resistance to the idea of changing to the use of sodium hydroxide as an alternative. With this in mind there are other measures which can be taken to improve the operational use of lime by limiting the build-up of deposited material or to move it to an area where it causes fewer problems and therefore incurs less expense.

Flushing of the dosing line with clean water every day helps to minimise the build up of scale as it removes any loose particles and carries them through the system.

The type of water used to create the slurry also has an impact on the deposition rate. A water that is very hard will quickly deposit the suspended lime on the pipe walls whereas a soft water will hold more lime for a longer time.

5.4.1 Pipework Design.

Sharp bends and constrictions in pipework cause a sudden pressure differential that promotes the deposition of scale. By designing the pipe lines so that large radius bends are employed, and pipes are of a continuous diameter throughout the system, and valves are only installed where essential, and all valves are full bore when open, the number of places that block repeatedly is kept to a minimum.

The pipe type also has an impact on scale deposition. Rigid pipes are more prone to scaling than semi-flexible pipes. The semi-flexible pipe pulses with the pump stroke minimising the pressure effects of moving the slurry and thus reducing the potential to deposit material on the pipe. Very flexible pipes are seldom used where high pressures are involved and consideration has to be taken of the corrosive nature of the lime, but there are some instances where very flexible pipes can be used beneficially. The best choice of pipe in this case is one that collapses flat when released of pressure. By this method the deposition is limited in two ways: i) the pipe wall pulses to reduce pressure effects, and ii) the pipe can be collapsed on a regular basis, e.g. daily, to loosen any scale that has been built up. Care has to be exercised in releasing the scale in this manner as if there are any small orifices further in the system they may become blocked. The actual material of construction may also have an impact on the deposition rate as it is believed that some plastics have a greater affinity for scaling than others.

5.4.2 Mixing and Storage.

The lime slurry is normally made up in a batch mixer by mixing the powder with water. It is then pumped to the point where it is needed. Alterations can be made to this simple design to improve the operation. If the fresh slurry is aged for approximately twenty minutes before it is pumped then the particles have a greater stability as a greater degree of hydration has occurred and they are thus less likely to deposit in the system. Also, if the ageing tank is only gently stirred any particles that are very heavy will collect in the base of the tank from where it is easier to remove the deposits.

5.4.3 Scale Elimination.

There are many products available on the market that are said to reduce or eliminate the amount of scale left by lime on the inside of pipes. This is a very real problem in the water industry where the dosing of the correct amount of lime to the treatment process is critical and the build up of lime on the inside of pipes causes considerable problems.

Scale elimination units generally operate using an electro-magnetic field to convert both the dissolved and suspended lime to a form that is less likely to adhere to the pipes and is more soluble in water. The precise mechanism for this process is not known, though some suggestions have been put forward for specific limited circumstances. The application of this type of technology is not always without problems and the factors influencing its effectiveness are not known, so its suitability to an application is normally on a trial and error basis. One model has been tried previously at Legacy WTW, namely a "Magnetron", which was unsuccessful. As part of this research project another model was tried from ETCetera Ltd. This worked by generating a radio field around the pipe and thus affecting the nature of the suspended lime. After the unit had been in place for six months a sample of pipe was cut. The visual appearance and the degree of coating inside the pipe had not been changed and so the unit was returned to the supplier.

5.5 Chapter Summary.

pH is adjusted in the water treatment process in the flash mixer and the final water using an hydrated lime slurry. Mixing and transporting the slurry can cause serious process problems as the slurry is prone to deposit throughout the mixing and dosing equipment. Deposition can be limited by applying several design methods, but this rarely eliminates the problem. Devices are available that claim to eliminate the scaling problem but none of those tried so far at Legacy WTW has been successful. There is currently no commercially suitable alternative to the use of lime.

The pH of water is generally thought to be a simple measurement to take but attempts to introduce a reliable, portable pH meter to the treatment works have failed. Extensive trials have been carried out on two very different hand-held pH meters but results were discouraging. Demonstrations of other pH meters have also failed to provide stable, accurate, repeatable, reliable readings. The reason for the observed poor behaviour of these instruments is not known.

6. RECOMMENDATIONS AND CONCLUSION.

6. RECOMMENDATIONS AND CONCLUSION.

6.1 Description of Legacy WTW at the End of the Project.

From the start of the project the performance of Legacy water treatment works has been continuously improved. The plant operation is now more flexible and more reliable, fewer alarms are generated and less overtime is spent there. The second saturator has given a new flexibility to the plant operation and this, in association with the installation of a new compressed air plant, has given far greater confidence in the reliability of the treatment process. Improvements in instrument performance have allowed tighter alarm parameters to be set, which incur fewer call-outs to false alarms. The installation of new rapid gravity filters using a granular activated carbon medium will give a greater security to the final water quality whilst enabling the treatment works to operate at its design output.

6.2 Recommendations.

The recommendations given aim to increase the efficiency and reliability of the water treatment works while bearing in mind the current pressures on the water industry to reduce expenditure. Some of the recommendations will give a payback in a very short time while others may take several years. However, they all will significantly improve the working conditions at the plant and allow greater control over the quality of water delivered to the customer.

6.2.1 Lime Plant Design.

The lime plant should be redesigned to take into account the ideas discussed in Section 5.4 to improve plant operation. Currently the very congested area in the mixing and metering area makes maintenance work on the pumps restricted and hazardous. The dosing equipment suffers damage from the dust laden air and pipe runs are often tortuous. The situation could be improved by leaving the lime silo in its current location but removing all the mixing and dosing equipment from its base. The dry powder could then be transferred by an archimedean screw feeder to a small hopper local to the mixing tank. The pumps could be laid out in an easily accessible fashion in a purpose-built mixing and dosing area in the base of the water tower. A similar installation exists already at Llwyn Onn treatment works.

6.2.2 Point of Application of Final pH Correction.

As discussed in Section 2.2.3 and Section 4.1.6 a high pH in the water greatly reduces the effectiveness of chlorine as a disinfectant. In order to overcome this the final lime dosing point could be moved to the outlet of the water tower, provided that satisfactory flow proportional control could be exercised. Historically at Legacy Water Treatment Works flow proportional control on the water tower outlet has been problematical due to widely varying flowrates, but with a consistent increased flow from the station and alterations of the distribution district boundaries to give a smaller variance in the flow, flow proportional control should be possible.

Moving the lime dosing point in this manner incurs another problem in that lime can take up to 20 minutes to be totally dissolved in the water. At Legacy WTW the first customer takes water from the distribution mains within several hundred yards of the treatment works at which point there would still be some particles of lime in the water. Some deposition of lime in the service reservoir has been noted and if the dosing point were moved that deposition would take place in the distribution mains instead.

Both these problems could be solved by the installation of a service reservoir that would then allow the water tower to become a true contact tank. Chlorine would be dosed prior to the contact tank and lime and sulphur dioxide after the contact tank but before the service reservoir.

6.2.3 Sludge Plant Operation.

The operation of the sludge thickening plant needs to be investigated. The basic operation is understood but detail is not known. The efficiency can be affected by many interferences but no knowledge is available in-Company on these. Problems currently encountered with the sludge blanket lifting can be due to bacteria or algae within the floc. The effect of some algae can be limited by careful administration of a precise dose of sodium hypochlorite. At the moment no analysis is made of the nature of the blanket but this should be investigated.

The operation of the sludge thickener generally should be improved by work undertaken by Biwater to provide a constant flow into the thickener as part of the filter contract. Greater security of the plant effluent is needed as non-consented discharges could damage aquatic life in the Pentrebychan Brook. The plant effluent has been diverted to incorporate the existing disused sludge settling lagoons into the effluent treatment plant. This will help to reduce the effect of a failure of the thickening plant on the stream but in itself is not enough. These beds are currently overloaded with sludge from previous use. They need overhauling and a regular maintenance programme to be set up. A series of submerged catchment walls are needed to partition the beds and keep the deposited sludge in primary areas, rather than spreading it throughout the entire bed. The initial cost of cleaning the beds will be very high but with improved operation of the sludge thickening plant and installation of partition walls the future operating costs should be much less.

A continuous monitor of the quality of the plant effluent would help to ensure that the plant met its performance requirements 100% of the time. Currently there is no continuous monitoring. The installation of a turbidity monitor would provide the necessary assurance both to Wrexham Water and to the National Rivers Authority that the discharge consent was not being infringed.

6.2.4 Flash Mixer Design.

The flash mixer itself employs a standard Rushton turbine impeller. Advances in technology have allowed impeller designs to be made that can give greater mixing and more efficient transfer of energy while employing the same motor. Consideration should be given to the use of these advanced designs to reduce the power requirements of the treatment plant.

6.2.5 Air Dispersion in Flotation Plant.

Whilst the dispersion plant is effective in its operation assessment should be made as to the efficiency of this unit. Inefficiencies are obviously experienced by this part of the water treatment process as large air bubbles, several centimetres in diameter, are frequently observed in the flotation tanks where the bubbles should be in the range 40 to 70 microns. (Ref. 5) These large bubbles disturb the floc blanket but are not thought to have a largely detrimental effect on the flotation process;

however it is a deficiency in the system. This is probably mainly due to design faults but some investigation into the problem and possible solutions are needed. Work could also be done on the actual bubble size encountered in the flotation process by use of an underwater camera as no checks are made that the bubble size is consistent or is the most effective for the process.

The quantity of water recycled to the saturator is recorded but no measurement is made of the amount of air used. The efficiency of the saturators could be measured if both these parameters were known. When the second saturator was installed the packed bed in the original vessel was found to be largely blocked by entrained material. Routine inspection and cleaning of the packed bed on a yearly basis should be instigated to ensure efficient operation.

6.2.6 Duplication of Essential Plant Items.

As Legacy WTW is Wrexham Water's second largest water treatment works providing 30% to 35% of the daily treated water demand, its operation has to be totally dependable. The treatment works is designed to allow the greatest flexibility and security in its operation. Most plant items are duplicated but several essential items are not.

The existing disinfection equipment is a very important piece of plant and yet there is only a single chlorinator at the site. There is no alternative continuous disinfectant dosing method available within the Company. All strategies rely on being able to repair any damaged parts in the chlorinator unit. A standby unit for this duty should be given high priority, with an operating back-up unit being preferable to a cold standby unit as detailed in Section 4.2.3.

Both the inlet and the second stage flash mixer are single duty items. The second stage flash mixer is seldom used and provided that the tank does not fail its operation is non-essential. The inlet flash mixer however is crucial to the correct operation of the entire treatment process. Again the tank itself is unlikely to fail but should the flash mixer motor drive fail the effects would be catastrophic. Currently the motor is regularly serviced to ensure it is kept in a state of good repair. A replacement unit should be held in stock against sudden and irreparable failure; however this would be expensive and maybe oversensitive to the event. As a compromise a strategy should be devised such that if the motor fails a replacement could be rapidly procured.

The coagulant is delivered to a single storage tank. Should anything happen to this tank a replacement would be very time consuming to procure and difficult to install. Installing a second tank is impractical at this stage due to constraints on available space. However an emergency action plan should be written out to cover this event.

At Legacy Water Treatment Works the dosing of polyelectrolyte is essential to the correct treatment of some of the raw water sources used. The polyelectrolyte is supplied as a powder and is mixed with water to create a liquid for dosing. The existing mixing, storage and dosing plant is a single duty item which supplies both the water treatment process and the sludge treatment process. There is no way of reliably cleaning or maintaining the unit while it is in service. Should a problem occur on this unit the entire treatment works would have to be shutdown. With this in mind a standby unit should be installed, or the unit should be replaced by one designed to allow maintenance while still in service.

6.2.7 Remote Chlorination.

The remote chlorination unit as described in Section 4.1.7 has given significant benefits to the system. The need for a method of remote chlorination is recognised by Wrexham Water but little progress has been made. A methodical application of the principle of remote chlorination needs to be undertaken in association with reviews of residual chlorine levels throughout the distribution system. Currently remote chlorination units are being targeted at known problem areas in the distribution system, which fail most often at the far reaches of the supply area. As steps are taken to improve the water quality at the beginning of the distribution system this will alter the requirements for the remote dosing units at the end of the system causing parts of the work to be undertaken more than once. This is a waste of both effort and resources, and a logically planned programme of action would eliminate this.

After the remote units have been installed the chlorine residual levels in the distribution system still need to be monitored as cleaning and flushing of the distribution mains will alter the chlorine demand of the distribution system, and may cause the water to have an excessive chlorine taste and odour.

6.2.8 Distribution System.

The existing distribution system needs to be rationalised without losing the necessary flexibility to cover emergencies and maintenance. Pumping mains should be purely for pumping water rather than being combined pumping and distribution mains. Consideration should be given to the effects of the industry's and customer's water needs within a supply area and the demands that this will put on the treatment works and the equipment therein. Where necessary a service reservoir should be provided in addition to a chlorine contact tank as this would alleviate some of the large variances that equipment in the treatment works has to deal with.

A regular scouring and flushing programme should be set up and adhered to as this significantly improves the quality of the distribution system without incurring high capital costs. This programme should be organised to progress through the distribution system, rather than targeting problem areas, to give the maximum overall benefit. When this has been completed the service reservoirs should then also be cleaned as some debris will accumulate there. This programme should be in addition to, not instead of, the existing distribution mains relining programme.

6.3 Improvements in Performance.

The performance of many aspects of Wrexham Water treatment works have been dramatically improved by the work undertaken as part of this project or work encouraged by the project. Improvements in the performance of instrumentation have increased confidence in readings, caused fewer problems in the treatment process due to faulty readings, caused fewer call-outs for Treatment and Technical Services staff, have allowed strategic and tactical decisions to be made from a better informed point of view and have allowed a better and more consistent water quality to be achieved. In addition to the performance improvements these operational improvements have given cost savings as detailed in Section 6.3.2.

6.3.1 Percentage Improvement in Performance.

Control of the treatment process has been improved and the number of telemetry alarms per month caused by genuine process faults has been reduced from a monthly average of 31 in 1992 to 22 in 1994, giving a 29% reduction. If site mains failures are extracted from this calculation a 32% increase in control can be demonstrated. Telemetry alarms in total have been reduced from 63 to 26 per month and the number of call-outs to the Treatment Department have been reduced by 43%. The performance of the instrumentation can be measured in a number of ways. Category B telemetry alarms have been cut from an average of 30 per month in 1992 to just 4 per month in 1994, an 87% reduction as shown in Figure 13. The improved performance of some of these instruments is shown in Appendices 8 and 9. The maintenance record sheets assessed over a six month period show a reduction in unplanned visits to instruments by the Technical Services Department of over 58%. The control bands for some chlorine residual instruments show a narrowing of parameters of up to 40%. The control bands for some pH instruments show a narrowing of parameters of up to 28%. These figures all show the documented effects of improvements so far. Further improvements are possible.

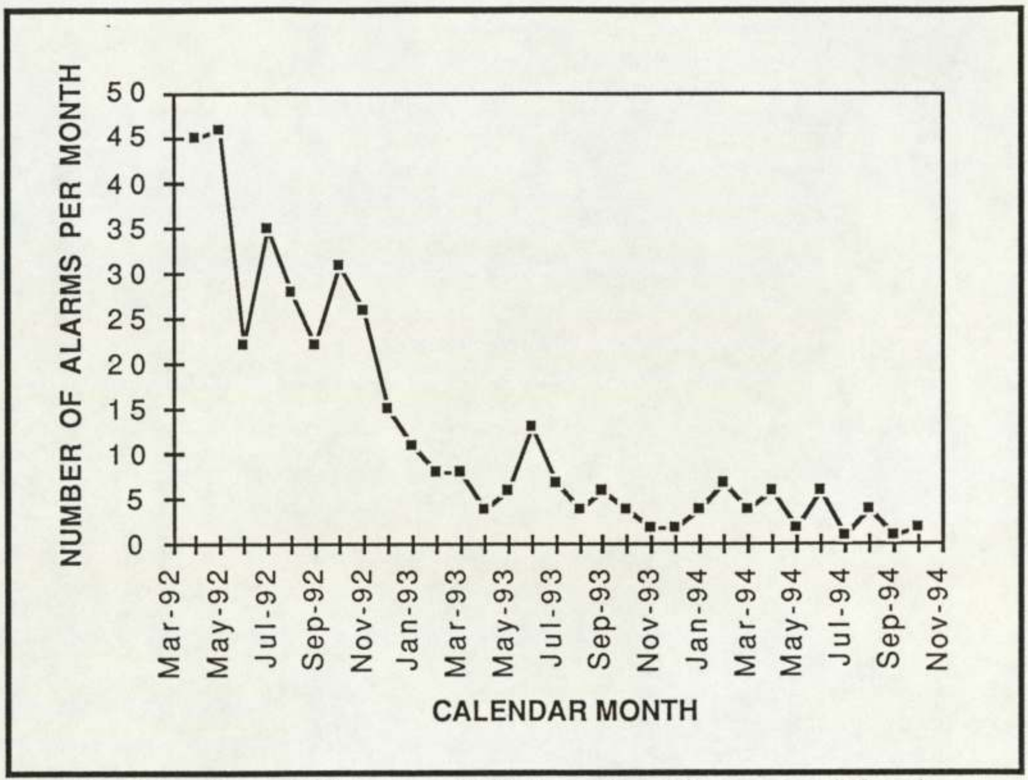

Figure 13 - Number of Category B Telemetry Alarms per Month.

6.3.2 Cost Savings.

In addition to these operational benefits there have also been considerable cost savings made as a direct consequence of improved instrumentation. Savings in overtime and call-outs in the Treatment and Technical Services departments so far amount to £27,200 per annum; this will increase as the review and analysis procedures put into place have further effect.

Changes in the treatment process itself have also given cost savings. Ceasing the use of lime at Llwyn Onn treatment works has given cost savings in the order of £44,950 per annum. Change in the use of alum to Ferral 2060 gives a 15% saving which translates to £12,300 per year.

Cost savings were also made in the procurement of the rapid gravity filter plant. Approaching the work from a chemical process engineering point of view rather than Wrexham Water's traditional civil engineering point of view, produced a tender that was £172,000 below its nearest rival; this tender occupied a significantly smaller area and allowed the existing chlorine dosing house to remain in place. Replacement of this facility would have incurred a capital cost of £130,000 and an additional running cost of £25,000 per annum.

6.4 Conclusion.

Despite the initial problems at the start of the project there have been substantial improvements in several areas. The performance of the instrumentation has been improved with an overall reduction in the number of problems of 87%. In addition to the cost savings associated with this change there are several operational benefits. Wrexham Water staff are no longer flooded with false alarms from faulty instruments and so they are more likely to respond rapidly and efficiently to any alarms that are generated. The operation of the treatment works is more constant as apparent fluctuations caused by instrument deficiencies have been greatly reduced.

Changing from an amperometric type cell to the colorimetric type residual chlorine meters has given a vast improvement in the reliability and accuracy of this measurement and has brought with it a much lower cost of ownership. Alarms, overtime and call-outs have all been reduced and thus the cost of maintenance and other ancillary services has been cut.

Despite several attempts to introduce a portable pH meter to the treatment works a reliable unit has not been identified. This has raised some questions over the operation of the existing in-line meters, as reason for the repeated failure of the portable meters is not known.

The introduction of a coagulant control system at Llwyn Onn WTW is the first automated dosing unit for this duty at Wrexham Water and its operation to date has been beneficial.

Specifying the requirements for the new filter plant at Legacy WTW involved people from many areas of the Company and caused thought to be put into the interaction of the various departments. The change from the normal method of procurement has provided an opportunity for all the people concerned with the plant operation to have an input into its design. This has involved a distinct change of philosophy within the Company.

The physical changes made to the plant, the addition of new technology and the improvement in instrument performance means that real problems are identified and quickly responded to so that the water quality leaving the treatment works is more consistent.

Many of the benefits of the work carried out under this research project are intangible and a monetary value is hard to place on them. However, the quantifiable cost savings amount to £109,450 per annum and one-off savings amount to £302,000.

7. NOMENCLATURE.

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m	metre
cm	centimetre
ml	millilitre
mg/l	milligrams per litre
μg/l	micrograms per litre
ng/l	nanograms per litre
g/m3	grams per cubic metre
μS	micro siemen
MLD	mega litres per day
mgd	million gallons per day
GAC	Granular Activated Carbon
DPD	diethyl-p-phenylene diamine
UPS	uninterruptible power supply
Co/Pt	Cobalt Platinum scale for colour measurement
NRA	National Rivers Authority
WRc	Water Research Centre
DWI	Drinking Water Inspectorate
WTW	Water Treatment Works
SPC	Statistical Process Control
ISFET	Ion Sensitive Field Effect Transistor

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More Basic Tools for Quality Improvement, R. Caulcutt, Process Engineering, v71, n3, pp 50 - 51, March 1990.

Can You Keep Your Customers Satisfied, R. Caulcutt, Process Engineering, v71, n4, pp 46 - 47, April 1990.

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Changes in Quality Under Scrutiny, R. Caulcutt, Process Engineering, v71, n6, pp 61 - 63, June 1990.

Setting Designs on Quality for Stronger Processes, R. Caulcutt, Process Engineering, v71, n8, pp 35 - 38, August 1990.

Using Statistics to Scale the Peaks of Quality, R. Caulcutt, Process Engineering, v71, n9, pp 49 - 52, September 1990.

9. APPENDICES.

Appendix 1 - Site Layout of Legacy Water Treatment Works.

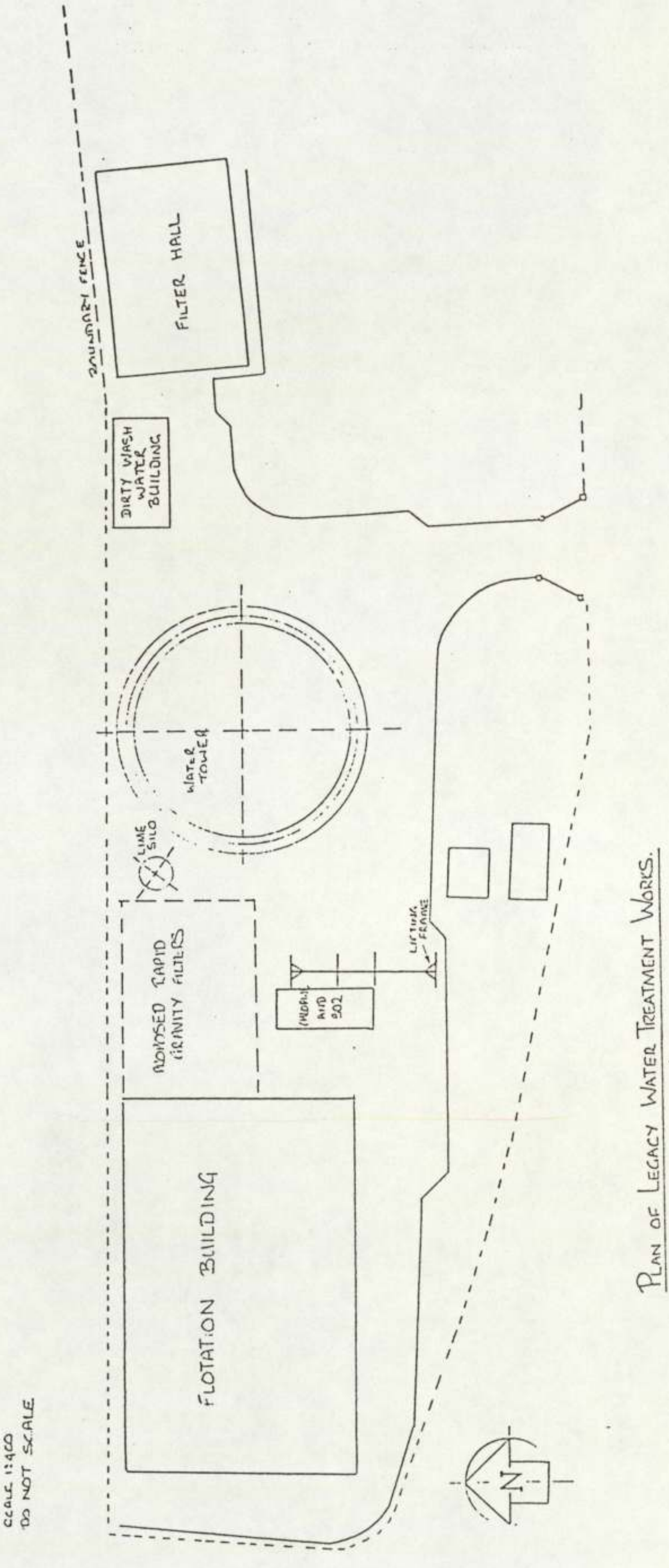


Figure 14 - Site Layout of Legacy Water Treatment Works.

Appendix 2 - Telemetry System.

2.1 List of Telemetry Parameters for Legacy WTW.

IDENTITY	NAME
E200	LEGACY TREAT WATER CL2
E201	LEGACY PRE RES CL2
E202	LEGACY TREAT WATER PH
E203	LEGACY FLASH MIXER PH
E204	LEGACY PDL WATER TURB
E205	LEGACY FILT WATER TURB
E206	LEGACY TREAT RES LEVEL
E207	LEGACY RAW WATER FLOW
E208	LEGACY TREAT WATER 18IN FLOW
E209	LEGACY TREAT WATER 12IN FLOW
E210	LEGACY PDL WATER FLOW
E211	LEGACY GRONWEN RES LVL
E212	LEGACY GRONWEN TRT WATER FLOW
E213	LEGACY GRONWEN BOOSTED FLOW
E251	LEGACY RAW WATER FLOW DAY
E252	LEGACY TW 18IN FLOW DAY
E253	LEGACY TW 12IN FLOW DAY
E254	LEGACY PDL FLOW DAY
E255	LEGACY GRONWEN TRT FLOW DAY
E256	LEGACY GRONWEN BST FLOW DAY
E288	LEGACY START TIME 1
E289	LEGACY STOP TIME 1
E290	LEGACY START TIME 2
E291	LEGACY STOP TIME 2
E292	LEGACY START TIME 3
E293	LEGACY STOP TIME 3
E294	LEGACY START TIME 4
E295	LEGACY STOP TIME 4
E296	LEGACY SRC RES START LVL
E297	LEGACY DST RES START LVL
E298	LEGACY DST RES STP LVL
E299	LEGACY DUTY PUMP
B200	LEGACY OS COMMS
B201	LEGACY OS MAIN
B202	LEGACY BATT LOW
B203	LEGACY SITE MAINS
B204	LEGACY ENG ON SITE
B205	LEGACY STATION MONITOR
B206	LEGACY INTRD DETECT
B207	LEGACY GEN 1 SR
B208	LEGACY GEN 1 NF
B209	LEGACY GEN 2 SR
B210	LEGACY GEN 2 NF
B211	LEGACY HL PMP 1 SR
B212	LEGACY HL PMP 1 NF
B213	LEGACY HL PMP 1 RL
B214	LEGACY HL PMP 2 SR
B215	LEGACY HL PMP 2 NF
B216	LEGACY HL PMP 2 RL
B217	LEGACY GAS LEAK
B218	LEGACY FILT WASH CON
B219	LEGACY FILT WASH FLT
B220	LEGACY FLOTATION FLT

B221	LEGACY GRONWEN MAINS
B222	LEGACY GRONWEN INTRD DETECT
B223	LEGACY GRONWEN COMMS FAIL
B224	FLOATATION OVERFLOW
B225	RAW WATER TURBIDITY
B226	PRE TRT WATER TURBIDITY
B267	LEGACY AUTO CNTRL FAIL
B268	LEGACY AUTO MANUAL
B269	LEGACY MANUAL CNTRL
B270	LEGACY AUTO CNTRL
B271	LEGACY BST PMP1 ON
B272	LEGACY BST PMP1 OFF
B273	LEGACY BST PMP2 ON
B274	LEGACY BST PMP2 OFF

2.2 Example of Schematic on Telemetry System.

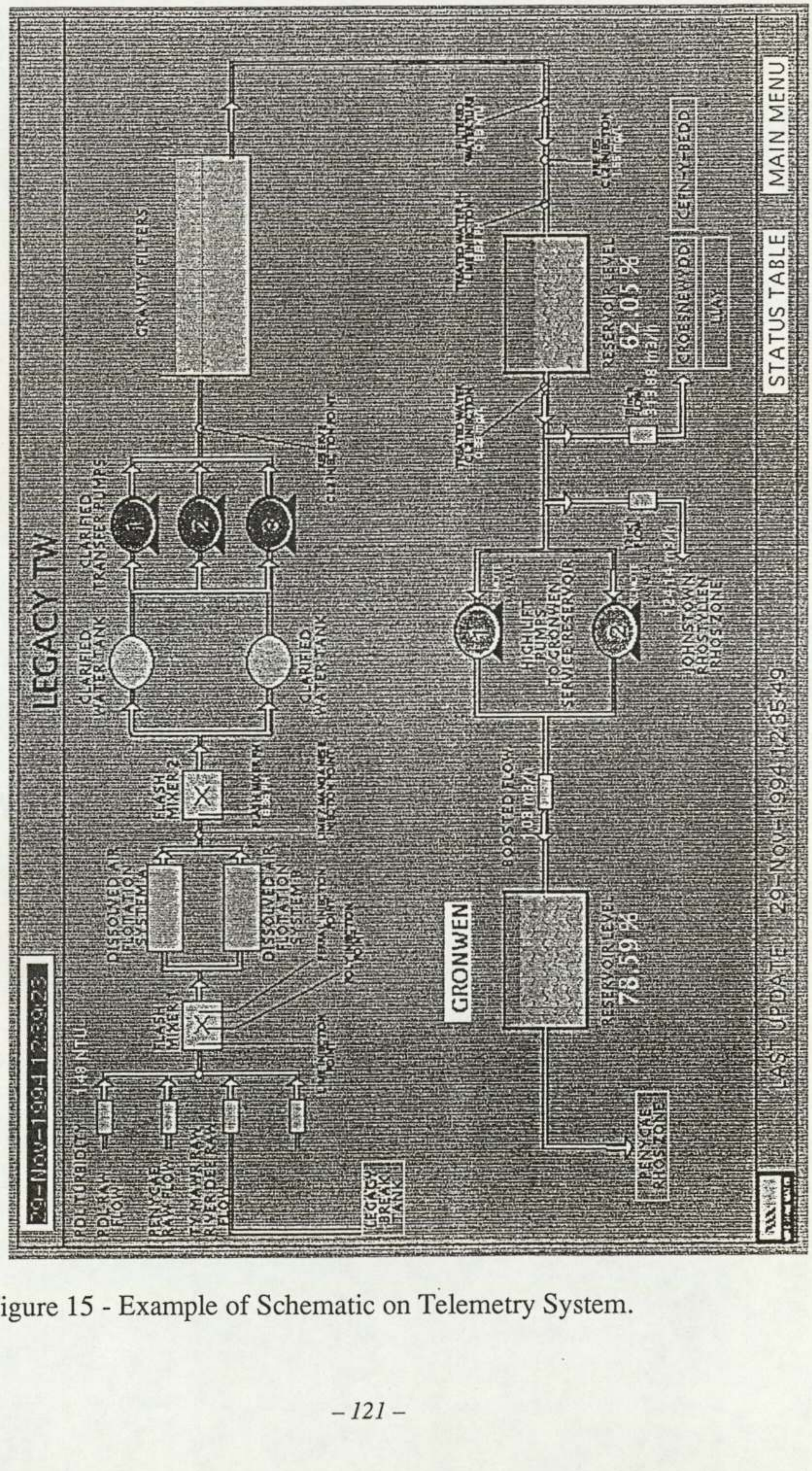


Figure 15 - Example of Schematic on Telemetry System.

2.3 Example of Graph on Telemetry System.

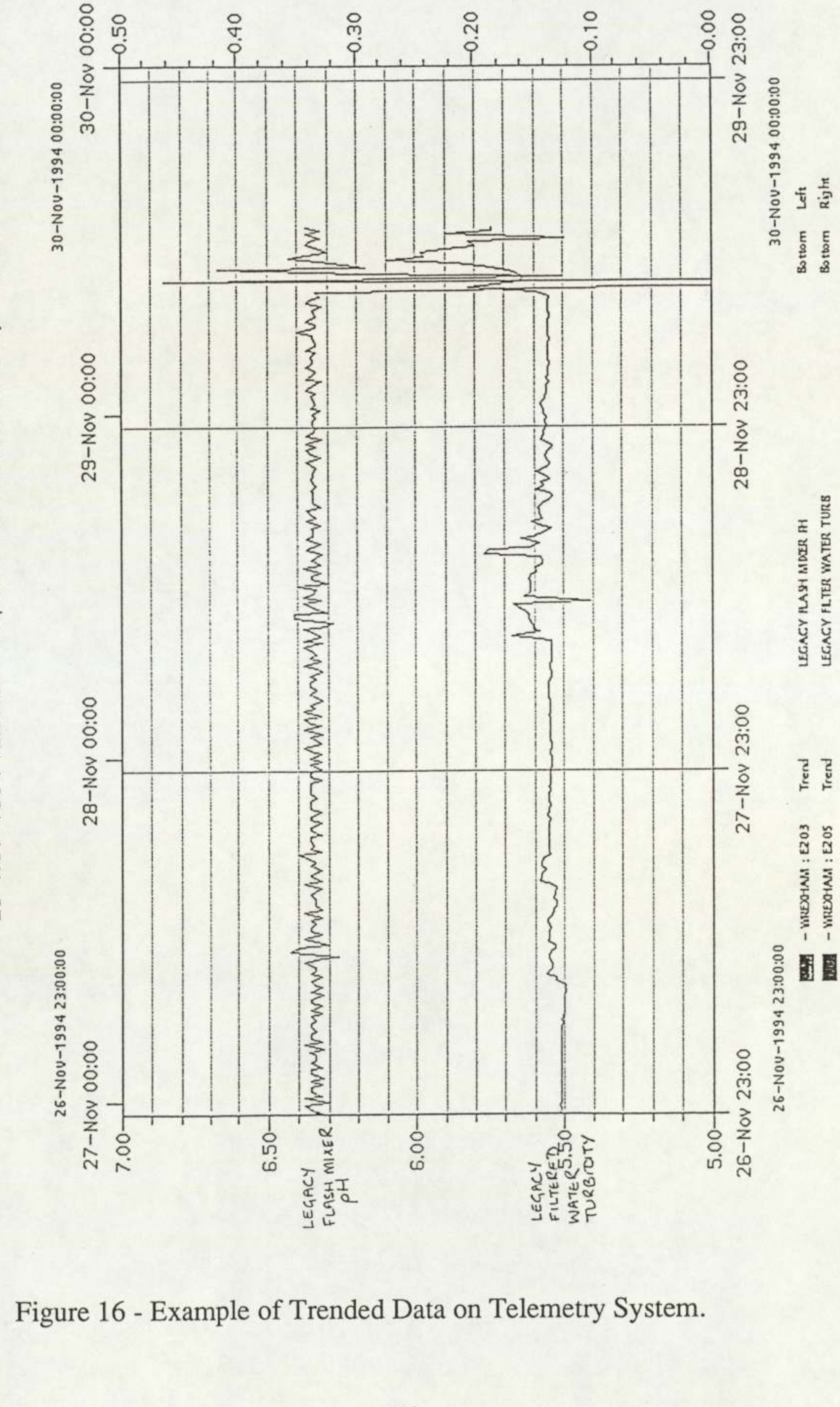


Figure 16 - Example of Trended Data on Telemetry System.

Appendix 3 - Data on Lasertrim Coagulant Control System.

CCS

LASERTRIM

COAGULATION CONTROL SYSTEM

INTRODUCTION

The treatment of Water and Effluent with Coagulant and Flocculant Chemicals such as, Aluminium Sulphate, Ferric-based products, PAC and Polyelectrolytes, can be monitored and controlled by utilisation of the CCS.

The old method of manual control was by means of off-line laboratory tests which can be valid for point-in-time reference, however, operating conditions can change (within a very short interval) to such an extent as to invalidate the laboratory results.

The CCS has been designed to meet the requirements of the Water Industry in terms of fine tuning chemical additions, whilst maintaining finished water quality within EC compliance levels.

Effluent Treatment, both Domestic Sewage and Industrial Processes, can also benefit by utilising the CCS for control of Polyelectrolytes.

Operational changes in plant conditions are also compensated for in terms of:–

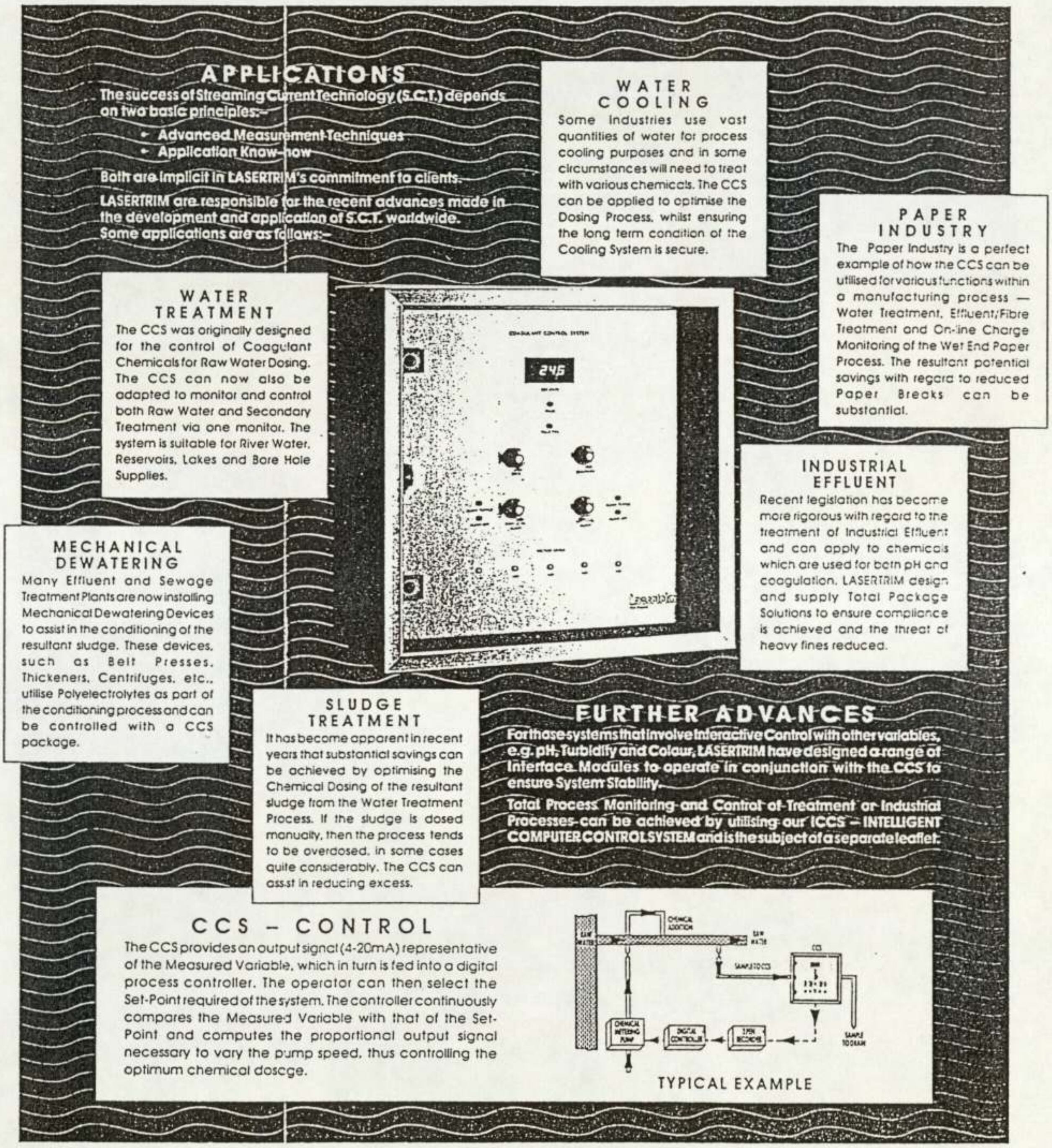
- **Variable flow rates**
- **Quantity and type of suspended solids**
- **Concentration of chemicals dosed**

MEASUREMENT PRINCIPLE

The CCS Measurement Cell is a continuous device and utilises an advanced method of monitoring the difference in the electrical charge generated between the mobile and stationary liquid phase of the treated fluid being measured. The resultant charge is relative to the chemical dosing process and provides an output suitable for control.

FEATURES

- **Superior Application of streaming current technology**
- **Improved water & waste quality**
- **Accurate and repeatable monitoring**
- **Automatic control of coagulation**
- **Chemical Optimisation**
- **Reduction in Chemical costs**
- **EC Compliance**
- **Alarm monitoring**
- **Ease of installation**
- **Return on investment**



APPLICATIONS

The success of Streaming Current Technology (S.C.T.) depends on two basic principles:–

- Advanced Measurement Techniques
- Application Know–how

Both are implicit in LASERTRIM's commitment to clients.

LASERTRIM are responsible for the recent advances made in the development and application of S.C.T. worldwide. Some applications are as follows:–

WATER TREATMENT

The CCS was originally designed for the control of Coagulant Chemicals for Raw Water Dosing. The CCS can now also be adapted to monitor and control both Raw Water and Secondary Treatment via one monitor. The system is suitable for River Water, Reservoirs, Lakes and Bore Hole Supplies.

MECHANICAL DEWATERING

Many Effluent and Sewage Treatment Plants are now installing Mechanical Dewatering Devices to assist in the conditioning of the resultant sludge. These devices, such as Belt Presses, Thickeners, Centrifuges, etc., utilise Polyelectrolytes as part of the conditioning process and can be controlled with a CCS package.

SLUDGE TREATMENT

It has become apparent in recent years that substantial savings can be achieved by optimising the Chemical Dosing of the resultant sludge from the Water Treatment Process. If the sludge is dosed manually, then the process tends to be overdosed, in some cases quite considerably. The CCS can assist in reducing excess.

WATER COOLING

Some Industries use vast quantities of water for process cooling purposes and in some circumstances will need to treat with various chemicals. The CCS can be applied to optimise the Dosing Process, whilst ensuring the long term condition of the Cooling System is secure.

PAPER INDUSTRY

The Paper Industry is a perfect example of how the CCS can be utilised for various functions within a manufacturing process — Water Treatment, Effluent/Fibre Treatment and On-line Charge Monitoring of the Wet End Paper Process. The resultant potential savings with regard to reduced Paper Breaks can be substantial.

INDUSTRIAL EFFLUENT

Recent legislation has become more rigorous with regard to the treatment of Industrial Effluent and can apply to chemicals which are used for both pH and coagulation. LASERTRIM design and supply Total Package Solutions to ensure compliance is achieved and the threat of heavy fines reduced.

FURTHER ADVANCES

For those systems that involve Interactive Control with other variables, e.g. pH, Turbidity and Colour, LASERTRIM have designed a range of Interface Modules to operate in conjunction with the CCS to ensure System Stability.

Total Process Monitoring and Control of Treatment or Industrial Processes can be achieved by utilising our ICCS – INTELLIGENT COMPUTER CONTROL SYSTEM and is the subject of a separate leaflet.

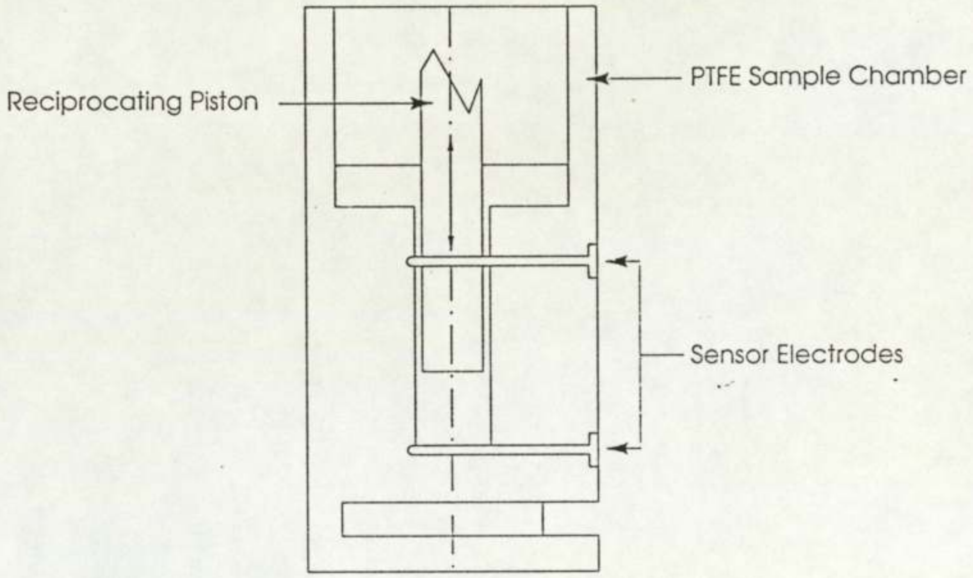
CCS – CONTROL

The CCS provides an output signal (4-20mA) representative of the Measured Variable, which in turn is fed into a digital process controller. The operator can then select the Set-Point required of the system. The controller continuously compares the Measured Variable with that of the Set-Point and computes the proportional output signal necessary to vary the pump speed, thus controlling the optimum chemical dosage.

TYPICAL EXAMPLE

PRINCIPLE OF OPERATION

The **SCT-004** operates on the principle of Streaming Potential and, by utilising Van Der Waals forces, high molecular charge carriers are preferentially absorbed onto the piston and cylinder surfaces. The flow produced by the reciprocating piston (between the two surfaces) results in the counter-ions being sheared off the particle on test and consequently a Streaming Potential is induced. Two electrodes within the unit measure the potential which is in turn conditioned and linearised within the electronic module to provide a digital display.



CONSTRUCTION OF SENSING CHAMBER

The SCT-004 features:

- L.C.D.
- Manual Operation
- Millivolt Output (up to 200mv)
- LED Status Indication - Cationic - Anionic
- Mains Supply - 110/220/240V 50/60Hz
- Portable, Stable Enclosure housing all the component parts

For further details of Lasertrim continuous on-line CCS monitors contact:

Lasertrim Ltd

Unit 1, Argyle Street Industrial Estate, Hull. HU3 IHD
Telephone: (0482) 215335 Fax: (O482) 216524

Appendix 4 - Details of Conjunctive Use Scheme.

WREXHAM WATER COMPANY CONJUNCTIVE USE SCHEME

Feasibility Study

1 INTRODUCTION

1.1 Brief History

One of the principal sources of the water supplied by the Wrexham and East Denbighshire Water Company is the River Dee. Water is pumped from an intake near Bangor on Dee (Sesswick Pumping Station) to Marchwiel Reservoir, which commands the Llwyn Onn Water Treatment Works, southeast of Wrexham, by gravity.

The original river intake, pumping station, rising main and treatment works at Llwyn Onn were built by the Ministry of Supply in 1940, to feed the then munitions factory on the present site of Wrexham Industrial Estate. These works were acquired in 1979 by the Wrexham and East Denbighshire Water Company, who then proceeded with increasing the output of the treatment works and the construction of the 140 000m^3 Marchwiel Reservoir.

Further increase in the security of supply was contemplated at that time by interconnecting Marchwiel and Ty Mawr reservoirs and the Legacy Water Treatment Works, south west of Wrexham. A location plan is included as Figure 1.1. Some initial steps in the implementation of this scheme were taken in 1980 and 1981 including the acquisition of pipeline easements on land between Legacy and Packsaddle, and further enquiries were made concerning land east of Packsaddle during 1989.

In May and early June 1991, discussions were held with Sir William Halcrow & Partners Ltd (Halcrow) which resulted in their appointment as consulting engineers for the Scheme.

1.2 Purpose of Scheme

The primary object of the Scheme is to increase the security of supply to users in the Wrexham area by

(i) allowing River Dee water stored at Marchwiel Reservoir to be pumped to Legacy Filter Station for treatment and distribution to consumers.

(ii) increasing the quantity of water available from Ty Mawr Reservoir to Legacy Filter Station.

(iii) allowing upland water stored at Ty Mawr Reservoir to gravitate to Marchwiel Reservoir, for treatment at Llwyn Onn and distribution to consumers, at times of surplus at Ty Mawr and during periods of pollution of the River Dee.

Water will be pumped from Marchwiel Reservoir to Legacy particularly during the summer months when inflow to Ty Mawr Reservoir may be restricted because of drought and when spare capacity at Legacy Water Treatment Works can be utilised.

In winter, when there is likely to be high run-off from the upland areas feeding Ty Mawr Reservoir, pumping costs at the River Dee intake can be reduced by transferring water from the Ty Mawr catchment to Marchwiel Reservoir. Similarly water can be transferred from Ty Mawr Reservoir should the River Dee source be polluted.

1.3 Description of Scheme

The Conjunctive Use Scheme will comprise a pipeline approximately 1.8km long between Ty Mawr Reservoir, top water level 244m above Ordnance Datum (AOD) and Legacy Water Treatment Works, inlet level 147.33m AOD, and a pipeline approximately 5.9km long between Legacy and Marchwiel Reservoir, top water level 84m AOD. The diameter of both pipelines will be 400mm. The two pipelines together are generally referred to as the Ty Mawr to Marchwiel Trunk Raw Water Main.

A pumping station will be built at Marchwiel Reservoir to be fed from an existing 400mm diameter offtake on the reservoir outlet. Water will be pumped at a maximum rate of 7.0million litres per day (Mld) to a new elevated tank at Legacy which will be connected directly to the treatment works.

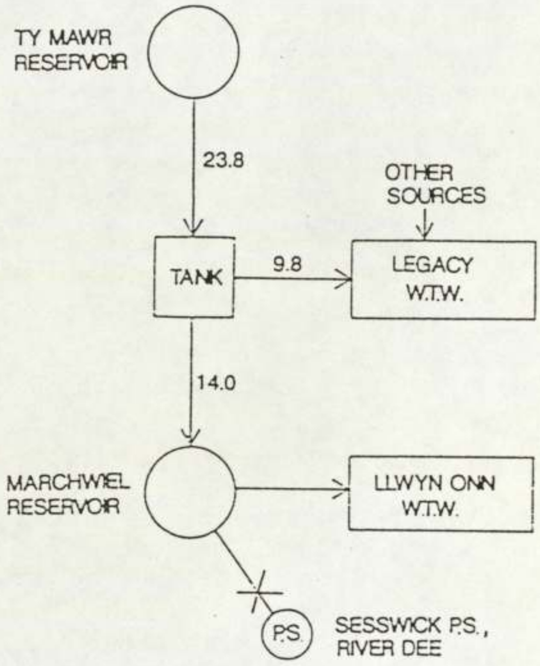
The purpose of the elevated tank is firstly to act as a break pressure tank preventing the full hydrostatic head at Ty Mawr Reservoir from being transferred to the installation at Marchwiel. Secondly, the tank will simplify control arrangements for the Scheme, being separate from the inlet tank in the Legacy Filter Station, which is served by three other sources in the Wrexham area. Thirdly, the tank will provide a balancing function while steady conditions on start-up and close-down are attained.

Water from Ty Mawr Reservoir will flow into the elevated tank at a rate of 2.8 Mld while pumping from Marchwiel Reservoir is in progress, and at a maximum rate of 23.8 Mld when supply from the River Dee is closed down. In this latter case, 14.0 Mld will be transferred to Marchwiel Reservoir. In both situations, therefore, the supply to Legacy Water Treatment Works from the Scheme will be 9.8 Mld. This arrangement is shown schematically in Figure 1.2.

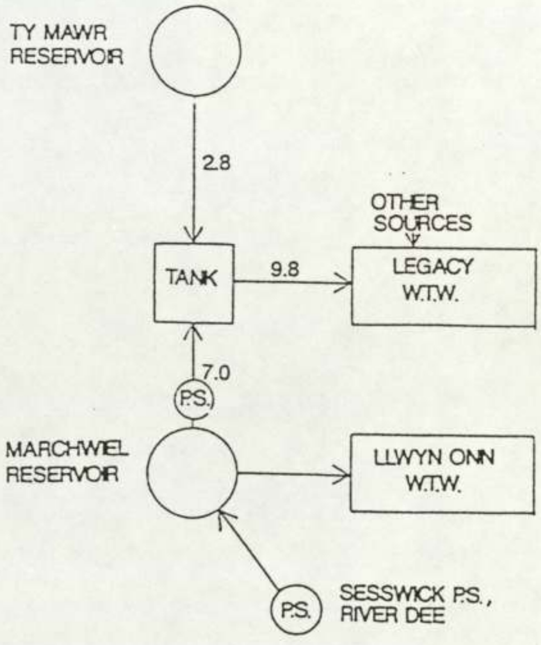
It is planned to provide a 200mm dia branch off the Trunk Raw Water Main, approximately 300m long, at the National Trust property at Erddig Hall for firefighting purposes.

SCHEMATIC ARRANGEMENT

1. POLLUTION SHUT-DOWN CASE



2. NORMAL PUMPING CASE



Notes:
Flows in Ml/d
WTW = Water Treatment Works
P.S. = Pumping Station

Figure 17 - Schematic of Conjunctive Use Scheme.

Appendix 5 - Detailed Filter Design.

Filtromatic Continuous Flow Filter

Installed on numerous sites throughout the world, the Filtromatic Continuous Flow Filter is an automatic labour saving unit which can also provide substantial savings in capital, running and maintenance costs, together with reduction in space requirements. It is eminently suitable for use in a variety of applications in water, sewage (tertiary) and industrial effluent treatment.

The Filtromatic Continuous-Flow Filter is a low-head, multi-compartment, valveless, gravity filter. It can remove suspended solids, objectionable tastes and odours, organic matter, colour or high chlorine residuals from industrial and municipal water and waste waters. The filter represents a revolutionary advance in media cleaning technology. Major advantages over conventional backwash filters include:

Continuous-Flow Design. The Continuous-Flow design means the filter is never out of service, even during backwash. Since only one cell of the filter is backwashed at a time, all other cells continue to filter water. This means at least 90 per cent of the filter is still in service during backwash obviating the need for standby filter capacity.

Backwash Indexing. With the Filtromatic Filter, the backwash mechanism indexes over each cell individually, seals off the cell and backwashes it. The significant advantage realised by indexing over the individual cells is the fact that all of the media in a given cell is thoroughly backwashed at the full rate for the full duration of the pump operation.

Vacuum Backwash. This design provides "vacuum cleaner" action at the top of the bed ensuring uniform backwash of the filter.

Multi-Compartment Design. Much lower instantaneous backwash rates are obtained with the multi-compartment design. This allows re-cycle of dirty backwash waters, where practical, without the need for intermediate holding tanks. It also eliminates the need for large washwater tanks to provide huge volumes of backwash water.

Valveless Design. There are no intake or filtrate valves required for the operation of the filter. No shut-off valves are required for the filter backwash.

Low-Head Loss. The Filtromatic Filter can be designed to operate on a pressure differential as low as 300mm.

Visible Operation. The top of the filter bed is visible during filtration. Therefore, visual inspection of the media is possible without filter shutdown.

Modular Design. The filter design permits shipment of relatively large, totally assembled, pre-packaged filters. This means less site labour and less installation time.

FILTER CONSTRUCTION

The filter is available either as a site constructed unit or, in the case of smaller applications, as a packaged unit. Site constructed units include the bridge and drive, cells, backwash hood and pump, controls and accessories necessary for operation. These site constructed units normally contain 10 to 50 cells, each of which may filter up to 50m³/h, depending on the chosen design and maximum filtering rates.

The packaged units, which include filter tank, cells, bridge, controls, backwash hood and pump are available with filtering areas from 12.5m² to 25m².

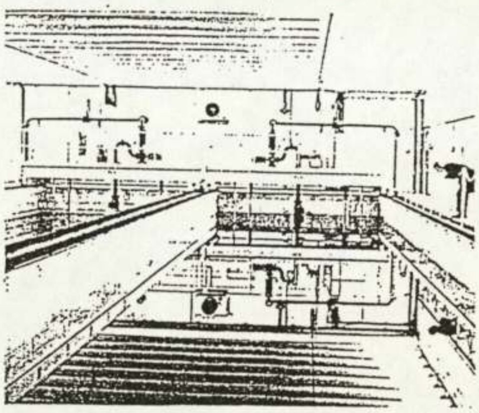
CELL CONSTRUCTION

The site constructed Filtromatic Filter can be designed with either pre-stressed concrete or fabricated steel filter cells. The cells may be shipped as complete units, ready for installation in the filter tank. Since the cells are self-supporting over their entire width, installation is reduced to simply setting the cells on supporting ledges built into the tank wall and grouting them in place.

Cell floors are smooth and uniform and are fitted with polypropylene nozzles. The nozzles are of a non-clog design and offer uniform distribution for filtering and backwashing.

The Filtromatic Filter is available with various filtering media or combinations of media, depending on the application.

Typical media and combinations of media available are sand, anthracite, activated carbon, anthracite/sand and carbon/sand. Filter media depths are tailored to the application and typically range from 450 to 600mm. For suspended solids removal applications, media selection is normally sand or a combination of anthracite and sand. For taste and odour problems, removal of organic matter and chlorine residuals, the normal media choice would be activated carbon. Deeper beds are usually required when carbon is used.



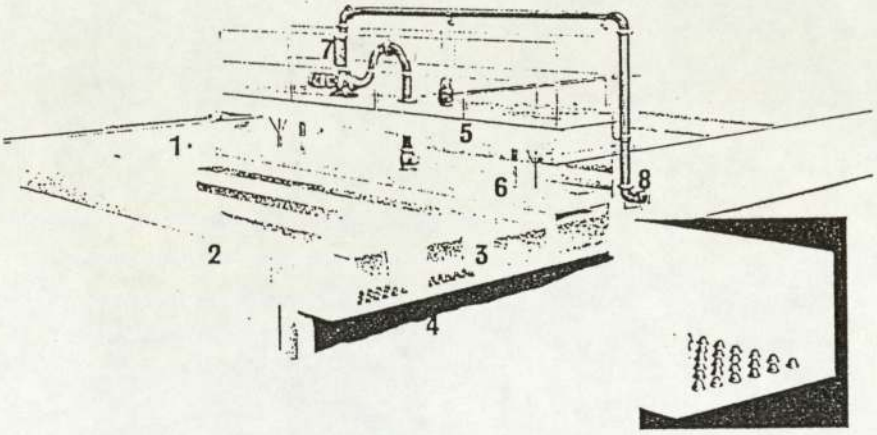
Biwater

CONTROL SYSTEM

All the automatic controls are equipped with manual overrides should manual operation be desired.

In the unlikely event that some part of the system malfunctions, safety interlocks are provided to stop operation and sound an alarm. All controls, limit switches, timers and sensors required for operation of the filter are furnished with the unit.

The Filtromatic Filter is a fully automatic unit requiring minimum operator attention. The backwash cycle of the filter is controlled by an adjustable differential level control which senses the head loss across the filter. The backwash time of the individual cells may be varied by means of an adjustable timer.



OPERATION

Raw water normally enters the unit through ports (1) in the sidewall of the filter, but the inflow can also be at the head of the filter basin.

All filter cells are immersed under the common minimum water-level which corresponds with the clean water overflow weir (2). The filter cells (3) are prefabricated or concrete elements in which the filter medium resides.

There is a clean water chamber under the cell floors (4), common to all the filter cells, connecting with the filtered water overflow weir at the end of the tank.

A travelling bridge (5) spans the width of the filter. This bridge carries beneath it the backwash hood (6), which can be raised or lowered, and has the same surface area as a single filter cell.

A suction pump (7) is connected to the interior of the hood and a discharge pipe carries the backwash water to a trough (8) along the length of the filter.

This trough delivers to the backwash water tank or, where appropriate, back to the plant inlet.

The bridge, when not in action, stands over the first filter cell with raised hood, which remains under the minimum water level.

When the head loss of the filter reaches the predetermined difference between the water level in the filter and the water level at the outlet weir, a liquid level control signals the start of a cleaning cycle.

The hood is lowered and closes tightly over the first filter cell. The pump starts, draws water from the top of the filter and expels it into the backwash water trough. Filtered water is pumped from the clean water chamber, through the nozzles and the filter.

The filter medium expands, the solids are released into suspension and pumped from the cell. Wash water is available continuously from under all the other filter cells in service.

The backwash duration depends on the type and amount of suspended solids retained by the filter. In general, backwashing occurs with an increase of head of 300 to 500mm, and takes one to two minutes to clean the filter cell thoroughly. Both the differential head which starts the backwash cycle, and the duration of the backwash settings, are adjustable to meet individual applications.

When the backwash cycle of a cell is complete, the pump stops, the hood is raised and the cleaned cell immediately begins to filter water again. The travelling bridge then automatically moves to the next filter cell and stops above it. The same sequence of operation then takes place and is repeated automatically until all filter cells have been cleaned. After the last filter cell has been washed, the travelling bridge returns to a point above the first cell where it remains awaiting the next signal from the level control, which starts another cycle. Alternatively, after backwashing the last cell, the bridge may remain parked there.

Biwater

Biwater Treatment
Biwater Place, Gregge Street, Heywood, Lancashire OL10 2DX England
Telephone: (0706) 367555 Telex 63410 BWATER G Facsimile (0706) 365598

A Division of Biwater Europe Limited

BTL 01/90 8

Appendix 6 - Instrument Audit Data.

6.1 Data from Initial Instrument Audit 1, Telemetry Data.

DATA FROM 7/10/92 TO 31/12/92. COLLECTED FROM RECORD OF TELEMETRY ALARM SHEETS (WW64), SEE APPENDIX 7.1.

	Llwyn Onn	Berwyn	Nant-y-Ffrith	Penycae	Pendinas	Legacy	Oerog	New Hall	TOTAL
Cl_2 needs Calibrating	7	6	3	4	7	0	1	0	**28**
Cl_2 needs mending	1	7	0	0	0	0	0	1	**9**
Turbidity meter needs cleaning	0	1	0	0	0	2	0	0	**3**
pH not controlling	1	0	0	0	1	0	0	0	**2**
pH needs recalibration	2	1	1	0	1	1	0	0	**6**
Filter Program "stuck"	0	0	0	0	0	1	0	0	**1**
TOTAL	**11**	**15**	**4**	**4**	**9**	**4**	**1**	**1**	49

Table 5 - Initial Instrument Audit Based on Category B Telemetry Alarms.

It should be noted that these figures are based on the Record of Telemetry Alarms sheet and that the term 'recalibration' in this case may be being used incorrectly.

6.2 Data from Instrument Audit 2, Maintenance Data.

DATA FROM 3/7/92 TO 17/1/93. COLLECTED FROM TECHNICAL SERVICES DEPARTMENT MAINTENANCE RECORD SHEETS (WW80), SEE APPENDIX 7.3.

Total number of Recalls -		290	
Of which	Reset -	141	(49%)
	Buffer tubes -	17	(6%)

WTW		TOTAL	PRE RES Cl_2	FINAL Cl_2	FLASH pH	FINAL pH
Llwyn Onn	Recalls	**54**	19	29	6	0
(19%)	Resets	**24**	7	16	1	0
	Buffer Tubes	**6**	4	2	-	-
Legacy	Recalls	**44**	12	24	7	1
(15%)	Resets	**21**	7	11	3	0
	Buffer Tubes	**1**	0	1	-	-
Nant-y-Ffrith	Recalls	**25**		23	2	0
(9%)	Resets	**17**		16	1	0
	Buffer Tubes	**-**		-	-	-
Berwyn	Recalls	**89**	56	23	7	3
(30%)	Resets	**37**	26	10	1	0
	Buffer Tubes	**8**	5	3	-	-
Pendinas	Recalls	**47**		37	5	5
(16%)	Resets	**20**		19	3	0
	Buffer Tubes	**2**		2	-	-
New Hall	Recalls	**17**		17		
(6%)	Resets	**11**		11		
	Buffer Tubes	**0**		0		
Oerog	Recalls	**14**		14		
(5%)	Resets	**9**		9		
	Buffer Tubes	**0**		0		
All	Recalls	**290**	87	167	27	9
	Resets	**141**	40	92	9	0
	Buffer Tubes	**17**	9	8	-	-

Table 6 - Second Instrument Audit Based on Maintenance Record Sheets.

6.3 Data from Instrument Audit 3, Maintenance Data.

DATA FROM 1/5/94 TO 31/10/94. COLLECTED FROM TECHNICAL SERVICES DEPARTMENT MAINTENANCE RECORD SHEETS (WW80), SEE APPENDIX 7.3.

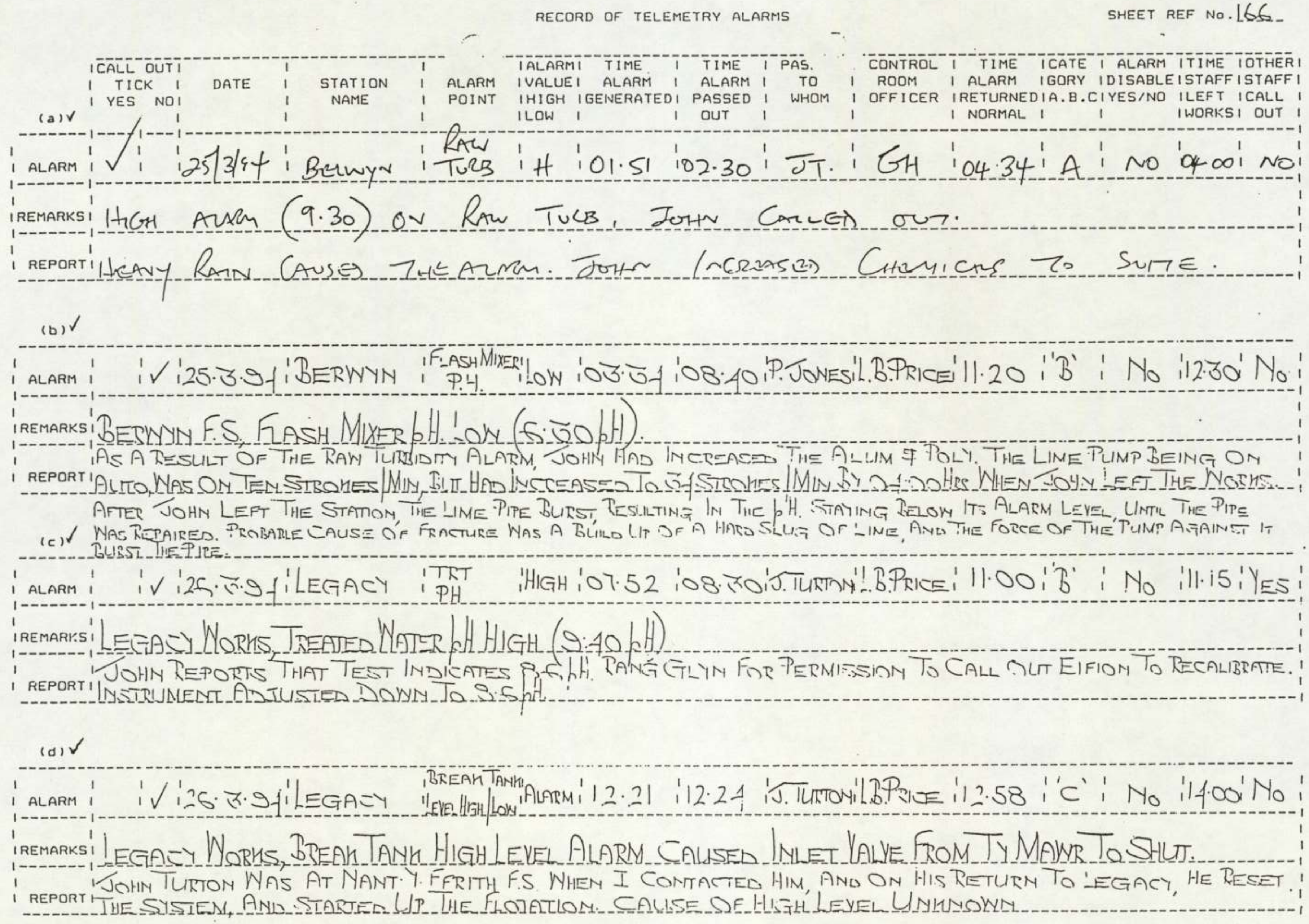
Total number of Recalls -		122	
Of which	Reset -	67	(55%)
	Buffer tubes -	11	(9%)
	Power -	24	(20%)

WTW		TOTAL	PRE RES Cl_2	FINAL Cl_2	FLASH pH	FINAL pH
Llwyn Onn	Recalls	**11**	3	7	1	0
(9%)	Resets	**5**	0	4	1	0
	Buffer Tubes	**1**	-	1	-	-
	Power	**2**	2	-	-	-
Legacy	Recalls	**43**	20	23	0	0
(35%)	Resets	**37**	17	20	0	0
	Buffer Tubes	**3**	1	2	-	-
	Power	**1**	1	-	-	-
Nant-y-Ffrith	Recalls	**10**		10	0	0
(9%)	Resets	**0**		0	0	0
	Buffer Tubes	**-**		-	-	-
	Power	**7**		7	-	-
Berwyn	Recalls	**35**	15	18	2	0
(28%)	Resets	**13**	0	11	2	0
	Buffer Tubes	**4**	-	4	-	-
	Power	**9**	9	-	-	-
Pendinas	Recalls	**12**		7	5	0
(10%)	Resets	**5**		0	5	0
	Buffer Tubes	**-**		-	-	-
	Power	**5**		5	-	-
New Hall	Recalls	**0**	0			
(0%)	Resets	**0**	0			
	Buffer Tubes	**0**	0			
	Power	**-**	-			
Oerog	Recalls	**11**	11			
(9%)	Resets	**7**	7			
	Buffer Tubes	**3**	3			
	Power	**-**	-			
All	Recalls	**122**	38	76	8	0
	Resets	**67**	17	42	8	0
	Buffer Tubes	**11**			-	-
	Power	**24**			-	-

Table 7 - Third Instrument Audit Based on Maintenance Record Sheets.

Appendix 7 - Record Sheets.

7.1 Example of Telemetry Alarm Record Sheet.

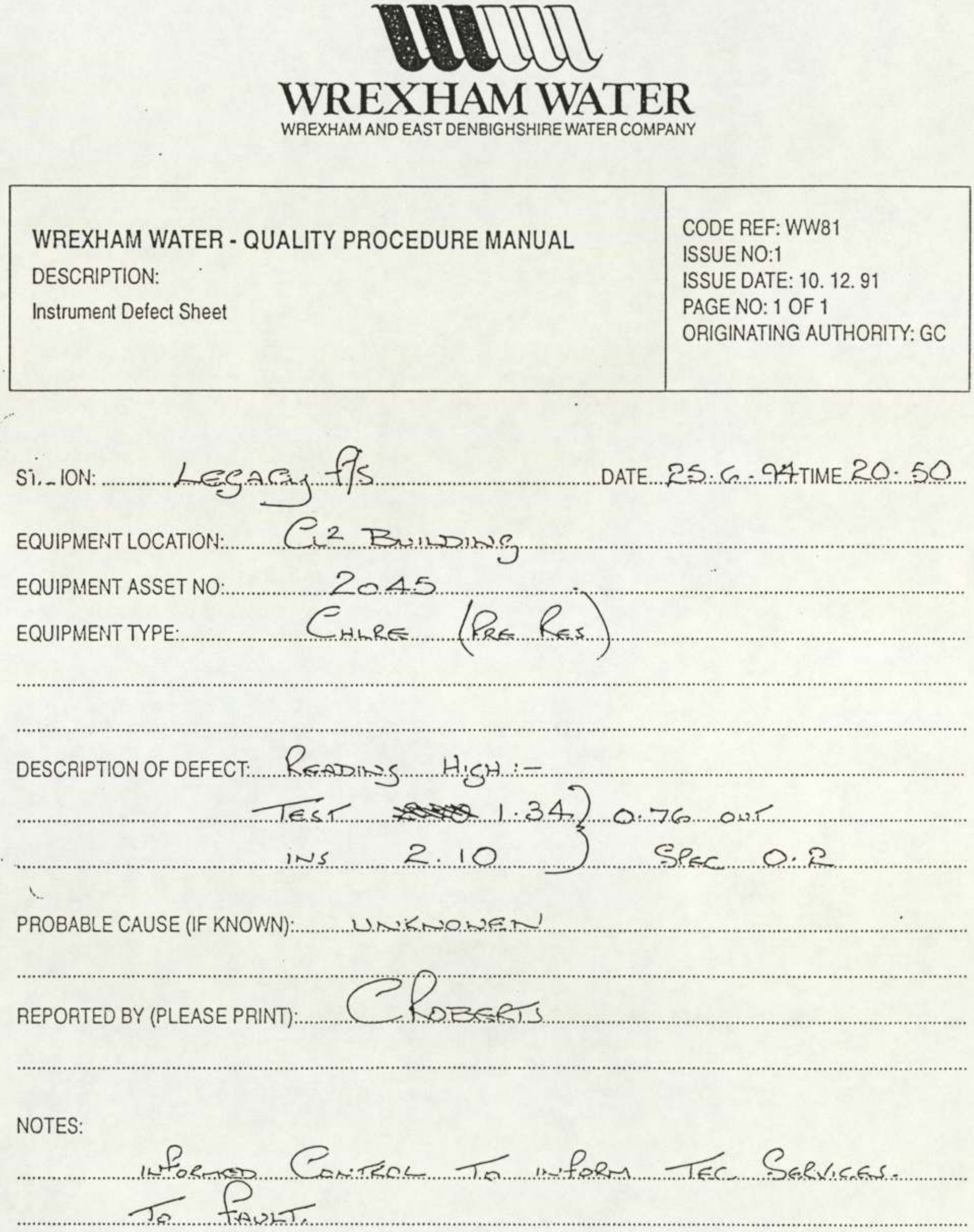


RECORD OF TELEMETRY ALARMS

SHEET REF No. 166

	CALL OUT TICK YES	CALL OUT TICK NO	DATE	STATION NAME	ALARM POINT	ALARM VALUE HIGH LOW	TIME ALARM GENERATED	TIME ALARM PASSED OUT	PAS. TO WHOM	CONTROL ROOM OFFICER	TIME ALARM RETURNED NORMAL	CATEGORY A.B.C	ALARM DISABLE YES/NO	TIME STAFF LEFT WORKS	OTHER STAFF CALL OUT
(a)✓															
ALARM	✓		25/3/94	Berwyn	Raw Turb	H	01·51	02·30	JT.	GH	04·34	A	NO	04·00	NO
REMARKS	High Alarm (9·30) on Raw Turb, John Called out.														
REPORT	Heavy Rain Caused The Alarm. John Increased Chemicals To Suite.														
(b)✓															
ALARM		✓	25.3.94	Berwyn	Flash Mixer P.H.	Low	03.34	08.40	P. Jones	L. B. Price	11.20	'B'	No	12.30	No
REMARKS	Berwyn F.S. Flash Mixer pH. Low (5.30 pH).														
REPORT	As A Result Of The Raw Turbidity Alarm, John Had Increased The Alum & Poly. The Line Pump Being On Auto, Was On Ten Strokes/Min, But Had Increased To 34 Strokes/Min By 04:00 Hrs When John Left The Works. After John Left The Station, The Line Pipe Burst, Resulting In The pH. Staying Below Its Alarm Level, Until The Pipe Was Repaired. Probable Cause Of Fracture Was A Build Up Of A Hard Slug Of Line, And The Force Of The Pump Against It Burst The Pipe.														
(c)✓															
ALARM		✓	25.3.94	Legacy	TRT PH	High	07.52	08.30	J. Turton	L. B. Price	11.00	'B'	No	11.15	Yes
REMARKS	Legacy Works, Treated Water pH High (9.40 pH)														
REPORT	John Reports That Test Indicates 8.6 pH. Rang Glyn For Permission To Call Out Eifion To Recalibrate. Instrument Adjusted Down To 8.5 pH.														
(d)✓															
ALARM		✓	26.3.94	Legacy	Break Tank Level High/Low	Alarm	12.21	12.24	J. Turton	L. B. Price	12.58	'C'	No	14.00	No
REMARKS	Legacy Works, Break Tank High Level Alarm Caused Inlet Valve From Ty Mawr To Shut.														
REPORT	John Turton Was At Nant-Y-Ffrith F.S. When I Contacted Him, And On His Return To Legacy, He Reset The System, And Started Up The Flotation. Cause Of High Level Unknown														

7.2 Example of Instrument Defect Sheet.



WREXHAM WATER
WREXHAM AND EAST DENBIGHSHIRE WATER COMPANY

WREXHAM WATER - QUALITY PROCEDURE MANUAL DESCRIPTION: Instrument Defect Sheet	CODE REF: WW81 ISSUE NO:1 ISSUE DATE: 10. 12. 91 PAGE NO: 1 OF 1 ORIGINATING AUTHORITY: GC

STATION: Legacy f/s DATE 25.6.94 TIME 20:50

EQUIPMENT LOCATION: Cl2 Building

EQUIPMENT ASSET NO: 2045

EQUIPMENT TYPE: Chlre (Pre Res)

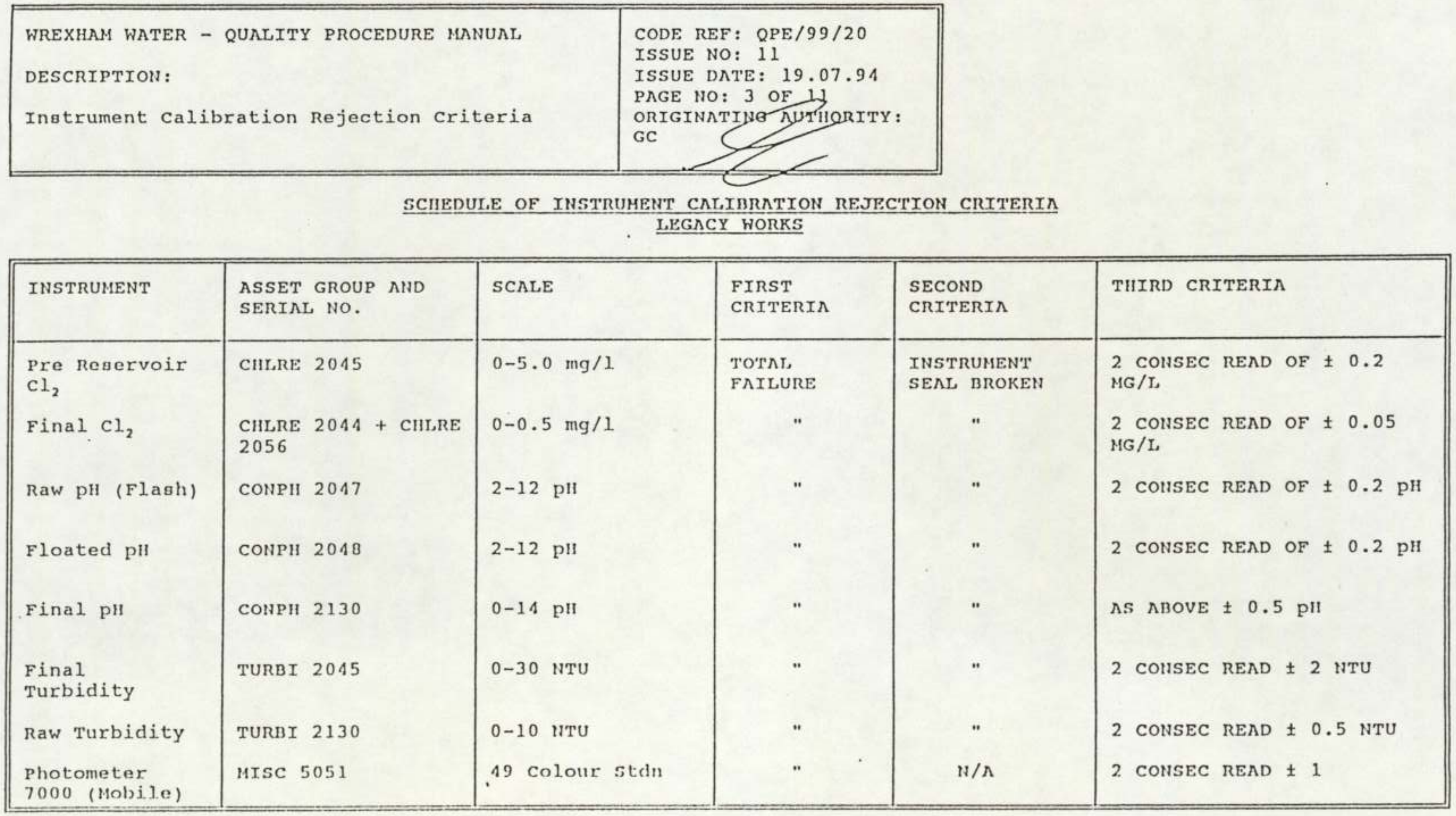
DESCRIPTION OF DEFECT: Reading High :-
Test ~~[illegible]~~ 1.34) 0.76 out
ins 2.10) Spec 0.2

PROBABLE CAUSE (IF KNOWN): Unknowen

REPORTED BY (PLEASE PRINT): C Roberts

NOTES:
informed Control to inform Tec Services.
To fault.

7.3 Example of BS5750 Instrument Calibration Rejection Criteria.



WREXHAM WATER - QUALITY PROCEDURE MANUAL DESCRIPTION: Instrument Calibration Rejection Criteria	CODE REF: QPE/99/20 ISSUE NO: 11 ISSUE DATE: 19.07.94 PAGE NO: 3 OF 11 ORIGINATING AUTHORITY: GC

<u>SCHEDULE OF INSTRUMENT CALIBRATION REJECTION CRITERIA</u>
<u>LEGACY WORKS</u>

INSTRUMENT	ASSET GROUP AND SERIAL NO.	SCALE	FIRST CRITERIA	SECOND CRITERIA	THIRD CRITERIA
Pre Reservoir Cl_2	CHLRE 2045	0-5.0 mg/l	TOTAL FAILURE	INSTRUMENT SEAL BROKEN	2 CONSEC READ OF ± 0.2 MG/L
Final Cl_2	CHLRE 2044 + CHLRE 2056	0-0.5 mg/l	"	"	2 CONSEC READ OF ± 0.05 MG/L
Raw pH (Flash)	CONPH 2047	2-12 pH	"	"	2 CONSEC READ OF ± 0.2 pH
Floated pH	CONPH 2048	2-12 pH	"	"	2 CONSEC READ OF ± 0.2 pH
Final pH	CONPH 2130	0-14 pH	"	"	AS ABOVE ± 0.5 pH
Final Turbidity	TURBI 2045	0-30 NTU	"	"	2 CONSEC READ ± 2 NTU
Raw Turbidity	TURBI 2130	0-10 NTU	"	"	2 CONSEC READ ± 0.5 NTU
Photometer 7000 (Mobile)	MISC 5051	49 Colour Stdn	"	N/A	2 CONSEC READ ± 1

Table 8 - Instrument Calibration Rejection Criteria for Legacy WTW.

7.4 Example of Maintenance Record Sheet.

WREXHAM WATER - QUALITY PROCEDURE MANUAL DESCRIPTION: **Instrument Record Sheets**	CODE REF: WW80 ISSUE NO: 3 ISSUE DATE: 08.02.93 PAGE: NO: 1 OF 1 ORIGINATING AUTHORITY: GC

STATION: LEGACY F/S DATE: WK25/94 TIME: 21 : 20

EQUIPMENT LOCATION: CHLORINE HOUSE

EQUIPMENT ASSET NO: 2045

EQUIPMENT TYPE.

CHLORINE CELL ☐ ☐ PHOTOMETER

CHLORINE IND./ TRANSMITTER ☐ ☐ WEIGHING SCALES

CHLORINE REC./ CONTROLLER ☑ ☐ NESSLERISER

P. H. IND./ CONTROLLER ☐

TURBIDIMETER ☐

CALIBRATION TYPE: ROUTINE ☐ RECALL ☑ OTHER ☐

DATE OF LAST CALIBRATION WK25/94

DATE OF NEXT CALIBRATION WK28/94

PRE CALIBRATION READING 1.80

CALIBRATION READINGS

REQUIRED READINGS	INSTRUMENT READING
1.38	1.80
1.41	1.40
1.40	1.40

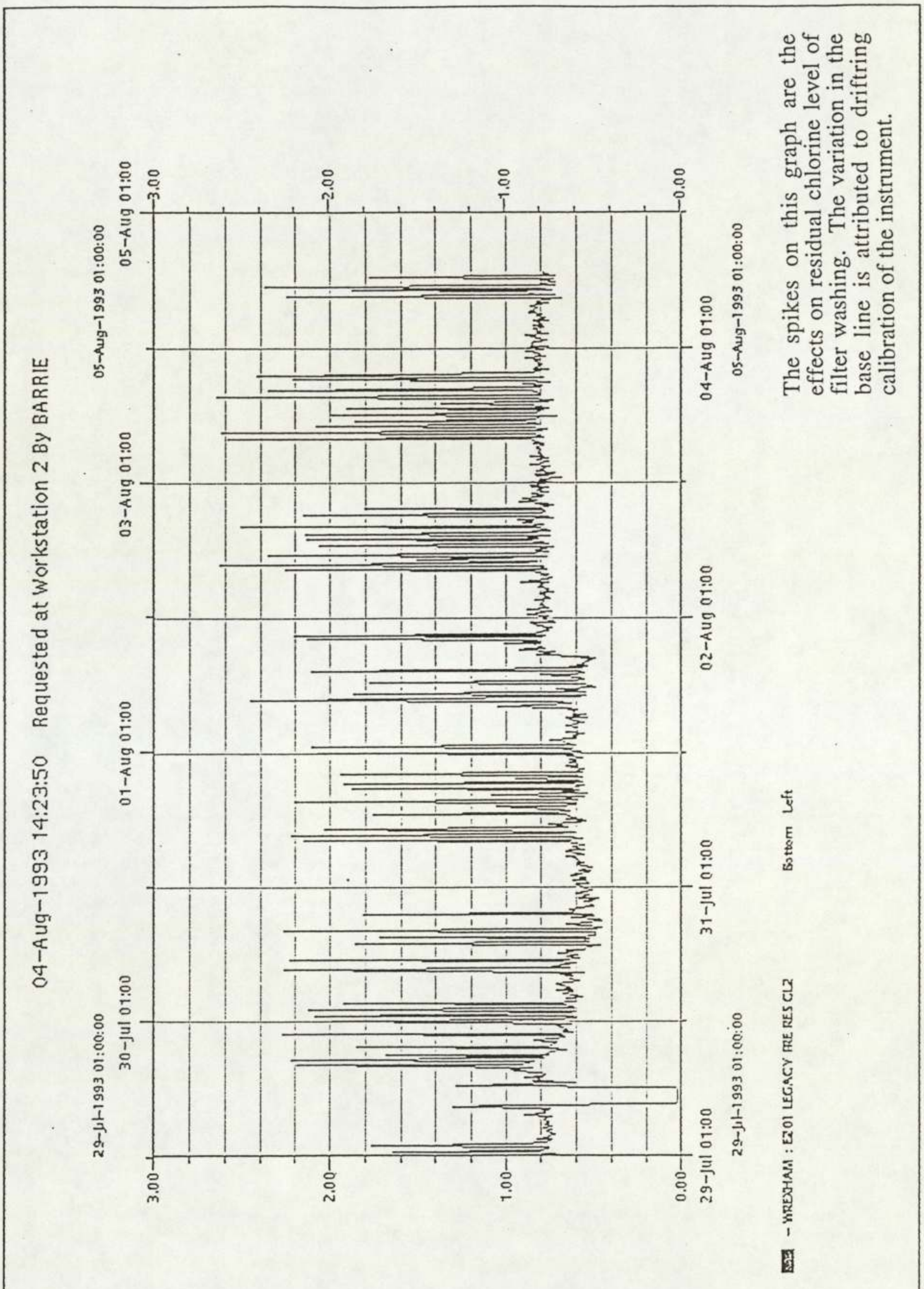
ACTION TAKEN: CHECKED CELL PANEL E.C.T CHECKED ZERO TESTED CHLORINE RESIDUAL AND SET CONTROLLER TO TEST RESULTS

FINAL READING: 1.40

NOTES:

WORK CARRIED OUT BY:

Appendix 8 - Graphs of Legacy WTW pre-Service Reservoir Chlorine Residual.



The spikes on this graph are the effects on residual chlorine level of filter washing. The variation in the base line is attributed to driftring calibration of the instrument.

Figure 18 - Legacy WTW pre-Service Reservoir Free Chlorine Residual Before Installation of Hach Cl17 Instrument.

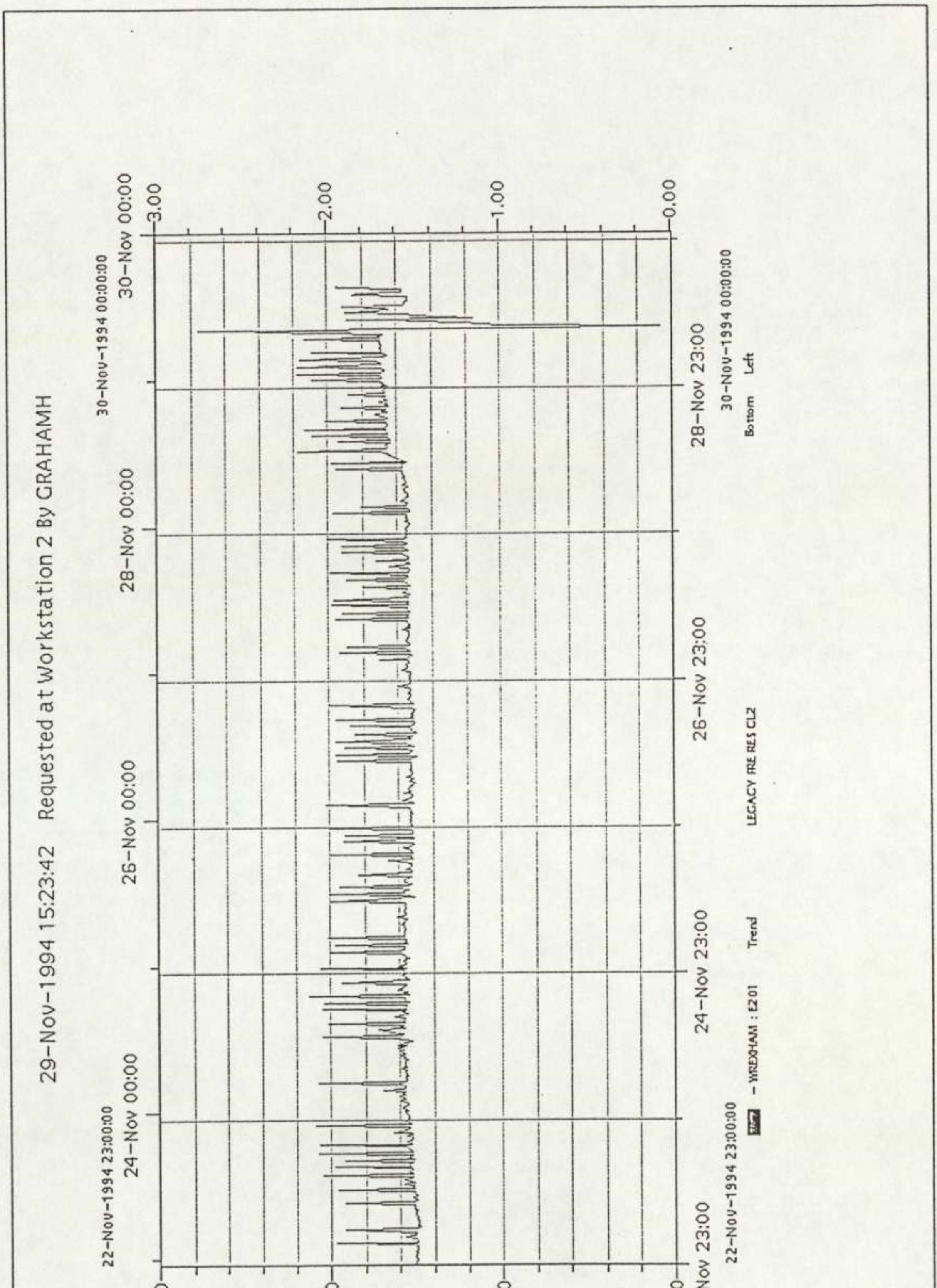


Figure 19 - Legacy WTW pre-Service Reservoir Free Chlorine Residual After Installation of Hach Cl17 Instrument.

Appendix 9 - Graph of Berwyn WTW Final Water Free Chlorine Residual.

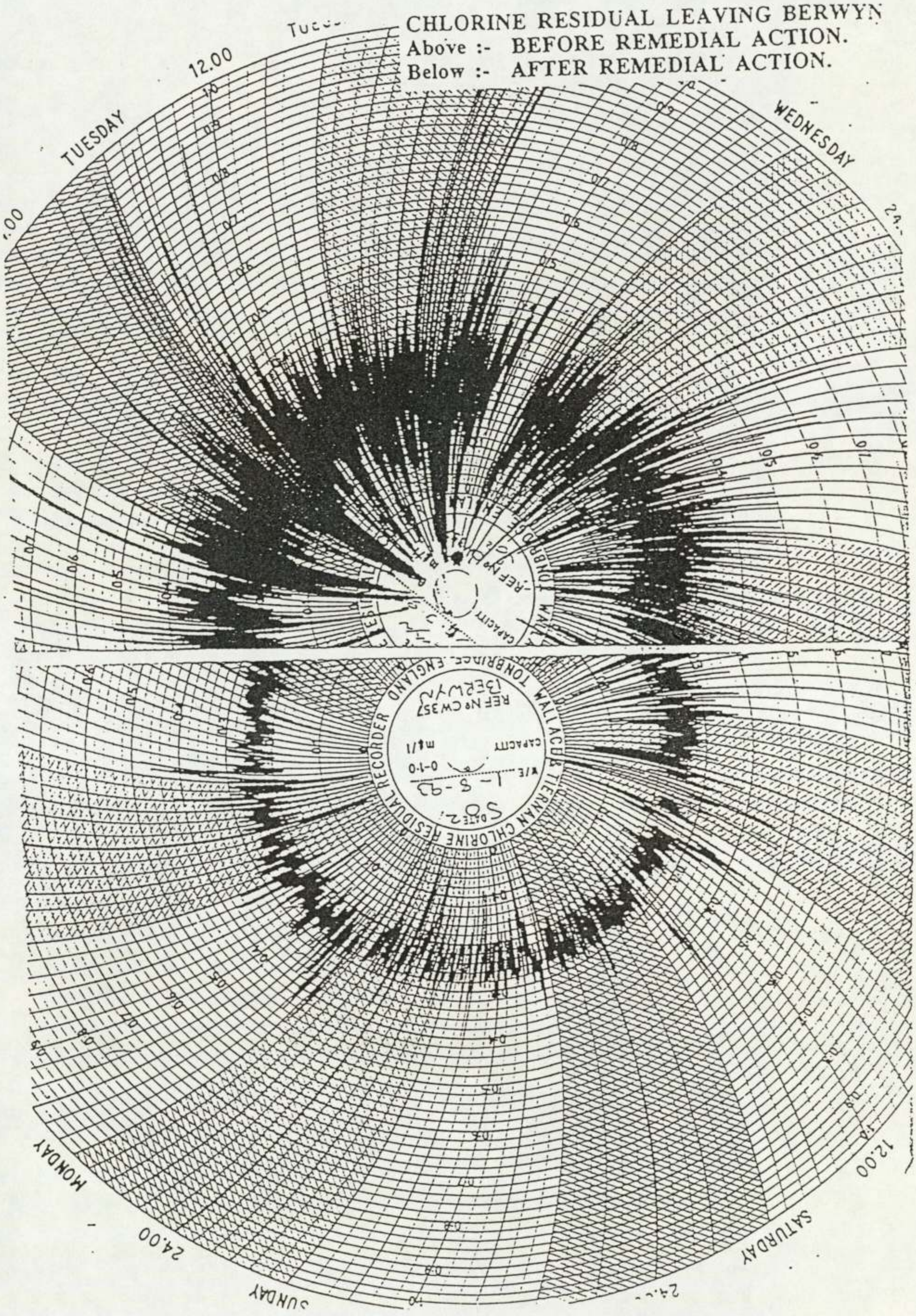


Figure 20 - Berwyn WTW Final Water Free Chlorine Residual Before and After Improvement.

Appendix 10 - Details of Chloros Booster Plant.

Penypalment Remote Chloros Dosing Plant.

The remote Chloros dosing plant is designed to raise the free residual chlorine level in the water at Penypalment Service Reservoir in order to reduce the risk of bacteriological failure. This is achieved by adding a controlled dose of Chloros to the pumping main as the water leaves Tan-Y-Fron Service Reservoir to go to Penypalment, as shown in Figure 21.

The plant consists of a carboy of Chloros in a plastic bund. A 'Prominent' solenoid driven metering pump is bolted on top of the bund. The Chloros is injected into the water main shortly after the reflux valve using a plastic injection lance. The dose rate of the Chloros is manually adjusted, normally by changing the stroke rate setting though the stroke length is also variable. The dosing pump is linked electrically to the water booster pump such that it can only operate when the water pump is on.

The pump suction in the carboy has a foot valve at the end of the suction line to stop the line draining during carboy change-over. This should be kept vertical.

The chlorine residual is measured twice weekly by the laboratory at the outlet of Penypalment service reservoir. The results are shown in Table 9.

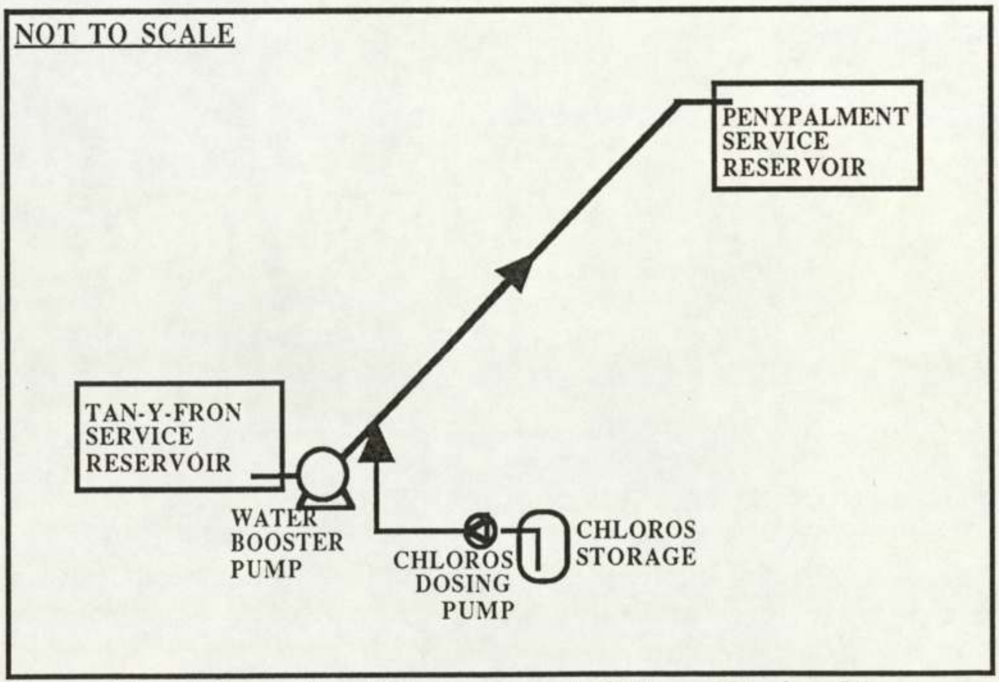


Figure 21 - Schematic of Penypalment Chloros Dosing Plant.

DATE	PENYPALMENT OUTLET		COMMENTS
	FREE	**TOTAL**	
5/7/94	0.01	0.05	
12/7/94	0.02	0.05	
19/7/94	0.02	0.05	
26/7/94	0.04	0.08	
2/8/94	0.03	0.05	
9/8/94	0.03	0.08	
16/8/94	0.01	0.03	Chloros booster commissioned 17/8/94
23/8/94	0.10	0.14	
25/8/94	0.12	0.16	
30/8/94	0.12	0.16	
2/9/94	0.10	0.12	
6/9/94	0.10	0.16	
8/9/94	0.12	0.16	
13/9/94	0.14	0.16	
15/9/94	0.06	0.08	Out of service 14/9/94 to 16/9/94, water pump burnt out.
20/9/94	0.10	0.14	
22/9/94			Out of service 20/9/94 to 26/9/94, testing PRV.
27/9/94	0.08	0.01	
29/9/94	0.08	0.14	
4/10/94	0.30	0.35	Chloros dose increased to 0·23 mg/l and manual chlorination stopped 3/10/94.
6/10/94	0.10	0.13	

Table 9 - Laboratory Results of Free Chlorine Residual Relating to Penypalment Chloros Booster Unit.

Appendix 11 - Drinking Water Quality Standards.

DRINKING WATER QUALITY STANDARDS. Standards for quality of drinking water in England and Wales are set by "The Water Supply (Water Quality) Regulations 1989", Statutory Instruments 1989, No. 1147.

PARAMETER	PERMISSIBLE CONCENTRATION OR VALUE
Colour	20 mg/l on the cobalt-platinum scale
Turbidity	4 Formazin turbidity units
Dilution odour	Dilution number 3 at 25°C
Dilution taste	Dilution number 3 at 25°C
Temperature	25°C
Hydrogen ion (pH)	5·5 to 9·5
Sulphate	250 mg/l
Magnesium	50 mg/l
Sodium	150 mg/l
Potassium	12 mg/l
Total dried solids	1500 mg/l
Nitrate	50 mg/l
Nitrite	0·1 mg/l
Ammonium	0·5 mg/l
Kjeldahl nitrogen	1 mg/l
Oxidisability	5 mg/l
Total Organic Carbon	No significant increase over that normally observed.
Dissolved or emulsified hydrocarbons	10 mg/l
Phenols	0·5 mg/l
Surfactants	200 µg/l (as lauryl sulphate)
Aluminium	200 µg/l
Iron	200 µg/l
Manganese	50 µg/l
Copper	3000 µg/l
Zinc	5000 µg/l
Phosphorus	2200 µg/l
Fluoride	1500 µg/l
Silver	10 µg/l
Arsenic	50 µg/l
Cadmium	5 µg/l
Cyanide	50 µg/l
Chromium	50 µg/l
Mercury	1 µg/l
Nickel	50 µg/l
Lead	50 µg/l
Antimony	10 µg/l
Selenium	10 µg/l
Pesticides and related products:	
(a) individual substances	0·1 µg/l
(b) total substances	0·5 µg/l
Polycyclic aromatic hydrocarbons	0·2 µg/l

Total coliforms	0/100 ml
Faecal coliforms	0/100 ml
Faecal streptococci	0/100 ml
Clostridia	Not more than 1/20 ml
Colony counts	No significant increase over that normally observed.
Conductivity	1500 µS/cm at 20°C
Chloride	400 mg/l
Calcium	250 mg/l
Substances extractable in chloroform	1 mg/l dry residue
Boron	2000 µg/l
Barium	1000 µg/l
Benzo 3, 4 Pyrene	10 ng/l
Tetrachloromethane	3 µg/l
Trichloroethane	30 µg/l
Tetrachloroethane	10 µg/l
Total Hardness	Standards only apply if water is softened
Alkalinity	Standards only apply if water is softened

Appendix 12 - pH Meters.

12.1 Details of In-line pH Electrode.

EIL Ltd, CHERTSEY, SURREY, ENGLAND July 1972.

MODELS 2868 AND 2869 INDUSTRIAL DIP ELECTRODE SYSTEMS

OPERATING INSTRUCTIONS

INTRODUCTION

This manual describes the Models 2868 and 2869 Industrial Dip Electrode Systems.

The systems are 3 ins. in diameter, and will fit 3 in. standard pipes. The Model 2868 is made of polypropylene throughout to eliminate metal corrosion, it may safely be used at temperatures up to 100°C and pressures of up to 40 lb/in^2. For higher temperatures and pressures, the Model 2869 stainless steel version should be used.

Standard E.I.L. industrial glass electrodes are used with these systems.

The systems are intended for operation with E.I.L. Model 28A or 28B pH Meter and automatic compensation for ambient temperature variations can be incorporated. Model 90 series pH Meters can also be used, in which no ambient temperature compensation is provided and the electrodes used must have 'N' fillings.

The standard electrode systems are fitted with neoprene and nitrile 'O' rings. Certain applications, however, may require Viton, silicone rubber or PTFE 'O' ring seals which are available as optional extras. Wall mounting clamps are also available, and low and high pressure flanges for standard pipe sizes up to 6 inches, (Fig. 1).

DESCRIPTION

Reservoir Systems

The 2868-1, 2868-2 and 2869-1, and 2869-2 each consist of two main parts, the upper part comprising the KCl reservoir and the junction box and the lower part comprising the tube electrode holder assemblies, (Fig. 1, 3, 5).

The KCl reservoir is fitted with a nylon valve which must remain open when the system is in operation; the valve acts as a vent during normal operation and allows the reservoir to be sealed when the system is not in use or has to be taken out for servicing. The reservoir is made of translucent polypropylene and the solution level can be ascertained without removing the cover.

A reference electrode is fitted at the bottom of the reservoir. A flexible tube carries the salt bridge solution to the liquid junction tube.

A junction box is housed directly below the reservoir. It is removable and is sealed throughout. Three rubber grommets at the back of the box provide individual entry for the cables from the reference electrode, glass electrode and temperature compensator.

A space is provided for the desiccator. The junction box cover moulding incorporates an eight-way terminal block, (Fig. 1) and has an outlet for the main cable.

The lower part of the system comprises the three inch diameter tube assembly which houses the neoprene KCl tube and the cables to the glass electrode and temperature compensator. The electrode holder is situated at the lower end of the tube; it holds in position, and seals, the glass electrode, liquid junction tube and temperature compensator.

A universal spanner is provided with the system to fit the valve, cable retaining nut, electrode retaining nuts and the clamp at the bottom of the system. The spanner should only be used to loosen these parts and never to tighten any of them, finger tightness is sufficient.

The standard flanges available (Fig. 1) are only suitable for use at ambient pressures; when a system is to be installed in a pressurised vessel the flange (stainless steel or polypropylene) must be welded to the stem of the system at the position specified by the user.

The standard system is made in nominal stem lengths of 3 ft. and 6 ft.

Non-Reservoir Systems

The Models 2868-5, and 2868-6 and 2869-6 (Fig. 2, 4, 6) are essentially similar to the -1 and -2 models except that a sealed reference electrode is used and the reservoir and salt bridge solution carrying tube are omitted. A blank securing ring with a sealing gasket is fitted to the top of the system.

These systems, however, cannot be used under pressure and are subject to the limitations of the reference electrode used. Conversion kits are available to convert these systems to -1 and -2 systems.

ELECTRODES

The Models 2868 and 2869 electrode systems are designed to use a glass or metal electrode, a reference electrode, and a temperature compensator. The type of electrode used depends on the application for which the electrode system is required.

Glass Electrodes

The Models 2868 and 2869 require electrodes with long leads (2.25m). The following glass electrodes are suitable:-

Part Number	pH Range	Temperature	Application
33 1027 900	0-14pH	50 to 140°C	Continuous high temperature
33 1072 130	0-14pH	-5 to 100°C	General purpose electrode
33 1072 030	0-14pH	10 to 100°C	Toughened general purpose electrode

Metal Electrodes

For special applications a platinum electrode Part No. 33 1203 900 fitted. Other metal electrodes such as gold, silver, antimony and tungsten can be fitted to special order.

Reference Electrodes

There are two main types of reference electrodes fitted in the 2868 and 2869. These are the sealed reference electrode, and the reservoir fed electrode. The Part No. 33 1320 810 (RK68) sealed reference electrode is used at steady temperatures up to 70°C. Where samples are above this temperature, or if the temperature fluctuates more than 10°C, or in pressurised systems, a reservoir fed reference electrode, usually 33 1310 710 (CZ68) must be fitted. The reservoir fed system has a self flushing action, and this helps to clear away any precipitate in the solution and prevent clogging of the liquid junction arrangement.

The reservoir fed system employs either 3.8$\underline{M}$ KCl solution, or in cases where this would react with the liquid being measured, a $\underline{M}$ Na_2SO_4 solution.

Temperature Compensation

A resistance thermometer can be fitted to provide automatic temperature compensation. The type of temperature compensator required depends on the pH meter being used:-

Part Number	Instrument
33 9898 100	EIL 98 Series and 2830 Series
33 9904 600	EIL Model 9904
33 2819 100	EIL Model 28A
33 2829 100	EIL Model 28B

Liquid Junction Tube

Where a remote reference electrode is used a liquid junction tube 33 1300 000 (LW28) is required.

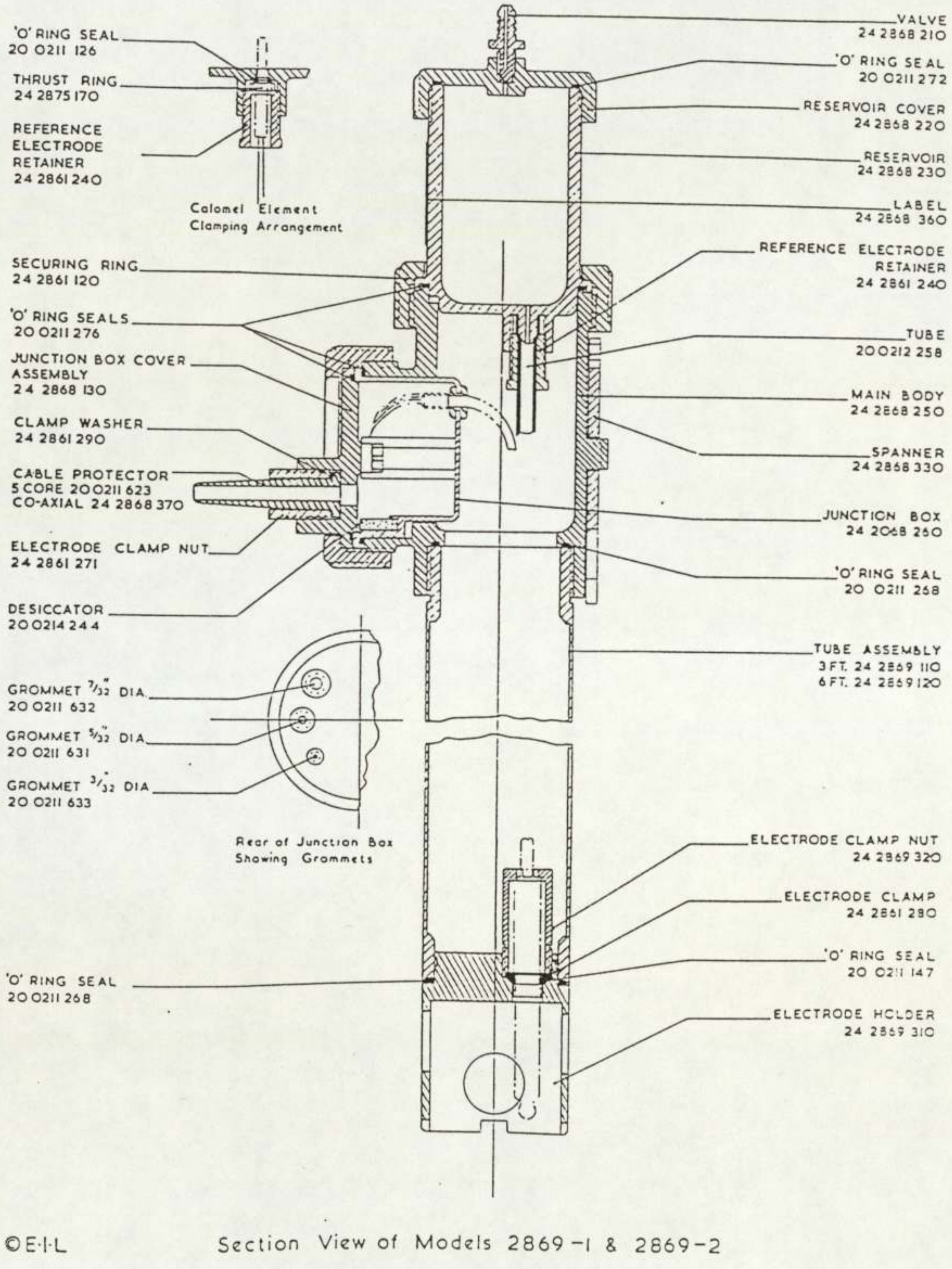


Figure 22 - Diagram of In-line pH Electrode.

12.2 Details of Hach pH Meters.

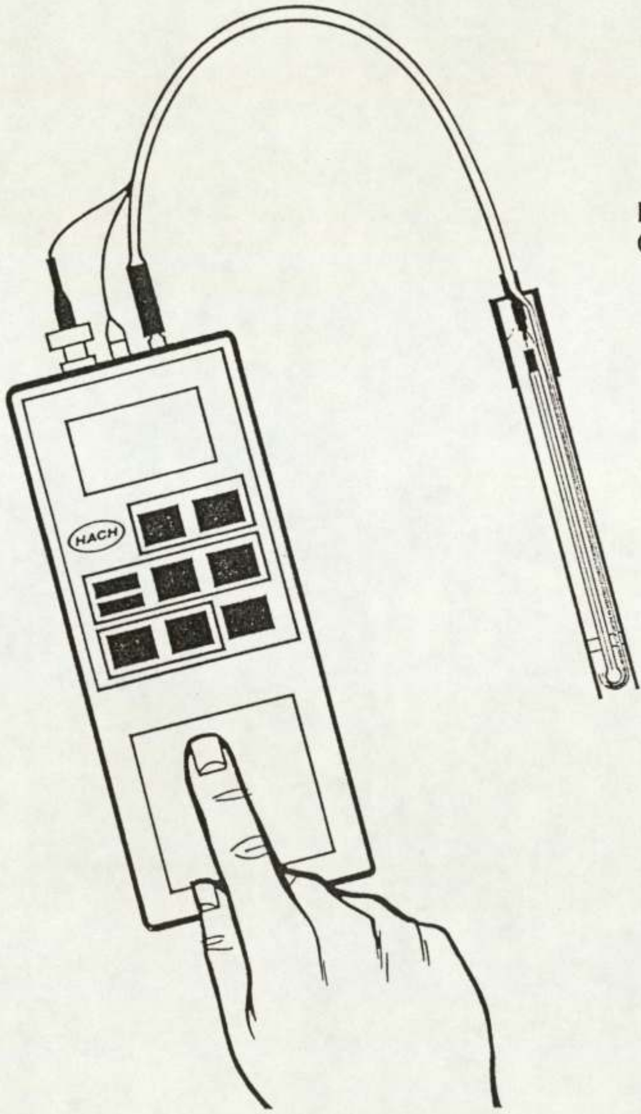
HACH ONE ELECTRODE TECHNOLOGY

For Ultra-Stable pH, Ion Concentration and ORP Measurements

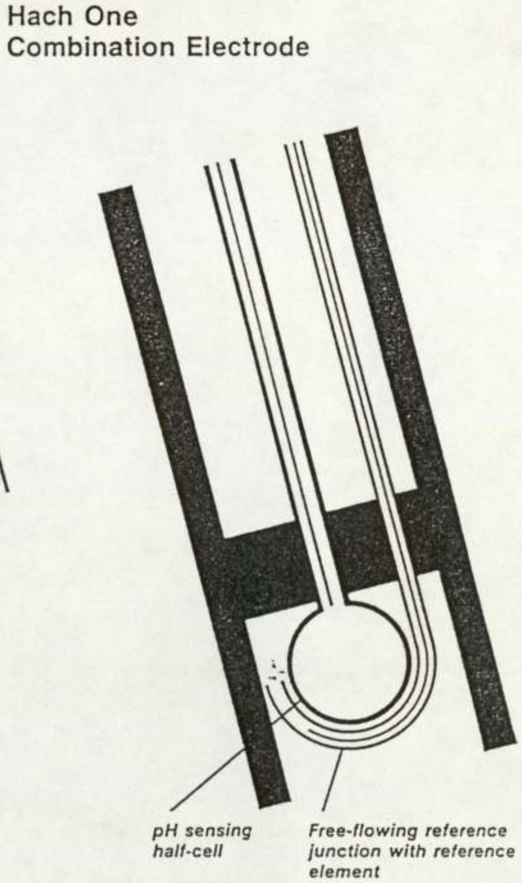
Hach One Technology Improves Analysis

- Fast, Stable Response
- Assured Accuracy
- Repeatable Results
- Long Electrode Life

Hach One systems incorporate a unique reference electrode design that replaces conventional porous junctions with a free-flowing, non-clogging liquid/liquid interface reference junction. An electrolyte cartridge contains the reference solution, which travels through a tube into the electrode. The tube forms a "J" at the end of the probe, and electrolyte is allowed to diffuse freely. Because there is no porous junction material to clog, free electrolyte flow is assured and response is more rapid than with conventional electrodes. The electrode lasts longer because it cannot become "fouled." The result is an electrode system that provides a fast response, assured accuracy, reproducible results and long life. This electrode technology is integral to Hach's complete line of pH/mV and pH/ISE Meters, and is also available for use with any meter.



Reference electrolyte solution is contained in a cartridge. One push on the dispenser forces 6 μL of electrolyte solution through the reference junction, creating a renewed potential with each measurement.



Hach's free-flowing reference junction design prevents clogging. Every measurement is rapid, accurate and stable, regardless of electrode age.

Conventional Electrodes Cause Errors

- Slow response
- Shifting calibration
- Non-repeatable results
- Early electrode failure

Conventional reference electrodes use a porous junction material to control the flow of reference solution. This design works well initially, but after a short time all porous junctions clog, impeding and changing the electrolyte flow rate. This causes unstable, inaccurate measurements, and early electrode failure.*

*Illingworth, John A., "A Common Source of Error in pH Measurements," *Biochemical Journal* (1981) 195, 259-262. Circle number 6061 on the reply card.
Kopelove, A.; Franklin, S.; McGaha Miller, G., "*Low Ionic Strength pH Measurement*" Circle number 6085 on the reply card.

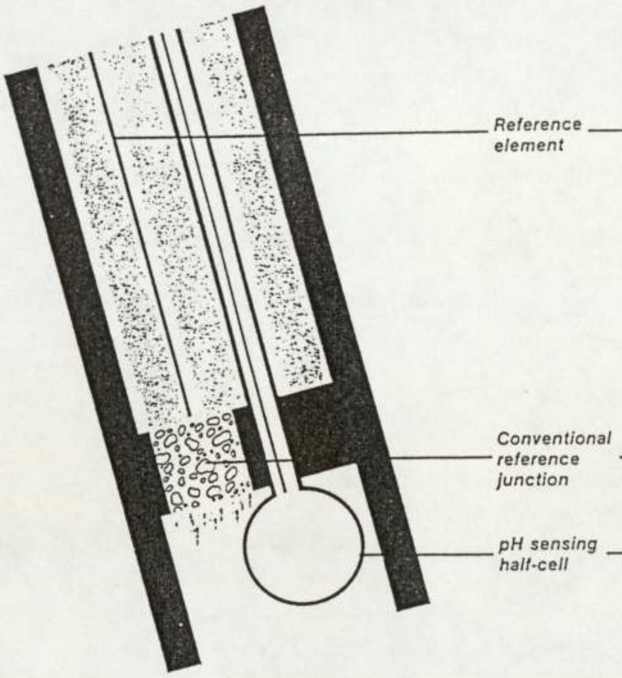
How accurate is the electrode you're currently using?

Use this simple procedure to check your electrode response.

1) Standardize the electrode using a two-point calibration.
2) Place the electrode in 250 mL of stirring, deionized water and note the pH reading.
3) Add 50 mg of ultrapure, solid KCl. Note the pH reading.

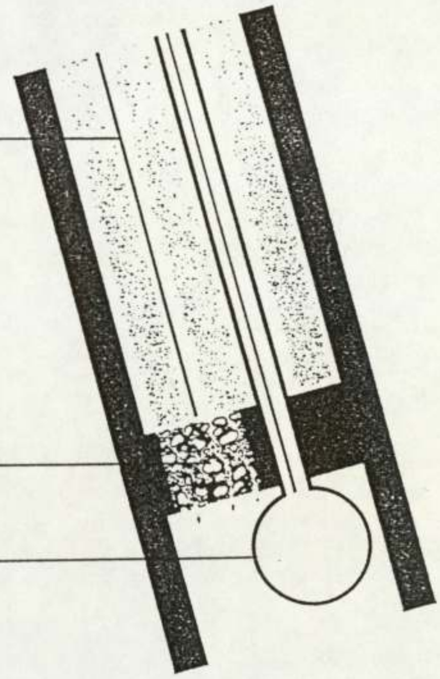
If pH changed more than 0.08 units, your results aren't as accurate as they should be.

Conventional Combination Electrode (New)



When new, conventional porous reference junction allows electrolyte solution to flow freely.

Conventional Combination Electrode (Used)



Even after just a few days, conventional reference junctions can become clogged, causing slow, unstable response and inaccurate results.

HACH ONE

At its Best in the Toughest Samples

Samples which are low in ionic strength can cause problems for most electrodes, but this is where the Hach One really shines. How do we know? We've extensively tested the Hach One against other leading electrodes on difficult samples such as deionized water and acid rain audit samples. Here's what we found:

Fast, Stable Response

The Hach One free-flowing reference junction allows rapid stabilization through unrestricted reference electrolyte flow. A nearly constant junction potential with minimal drift (0.00005 pH units/hour) is established for each measurement (Figure 1).

Conventional electrodes become plugged, causing sluggish, variable electrolyte solution flow. This results in slow response and a shifting junction potential.

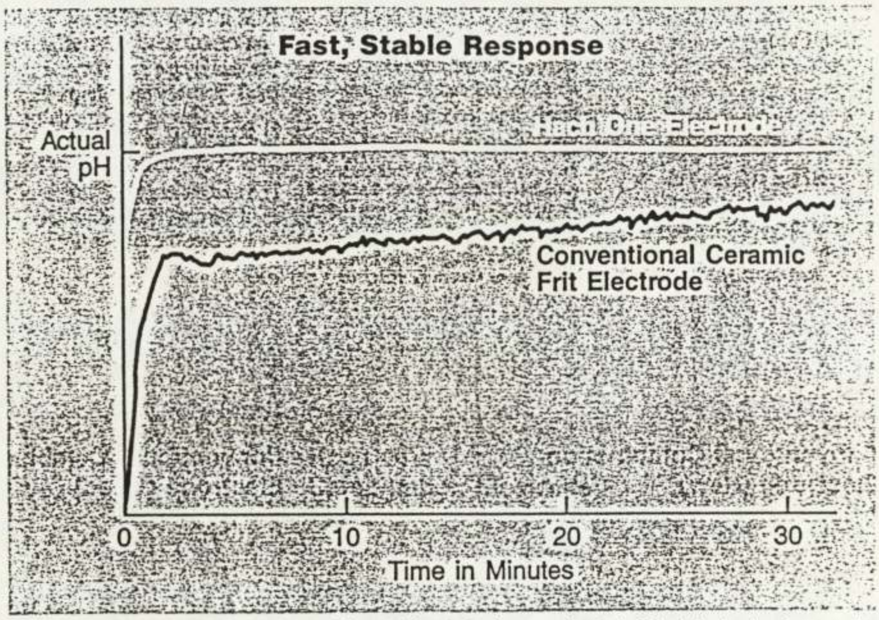


Figure 1: The Hach One Electrode provides stable results in one minute in this deionized water sample. The conventional ceramic frit junction electrode shows a slow, noisy response.

Assured Accuracy

Hach One electrodes are not only fast, but accurate as well. Conventional reference junction electrodes can provide inaccurate measurement without any sign of malfunction. Many read calibration buffers correctly, yet give incorrect results for samples with varying ionic strength.
The Hach One free flowing reference junction assures consistent electrolyte flow for error-free measurements, even in the toughest samples (Figure 2).

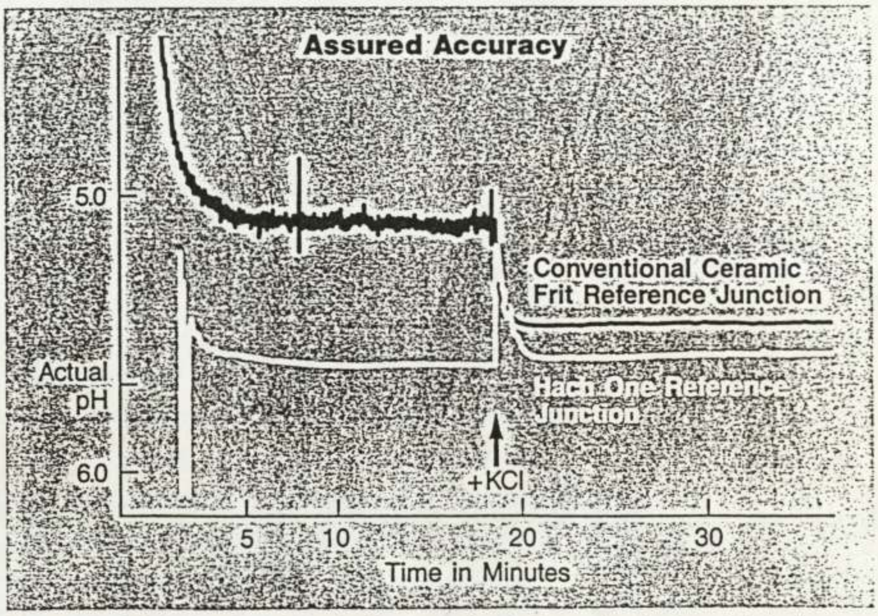


Figure 2: The inital pH reading obtained with a conventional reference junction for a deionized water sample was incorrect, and shifted by 0.36 pH units when the sample ionic strength was increased by adding 50 mg of ultrapure KCl (black). The same electrode with a Hach One reference electrode (white) showed significantly improved stability and accuracy.

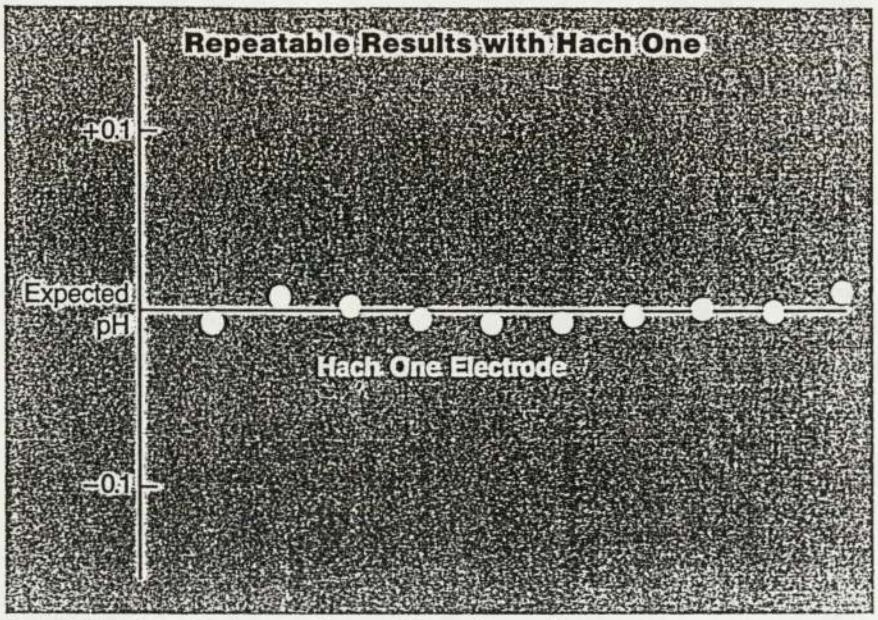


Figure 3: Hach One pH systems provide repeatable results every time.

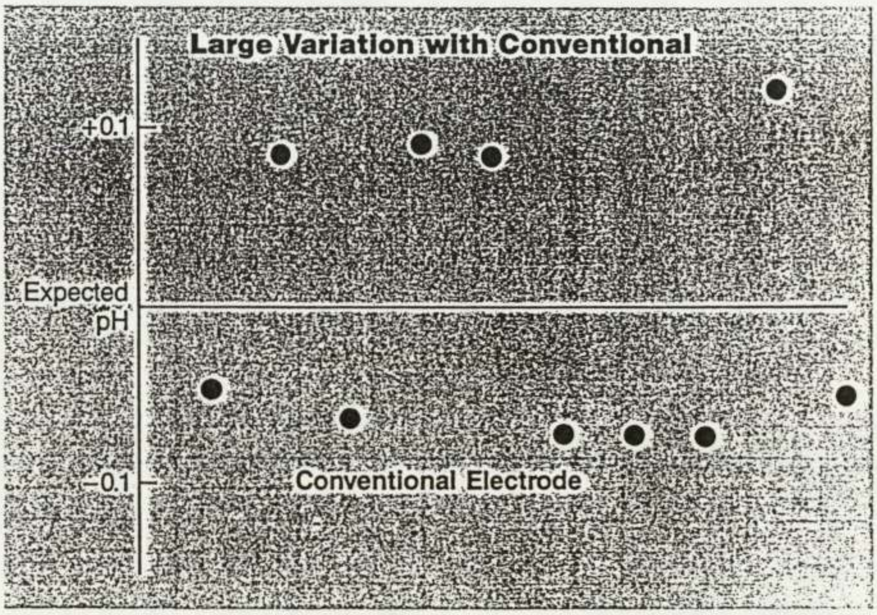


Figure 4: This conventional electrode varies greatly from one measurement to the next.

Repeatability Testing

A renewed reference junction for each measurement means that Hach One electrodes provide repeatable results test after test.

The pH of a USEPA* acid rain audit sample was measured 10 times with a Hach One pH Electrode, and 10 times each with several conventional ceramic frit electrodes over a period of one hour. Results obtained with the Hach One combination electrode varied from the mean by no more than 0.011 pH units (Figure 3). The other electrodes showed much larger variations; one electrode varied 0.19 pH units—nearly 20 times the variation of the Hach One (Figure 4).

Long Electrode Life

Hach's unique reference junction design provides reliable results, test after test. The reference junction cannot become clogged, and junction potential is renewed *for each measurement.* Some analysts are reporting up to three years of continuous use (see page 15).

How To Order

Cat. No.
Hach One Reference Electrodes
Single Junction, with electrolyte dispenser
44250-00
Single Junction, without electrolyte dispenser
44250-20
Double Junction for use with Hach One meters. Built-in temperature sensor, mini phone plug connector.
44551-20
Double Junction, with electrolyte dispenser
44550-00
Double Junction, without electrolyte dispenser
44550-20
Adapter, Reference Pin-to-BNC
42393-00

*United States Environmental Protection Agency

12.3 Data on Hach One pH Meters.

Summary of Use of Hach One pH Meters.

JUNE/JULY 1993. Initial investigations into Hach One pH meter were made. Contact with Dave Chisell, regional representative. States categorically that the meter gives very rapid, reliable results including low ionic waters. Time taken to give reading was stated by rep and by literature to be 'seconds'. Even after site visit to Legacy by Mr Chisell this statement was not altered.

Excellent references from Severn Trent Quality Assurance laboratories.

Meter loaned on trial and results gained after a fortnight appeared to be good, though there was not the opportunity to compare two Hach meters.

AUGUST 1993. Hach one pH meters arrive at Legacy and are commissioned. Calibration is recommended before use every day. Results gained from meters are not good. Reported to Camlab - reply says we must be wrong, they work well everywhere else. Response time for meters is still stated to be 'seconds'.

NOVEMBER 1993. Visit to IWEX in Birmingham. Discussion on trade stand resulted in further visits from Mr Chisell to Legacy. He now states that the meter should give a reading within three minutes. He suggests that Camlab have received a bad batch of electrodes from Hach in America and they will arrange for some new ones to be delivered. Also states that the electrodes do not have batch numbers on them, so there is no traceability.

DECEMBER 1993. New electrodes installed on 24th December 1994. Results gained since do not show any significant improvement. Failure rates, using the criteria of a reading to take less than three minutes and a repeat reading to be within 0.15 pH units, are more than one third.

JANUARY 1994. Electrode at Berwyn suffered a broken elbow on the buffer supply line, replaced with the one from Technical Services meter. Dave Chisell visited on 5th Jan. 1994 to see Glyn Davies, Treatment Superintendent. While on site the electrode at Legacy was declared totally inoperable and was removed from the meter. Mr Chisell took it away with him for inspection. No replacement or further information has since been received. No replacement electrode has been sent. Mr Chisell now states that response time should be within five minutes. He also recommends that calibration should only be done on a weekly basis.

Most of the meters take on average 10-15 minutes to give a stable reading. Readings can sometimes take up to 40 minutes. Even after this length of time the readings gained are not reliable.

FEBRUARY 1994. The Pendinas meter has failed completely. The meter itself will not turn on or off and is completely inoperable. Returned to Camlab by Eifion Phillips, Instrument Technician.

Tests carried out show that no comparison can be made between the meters. Response from the meters in buffer solutions are fairly rapid, but the readings do deviate from the required value. Swapping the electrodes on the meters indicates that the problem is entirely with the electrodes.

Performance of Hach One pH Meters.

After the initial problems with the operation of the instrument a new set of electrodes were obtained and installed on 24th December 1993. The readings gained using new electrodes were recorded each time the instruments were used. Two readings were taken of each sample and the time for a stable response to be gained was also recorded. Records were kept for one month and the results then correlated. These records show that the new electrodes were still giving a very poor response. The readings took an inordinate amount of time to stabilise and the results which were gained were inaccurate, unreliable and unrepeatable. Figure 23 shows the spread of response times for a stable reading to be gained. Some 33% of the tests took more than 5 minutes to stabilise, with 14% taking longer than 20 minutes.

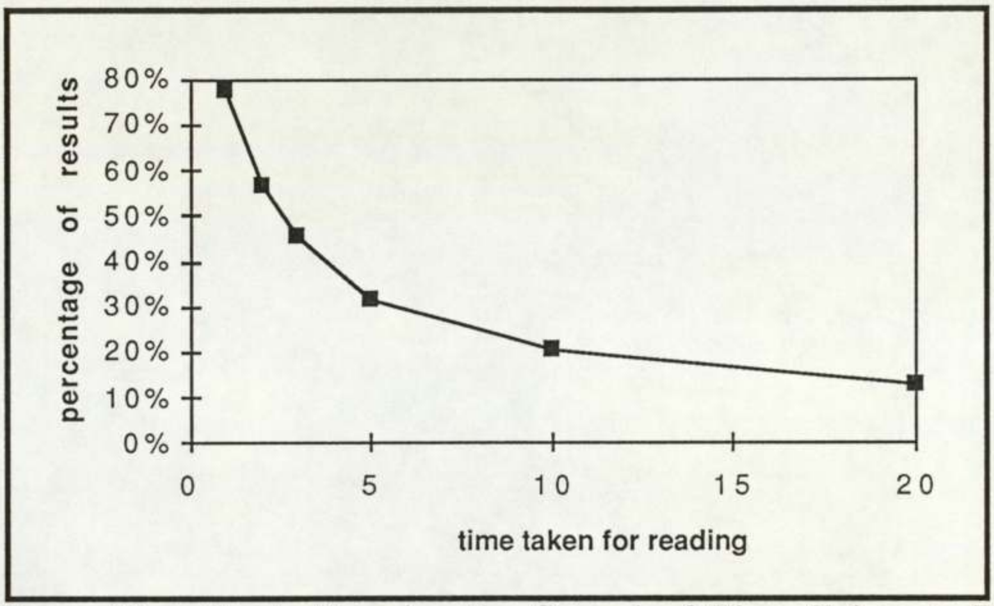


Figure 23 - Graph Showing the Spread of Time Taken to Read Results.

After being in use for one month four instruments were taken to one site and placed together in the same sample. The response gained from this test is shown in Figure 24. Three responses are shown instead of four as one instrument was found to be totally unusable. Despite regular calibration the three meters do not appear to be trending towards the same result. The response of each electrode is obviously quite different.

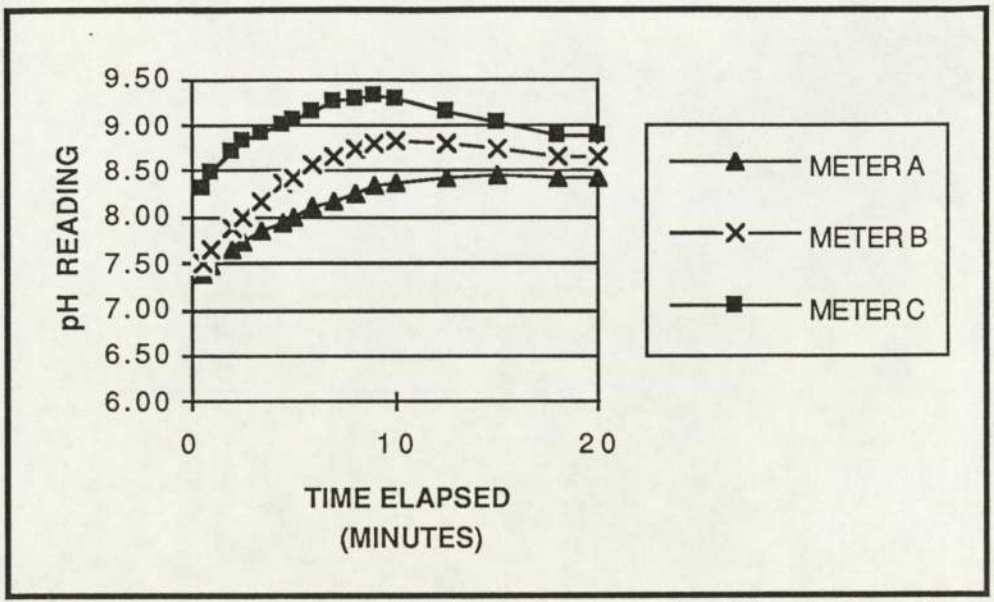


Figure 24 - Response of 'Dirty' Electrode in a Single Sample.

The instrument suppliers stated repeatedly that no routine cleaning was necessary for the instrument. Despite this assurance the electrodes were cleaned using an acid and alkali system and then soaked in distilled water according to manufacturers instructions. The electrodes were again placed together in the same sample. The similarity of the readings gained after this cleaning procedure was much improved but the response time was still excessive. The results are shown in Figure 25 using the same scales as Figure 24.

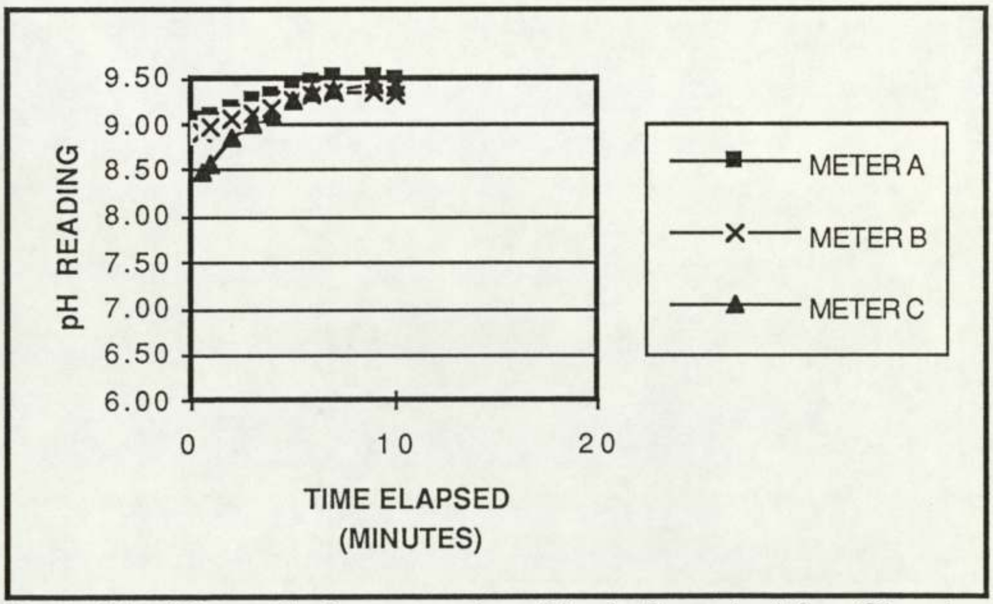


Figure 25 - Electrode Response in a Single Sample After Cleaning.

Given this data the instrument suppliers took the four instruments away to their own testing facility for further investigation, leaving in their place one previously tried and tested demonstration instrument. The results for this instrument show yet again the rapid development of some sort of fouling of the system. Contamination of the electrode by polyelectrolyte was suggested. To verify this theory a new electrode was obtained and used at a treatment works where polyelectrolyte is not used. The response times of the instrument are shown in Figure 26. There is a very definite decay in the performance of the electrode. Over this time period the repeatability of the readings was not affected but the response time again became unreasonable.

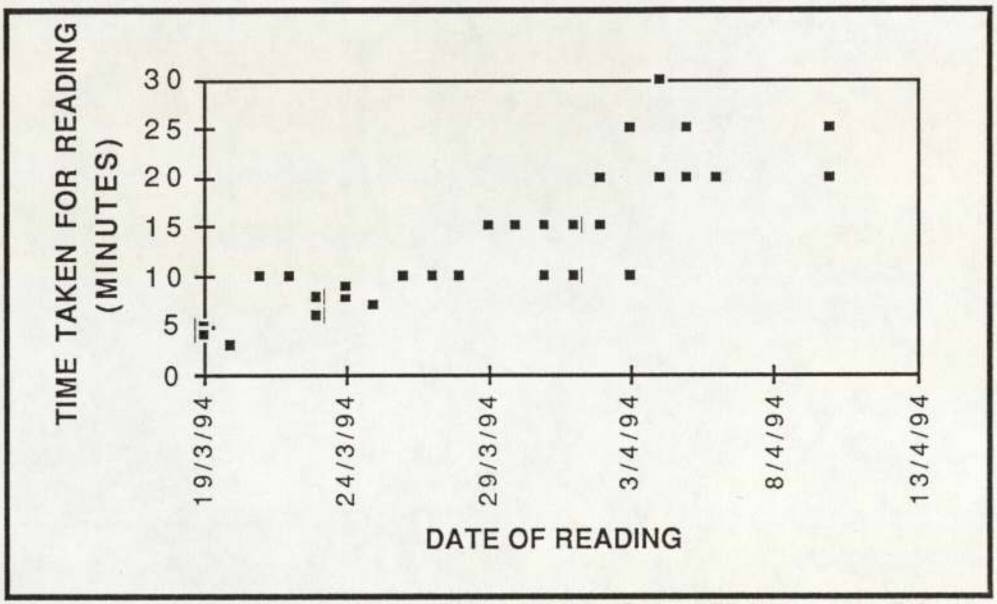


Figure 26 - Results Gained from Hach One pH Meter at Llwyn Onn WTW for the Period 13/3/94 to 10/4/94.

Despite identifying a manufacturing error, a minor operator error and potential contaminants in the water a convincing answer has not been found and the performance of the instruments are still unsatisfactory. With this last set of results the instrument suppliers and the manufacturers were at a loss to suggest any further remedy. They have admitted that their instrument, designed to cope with low ionic strength solutions, is not appropriate for measuring the pH of the water at Wrexham Water.

12.4 Details of ISFET Meter.

THE REVOLUTIONARY HANDHELD pH SYSTEM THAT GOES ANYWHERE

SENTRON 1001

The Sentron ISFET, so rugged you can clean it with a toothbrush.

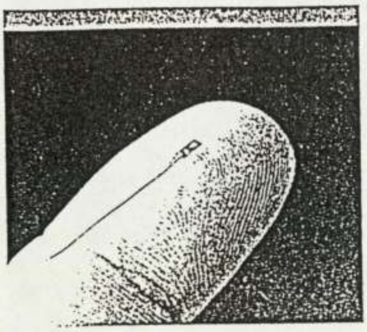
PUT THE SENTRON ADVANTAGE TO WORK FOR YOU.

- Non-glass, completely submersible probe resists breakage.
- Probe stores dry, requires no routine maintenance.
- Delivers stable readings in less than 3 seconds for most samples.
- Features a clog-resistant, ISFET-based sensor for easy cleaning with a toothbrush.
- Operates on 9V battery for easy field use.
- Accurately measures even a single drop.
- Requires only one probe to test everything from liquids to semi solids.
- EPA-approved method.

Until now pH testing meant coping with fragile glass electrodes that broke easily and required wet storage. It meant buying several different electrodes to handle a variety of sample types. And it meant clogged electrodes that made it difficult or impossible to test thick, dirty or semi-solid samples.

The Sentron 1001 pH system puts an end to those problems once and for all. It combines a rugged, handheld meter with an advanced, ISFET-based (Ion-Sensitive Field Effect Transistor) non-glass probe that tests everything from liquids to semi-solids. The Sentron 1001 fits easily in your hand and in your budget.

sentron®
Integrated Sensor Technology



SENTRON'S PATENTED ISFET TECHNOLOGY ELIMINATES GLASS AND SPEEDS RESULTS.

The Sentron 1001 pH system offers easy take-anywhere portability with a solid-state, handheld meter and a unique non-glass probe that stores dry and requires no routine maintenance. The Sentron probe replaces fragile glass electrodes with a sturdy silicon ISFET microchip that responds instantly.

Dry probe storage and operation on a standard 9V battery means you can take the Sentron 1001 anywhere. Unique ISFET technology makes the probe clog resistant and gives you the power to test just about anything — from clear liquids to dirty samples to bread dough. Even samples as small as a drop. To clean it just rinse with water. For oily or especially dirty samples you simply brush it with a soft-bristle toothbrush.

> pH is a convenient and readily understood means of expressing hydrogen ion concentration, or activity. The ISFET sensor features a hydrogen ion sensitive surface that contacts the sample. The probe also includes a reference electrode that contacts the sample, completing the circuit. When the hydrogen ion concentration varies, the current flow through the ISFET changes. These changes are converted by the meter to pH readings.

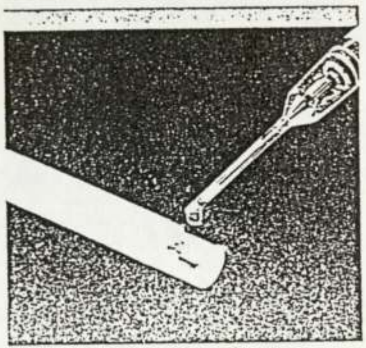
DESIGNED TO MAKE YOUR JOB EASIER.

- Sensor, reference, and automatic temperature compensation (ATC) are combined in one 9.5mm probe that fits into the smallest standard test tube.
- Easy calibration and auto-buffer recognition (2.00, 4.00, 7.00, 10.00, 12.00) enable you to go from power-up to sample reading in 30 seconds.
- Calibration memory saves time.
- Data memory stores up to five pH/temperature readings for quick recall.

ENTER THE FUTURE OF pH TESTING.

The Sentron 1001 meter with it's unique, unbreakable ISFET-based probe delivers fast, reliable, trouble-free performance to handle a wide variety of pH testing applications. With its rugged construction and handy size, the 1001 goes anywhere.

For more demanding applications the Sentron 2001 desktop/portable model offers additional features including: dual LCDs for simultaneous pH/temperature or pH/mV readings, custom calibration points, recorder output, and both battery and AC operation.



Sentron's unique non-glass probe can measure samples as small as a drop.

Sentron pH systems provide the most revolutionary pH testing technology in 50 years. Both the Sentron 1001 handheld and the Sentron 2001 desktop/ portable systems set new industry standards for pH testing performance. Put the future of pH testing to work for you *today*.

The future of pH testing.

SENTRON 1001 pH SYSTEM SPECIFICATIONS

SENSOR	Ion Sensitive Field Effect Transistor (ISFET) Patent No. 4,020,830 Electrostatic Discharge (ESD) Protection Patent No. 4,589,970
READOUT	Liquid Crystal Display
CALIBRATION & CALIBRATION MEMORY	One- or Two-Point
BUFFER RECOGNITION	pH 2.00, 4.00, 7.00, 10.00, 12.00
SAMPLE MEMORY	Up to 5 measurements of pH/Temperature
AUTOMATIC TEMPERATURE COMPENSATION (ATC)	0-60°C
SELF-DIAGNOSTICS	Meter and Probe Errors
DISPLAYS	pH, Slope, Temp, mV, Error Codes
POWER	9V Battery
RANGE	pH 0-14 mV ±400 Temp 0-60°C
RESOLUTION	pH 0.01 mV 0.1 Temp 0.1°C
ACCURACY	pH ±0.01 (Plus 1 least significant digit) Two-point calibration ±0.1 One-point calibration and memory (resolution 0.01) mV ±1 Temp: ±0.5°C
SUBMERSIBLE	Probe: length of cable
DIMENSIONS	Meter: 7.5"L x 2.6"W x 1.0"D (190mm L x 67mm W x 25mm D) Probe: 0.38"D x 8.0"L (9.5mm D x 203mm L) Cable: 60" (155 cm)
WEIGHT	Meter: 10 oz. (283g) Probe: 2 oz. (57g)
WARRANTY	Meter: one year parts and labor Probe: repair or replacement, six months normal use

Specifications subject to change without notice.

Order your Sentron products from:

sentron
Integrated Sensor Technology

34008 9th Avenue S.
Federal Way, WA 98003
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(206) 838-7701
FAX: (206) 838-7933

P.O. Box 125
9300 AC Roden
The Netherlands
31-(0)5908-13800
FAX: 31-(0)5908-16834

12.5 Data from ISFET Meter.

DATE	WTW	IN-LINE METER	SENTRON METER	NESSLERISER	SAMPLE
3/10/94	LEGACY	8.80	8.80	8.6/8.8	FINAL
3/10/94	LEGACY	6.70	6.78	6.4/6.6	FLASH MIXER
3/10/94	LEGACY	7.30	7.40	7.4/7.6	RAW
4/10/94	LEGACY	8.78	9.02	8.6/8.8	FINAL
4/10/94	LEGACY	6.76	6.63	6.4/6.6	FLASH MIXER
4/10/94	LEGACY	7.30	7.33	7.4/7.6	RAW
5/10/94	LEGACY	8.89	8.62	8.6/8.8	FINAL
5/10/94	LEGACY	6.54	6.55	6.4/6.6	FLASH MIXER
5/10/94	LEGACY	7.23	7.22	7.2/7.4	RAW
6/10/94	LEGACY	8.78	8.60	8.6/8.8	FINAL
6/10/94	LEGACY	6.60	6.77	6.4/6.6	FLASH MIXER
6/10/94	LEGACY	7.26	7.45	7.2/7.4	RAW
7/10/94	LEGACY	8.80	8.75	8.6/8.8	FINAL
7/10/94	LEGACY	6.71	6.80	6.4/6.6	FLASH MIXER
7/10/94	LEGACY	7.30	7.22	7.2/7.4	RAW
8/10/94	LEGACY	6.70	6.81	6.4/6.6	FINAL
8/10/94	LEGACY	7.35	7.23	7.2/7.4	FLASH MIXER
8/10/94	LEGACY	8.80	8.71	8.6/8.8	RAW
9/10/94	LEGACY	8.75	8.60	8.6/8.8	FINAL
9/10/94	LEGACY	6.74	6.85	6.4/6.6	FLASH MIXER
9/10/94	LEGACY	7.31	7.20	7.2/7.4	RAW
10/10/94	LEGACY	6.62	6.80	6.4/6.6	FLASH MIXER
10/10/94	LEGACY	8.82	8.70	8.6/8.8	PRE-RES
10/10/94	LEGACY	7.28	7.12	7.2/7.4	RAW
11/10/94	LEGACY	6.82	6.74	6.4/6.6	FLASH MIXER
11/10/94	LEGACY	8.80	8.52	8.6/8.8	PRE-RES
11/10/94	LEGACY	7.29	7.06	7.2/7.4	RAW
12/10/94	LEGACY	6.83	6.57	6.4/6.6	FLASH MIXER
12/10/94	LEGACY	8.73	8.30	8.4/8.6	PRE-RES
12/10/94	LEGACY	7.31	7.40	7.2/7.4	RAW
13/10/94	LEGACY	6.90	6.78	6.4/6.6	FLASH MIXER
13/10/94	LEGACY	8.71	8.51	8.4/8.6	PRE-RES
13/10/94	LEGACY	7.31	7.00	7.2/7.4	RAW
14/10/94	LEGACY	6.90	6.79	6.4/6.6	FLASH MIXER
14/10/94	LEGACY	8.58	8.05	8.4/8.6	PRE-RES
14/10/94	LEGACY	7.71	7.01	7.2/7.4	RAW
15/10/94	LEGACY	7.71	7.10	6.6/6.8	FLASH MIXER
15/10/94	LEGACY	8.43	8.10	8.4/8.6	PRE-RES
15/10/94	LEGACY	7.72	7.50	7.4/7.6	RAW
16/10/94	LEGACY	6.87	6.56	6.6/6.8	FLASH MIXER
16/10/94	LEGACY	8.60	8.12	8.4/8.6	PRE-RES
16/10/94	LEGACY	7.71	7.52	7.4/7.6	RAW

Table 10 - Results from Legacy WTW using ISFET pH Meter.

DATE	WTW	IN-LINE METER	SENTRON METER	NESSLERISER	SAMPLE
21/10/94	NANT-Y-FFRITH	8.40	7.7	8.4/8.6	FINAL
21/10/94	NANT-Y-FFRITH	6.20	6.3	6.0/6.2	FLASH MIXER
21/10/94	NANT-Y-FFRITH	*	7.2	7.2/7.4	RAW
22/10/94	NANT-Y-FFRITH	8.80	8.0	8.6/8.8	FINAL
22/10/94	NANT-Y-FFRITH	6.20	6.3	6.0/6.2	FLASH MIXER
22/10/94	NANT-Y-FFRITH	*	7.2	7.2/.74	RAW
23/10/94	NANT-Y-FFRITH	8.40	8.0	8.4/8.6	FINAL
23/10/94	NANT-Y-FFRITH	6.18	6.3	6.0/6.2	FLASH MIXER
23/10/94	NANT-Y-FFRITH	*	8.2	7.2/7.4	RAW
24/10/94	NANT-Y-FFRITH	8.40	7.8	8.2/8.4	FINAL
24/10/94	NANT-Y-FFRITH	6.18	6.2	6.0/6.2	FLASH MIXER
24/10/94	NANT-Y-FFRITH	*	7.2	7.2/7.4	RAW
25/10/94	NANT-Y-FFRITH	8.20	7.8	8.0/8.2	FINAL
25/10/94	NANT-Y-FFRITH	6.18	6.3	6.0/6.2	FLASH MIXER
25/10/94	NANT-Y-FFRITH	*	7.2	7.0/7.2	RAW
26/10/94	NANT-Y-FFRITH	8.20	7.6	8.2/8.4	FINAL
26/10/94	NANT-Y-FFRITH	6.18	6.3	6.0/6.2	FLASH MIXER
26/10/94	NANT-Y-FFRITH	*	7.4	7.0/7.2	RAW
27/10/94	NANT-Y-FFRITH	8.20	7.6	8.2/8.4	FINAL
27/10/94	NANT-Y-FFRITH	6.16	6.3	6.0/6.2	FLASH MIXER
27/10/94	NANT-Y-FFRITH	*	7.2	7.0/7.2	RAW
28/10/94	NANT-Y-FFRITH	8.40	8.3	8.4/8.6	FINAL
28/10/94	NANT-Y-FFRITH	6.12	6.0	5.8/6.0	FLASH MIXER
28/10/94	NANT-Y-FFRITH	*	7.2	7.0/7.2	RAW
31/10/94	NANT-Y-FFRITH	8.00	6.4	8.0/8.2	FINAL
31/10/94	NANT-Y-FFRITH	6.18	6.2	6.0/6.2	FLASH MIXER
2/11/94	NANT-Y-FFRITH	8.20	6.7	8.0/8.2	FINAL
2/11/94	NANT-Y-FFRITH	6.18	6.1	6.0/6.2	FLASH MIXER
3/11/94	NANT-Y-FFRITH	8.60	7.1	8.4/8.6	FINAL
3/11/94	NANT-Y-FFRITH	6.18	6.2	6.0/6.2	FLASH MIXER
4/11/94	NANT-Y-FFRITH	8.20	6.70	8.2/8.4	FINAL
4/11/94	NANT-Y-FFRITH	8.20	6.30	6.0/6.2	FLASH MIXER
5/11/94	NANT-Y-FFRITH	8.20	6.90	8.0/8.2	FINAL
5/11/94	NANT-Y-FFRITH	6.18	6.30	6.0/6.2	FLASH MIXER
6/11/94	NANT-Y-FFRITH	8.30	6.90	8.2/8.4	FINAL
6/11/94	NANT-Y-FFRITH	6.18	6.30	6.0/6.2	FLASH MIXER
7/11/94	NANT-Y-FFRITH	8.15	7.90	6.8/7.0	FINAL
7/11/94	NANT-Y-FFRITH	6.18	6.60	8.2/8.4	FLASH MIXER
7/11/94	NANT-Y-FFRITH	*	6.90	6.6/6.8	RAW
8/11/94	NANT-Y-FFRITH	8.30	7.80	8.0/8.2	FINAL
8/11/94	NANT-Y-FFRITH	6.15	6.60	6.0/6.2	FLASH MIXER
8/11/94	NANT-Y-FFRITH	*	7.10	6.8/7.0	RAW
9/11/94	NANT-Y-FFRITH	8.20	8.00	8.0/8.2	FINAL
9/11/94	NANT-Y-FFRITH	6.20	6.00	6.0/6.2	FLASH MIXER
9/11/94	NANT-Y-FFRITH	*	6.95	6.8/7.0	RAW
10/11/94	NANT-Y-FFRITH	8.20	6.90	8.2/8.4	FINAL
10/11/94	NANT-Y-FFRITH	8.20	7.37	8.2/8.4	FINAL WITH DECHLORINATING AGENT
10/11/94	NANT-Y-FFRITH	6.20	6.30	6.0/6.2	FLASH MIXER
10/11/94	NANT-Y-FFRITH	*	6.51	7.0/7.2	RAW
11/11/94	NANT-Y-FFRITH	8.40	7.00	8.4/8.6	FINAL
11/11/94	NANT-Y-FFRITH	6.20	6.50	6.0/6.2	FLASH MIXER
11/11/94	NANT-Y-FFRITH	*	7.00	6.8/7.0	RAW
12/11/94	NANT-Y-FFRITH	8.39	7.10	8.2/8.4	FINAL
12/11/94	NANT-Y-FFRITH	6.19	6.70	6.0/6.2	FLASH MIXER
12/11/94	NANT-Y-FFRITH	*	6.95	6.8/7.0	RAW

Table 11 - Results from Nant-y-Ffrith WTW using ISFET pH Meter.

DATE	WTW	IN-LINE METER	SENTRON METER	NESSLERISER	SAMPLE
21/10/94	PENDINAS	8.41	7.3	8.4/8.6	FINAL
21/10/94	PENDINAS	6.98	6.4	6.8/7.0	PRE-FILTERS
21/10/94	PENDINAS	*	6.2	6.2/6.4	RAW
22/10/94	PENDINAS	8.36	7.2	8.2/8.4	FINAL
22/10/94	PENDINAS	6.97	6.5	6.8/7.0	PRE-FILTERS
22/10/94	PENDINAS	*	6.5	6.4/6.6	RAW
23/10/94	PENDINAS	8.40	7.4	8.2/8.4	FINAL
23/10/94	PENDINAS	7.13	6.6	7.0/7.2	PRE-FILTERS
23/10/94	PENDINAS	*	6.5	6.4/6.6	RAW
24/10/94	PENDINAS	8.33	7.4	8.2/8.4	FINAL
24/10/94	PENDINAS	6.91	6.5	6.8/7.0	PRE-FILTERS
24/10/94	PENDINAS	*	6.4	6.4/6.6	RAW
25/10/94	PENDINAS	8.32	7.7	8.2/8.4	FINAL
25/10/94	PENDINAS	7.00	6.8	7.0/7.2	PRE-FILTERS
25/10/94	PENDINAS	*	6.4	6.2/6.4	RAW
26/10/94	PENDINAS	8.20	7.2	8.0/8.2	FINAL
26/10/94	PENDINAS	6.96	6.5	6.8/7.0	PRE-FILTERS
26/10/94	PENDINAS	*	6.8	6.6/6.8	RAW
27/10/94	PENDINAS	8.34	7.4	8.2/8.4	FINAL
27/10/94	PENDINAS	6.91	6.5	6.8/7.0	PRE-FILTERS
27/10/94	PENDINAS	*	6.8	6.6/6.8	RAW
28/10/94	PENDINAS	7.60	8.4	8.4/8.6	FINAL
28/10/94	PENDINAS	*	6.6	6.4/6.6	RAW
31/10/94	PENDINAS	8.36	7.20	8.2/8.4	FINAL
31/10/94	PENDINAS	7.04	6.20	7.0/7.2	RAW
1/11/94	PENDINAS	8.36	7.20	8.2/8.4	FINAL
1/11/94	PENDINAS	7.01	6.20	7.0/7.2	RAW
2/11/94	PENDINAS	8.41	7.20	8.4/8.6	FINAL
2/11/94	PENDINAS	7.00	6.20	7.0/7.2	RAW
3/11/94	PENDINAS	8.44	7.07	8.4/8.6	FINAL
3/11/94	PENDINAS	7.07	6.40	7.0/7.2	RAW
4/11/94	PENDINAS	8.35	7.20	8.2/8.4	FINAL
4/11/94	PENDINAS	6.95	6.20	6.8/7.0	RAW
5/11/94	PENDINAS	8.49	6.98	8.4/8.6	FINAL
5/11/94	PENDINAS	6.99	6.43	7.0/7.2	RAW
6/11/94	PENDINAS	8.41	6.80	8.2/8.4	FINAL
6/11/94	PENDINAS	6.94	6.60	6.8/7.0	RAW
7/11/94	PENDINAS	8.34	7.15	8.2/8.4	FINAL
7/11/94	PENDINAS	6.94	6.95	6.8/7.0	MANGANESE
7/11/94	PENDINAS	*	6.44	6.6/6.8	RAW
8/11/94	PENDINAS	8.31	7.80	8.2/8.4	FINAL
8/11/94	PENDINAS	6.87	6.91	6.8/7.0	MANGANESE
8/11/94	PENDINAS	*	6.51	6.6/6.8	RAW
9/11/94	PENDINAS	8.40	8.15	8.2/8.4	FINAL
9/11/94	PENDINAS	6.87	6.90	6.8/7.0	MANGANESE
9/11/94	PENDINAS	*	6.41	6.4/6.6	RAW
10/11/94	PENDINAS	6.79	6.70	7.0/7.2	FINAL
10/11/94	PENDINAS	6.79	6.52	7.0/7.2	FINAL WITH DECHLORINATING AGENT
10/11/94	PENDINAS	7.16	6.43	7.0/7.2	MANGANESE
10/11/94	PENDINAS	7.16	6.55	7.0/7.2	MANGANESE WITH DECHLORINATING AGENT
10/11/94	PENDINAS	*	6.56	6.6/6.8	RAW
11/11/94	PENDINAS	8.36	6.77	8.2/8.4	FINAL
11/11/94	PENDINAS	6.91	6.42	6.8/7.0	MANGANESE
11/11/94	PENDINAS	*	6.22	6.6/6.8	RAW
12/11/94	PENDINAS	8.29	7.00	8.2/8.4	FINAL
12/11/94	PENDINAS	6.90	6.53	6.8/7.0	MANGANESE

Table 12 - Results from Pendinas WTW using ISFET pH Meter.