# TECHNOLOGICAL STUDY FOR THE EVALUATION OF BREWING RAW MATERIALS

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## S U M M A R Y

A brief review is made of the available carbohydrate raw materials and of the limitations of laboratory- or production-scale evaluation. A 30-brl (5,000-1) experimental brewery was designed and built to facilitate adequate scientific control and to minimise differences of scale in the evaluation of selected raw materials. Wheat and barley flours and flaked barley were considered as possible substitutes for malt in the grist at levels of 10% to 25%. On technological and economic considerations wheat flour proved to be the most suitable mash-tun adjunct; the optimum level of usage was found to be 15% of the malt grist. Laboratory experiments indicated that the severe processing difficulties encountered when using 25% wheat flour could be overcome in a slurrying process. This work led to the finding that flour slurries might also be used for the preparation of syrups in the brewery. Analyses of traditional malt wort and flour-slurry enzyme hydrolysates showed encouraging correspondence in sugar and amino-acid spectra. Commercially available brewing syrups were also evaluated in the pilot brewery: wort syrups proved to be more attractive commercially than barley or green-malt syrups. (Wort syrups being derived from maize or wheat)

The extraction efficiency of available extract from a traditional malt grist was ~ 97%. Although cost evaluation showed that sizeable savings can be made by using 15% wheat flour or 33% wort syrup in the grist, the Excise Duty levied on wort increases the cost tenfold; thus it is of paramount importance that maximum use is made of dissolved solids. The mass-balance of grist solids during wort preparation was therefore extended to the fermentation stage of beer production, and it was revealed that brewery utilisation of wort solids might be improved by making better use of dextrins, by using primings in place of residual wort sugars and by reducing yeast growth in various ways.

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## GENERAL INTRODUCTION

The importance of raw material costs particularly those of carbohydrates is recognised by most large brewery groups and, as will be demonstrated, there is scope for a considerable financial saving, even under the constraint of using existing traditional brewery plant. Curtis (1) pointed out that the contribution of raw materials to the overall cost of beer was often considered to be small in comparison with other overheads. Consequently economies had been sought in other fields and some brewers were reluctant to adopt processes aimed solely at economy in the use of raw materials. Nevertheless, reference to the National Board for Prices and Incomes report (2) 1966, entitled 'Costs, prices and profits in the Brewery Industry' reveals that raw materials costs are as much as a quarter of the total, excluding Excise Duty. From information supplied by brewers producing about half of the country's total output of beer, the Board estimated the following figures for 1966:-

Cost of brewing, bottling and distribution

| | |
|---|---|
| Brewing materials | 23% |
| Bottling materials | 5% |
| Production labour | 17% |
| Distribution labour | 11% |
| Other costs | 37% |
| Depreciation | 7% |
| | 100% |

(Excise Duty represented 62% of the wholesale selling price, excluding profits and purchased beer.)

These statistics underline the importance of development work in this field, particularly in pilot scale brewing trials with full technological and economic evaluation of results. There are many carbohydrate raw materials worthy of attention, including wheat and barley flours and the syrups derived from various cereals. Amongst review articles that have recently appeared are those of Harris (3) (4); Macey (5) who reviewed various carbohydrate sources with particular emphasis on process economics; Imrie (6) (7) who discussed the use of 'wort syrups' derived enzymically from wheat and barley; and Russell-Eggitt (8) on wheat-flour in brewing. The aims of the succeeding paragraphs are to review the technology underlying the use of wheat and barley flours, and 'wort syrups' in brewing and to reveal the 'gaps' in knowledge which the present work is designed in part to bridge.

## Wheat and Barley Flours

The diastatic activity of malt is usually more than sufficient to convert the malt starch itself (9). Thus, other starch-rich materials may be used although their own diastatic activity may be negligible. Adjuncts commonly used are flaked maize, maize grist, flaked barley and wheat-flour. Rice is currently too expensive in this country to merit consideration.

Wheat-flour is one of the cheaper adjuncts and is readily available both as 'straight run' flour and air-classified low nitrogen flour. Straight run flours are derived from wheat low in nitrogen content and are prepared by the normal milling process in which bran and germ are removed and the endosperm reduced to a fine powder. Air-classification can be used to eliminate some of the protein debris. A particle size range of 17 to 35 microns is usually selected (8), thus eliminating the finer debris and aggregates of starch granules held in a proteinaceous matrix. The nitrogen content may be reduced from 1.6% of solids to 1.2% of solids by air-classification. Barley flour is also available and can be combined with some husk to assist run-off from the mash tun.

Both wheat and undried barley are unsuitable for milling in conventional brewery malt-mills. It has been found (10) that such mills tend to flatten rather than break the hard unmodified barley. Martin (11) had some success in crushing barley in a malt mill passing the material twice through, but the utilisation was low. Elsewhere (12) successive passages through a roll mill have been used, giving a finely powered endosperm but leaving the husk relatively undamaged. Wheat and barley may be hammer-milled: in one process (13), feed barley is hammer-milled and subsequently milled in a roll mill. In another (14) dressed grain is screened and fed into a hammer mill which reduces size until the 'meal' is forced through a 1/16th inch of 3/16th inch aperture screen for wheat and barley respectively. A considerable amount of barley husk remains relatively undamaged which helps to improve drainage in the mash tun. Steeped barley can be milled in a differential roll mill if the moisture content is between 35-40% (15). Below 35%, the grain is too hard but above 40% an adhesive slurry is formed. In breweries equipped with wet-mills it is advantageous to steep the barley for 1 hour before grinding.

Wheat flour has a bulk density of 35 $lb/ft^3$ (8), much higher than malt, so that storage costs are lower. Flour is not free-flowing, as is malt, so that hopper sides must be inclined more steeply and vibrators used. However, flour is very readily conveyed pneumatically and thus transferred from bulk tanks to brewers' bins.

Wheat flour is normally used in admixture with malt in the mash tun. Wheat starch is readily attacked by normal diastase enzymes (9). It has been emphasised (9) (15) that the flour should be perfectly mixed with the malt, using a mechanical feeding device, and kept evenly mixed up to the point of ejection into the tun. A Steele's masher is recommended (15) and a thick mash, ~~2-2¼~~ 2.0-2.25 brl per quarter preferred as this helps to prevent separation of the finer particles in the tun. If fine material is drawn down forming a layer above the mash-tun plates, wort run-off is slowed and there is increased risk of reduced extraction efficiency. There is some indication (8) that a fairly coarse malt grind may help to prevent separation of fine particles in the tun.

In order to use high wheat flour levels in commercial-scale brewing, the use of a highly enzymic malt, such as green malt or 6-row high nitrogen distillers malt, or improvement of drainage from the tun by the use of wet-milling have been suggested as possible techniques (16). On the laboratory, or model-brewery scale, levels of 50% wheat and raw barley have been used (16) but raw barley was found to give inefficient extraction (89-92%) at this level, and at 70% gave low fermentability and incomplete extraction. Various grist compositions have been used, some of which are listed below:-

| Material | Percentage of grist in mash tun | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Pale Malt | 65 | 55½ | 75 | 46 | 29 | - | 67 | 67 - 75 |
| Green Malt | - | - | - | 20 | 28 | 40 | - | - |
| Distillers Malt | - | - | - | 10 | 14 | 25 | - | - |
| Crystal Malt | 6 | 6 | - | 4 | 3½ | 6 | 5½ | 5 |
| Wheat-flour | 18½ | 20 | - | 20 | 24 | 30 | 24 | 10 - 15 |
| Barley-flour | 10½ | 18½ | 25 | - | - | - | - | 10 - 15 |
| Malt extract | - | - | - | 1 | 1 | - | 4 | - |
| Reference | (10) | (10) | (12) | (15) | (15) | (15) | (15) | (11) |

The optimum mash temperature is commonly quoted as 66°C. The temperature of mashing liquor used (striking heat) should be a little higher than usual as there is lower heat of hydration when using wheat-flour (8). The use of wheat and barley flours, especially at high levels, tends to give reduced rates of run-off from the mash tun, but little detailed or truly comparable data has been published on this subject. One of the aims of the present work is to determine such data.

There are several important effects of flour usage on wort and beer properties. The concentration of nitrogen in wort is decreased as compared with all-malt brews (16) (17). This effect is more pronounced with barley due to the presence of proteolytic enzyme inhibitors (17) (18) particularly with respect to the amino acid fraction. In wheat flour worts it appears (19) that the proportion of high molecular weight nitrogen compounds is increased, suggesting that the malt enzymes assist solubilisation of the wheat-flour proteins without hydrolysing them to any extent. Conversely the free amino acids content is generally reduced by ~ 20%. It has been found that wheat-flour contributes no amino acids to the wort (19) (20).

Birtwistle (21) found that using 25% wheat-flour, beer nitrogen and anthocyanogens were reduced by 20%, shelf life was improved, wort fermentability was unchanged, bitterness and head retention were improved by 12% and 15% respectively. The superior head retention has been attributed to the salt-precipitable protein contributed by the wheat-flour (19). Taste tests have shown little difference between wheat-flour and traditional beers (8).

Syrups and Sugars

The total solids content of copper wort in Pale Ale brews is generally made up of material derived by extraction of the grist in the mash tun and of carbohydrates added in the form of sugars and syrups to the copper. The carbohydrate compositions of sweet worts ex mash tun have been reviewed (22) (23) (24) and the data has been recalculated to a common total carbohydrate basis below:-

| Reference | Percentage of total carbohydrates | | | | | |
|---|---|---|---|---|---|---|
| | (23) | (23) | (22) | (24) | Mean | |
| Fructose | 2.2 | 3.5 | 10.5 | 9.8 | 2.5 | 61.5 RFS |
| Dextrose | 8.8 | 10.6 | | | 8.8 | |
| Sucrose | 4.7 | 5.6 | 6.5 | 5.2 | 5.5 | |
| Maltose | 49.6 | 41.4 | 42.3 | 45.3 | 44.7 | |
| Maltotriose | 14.0 | 12.1 | 14.0 | 14.5 | 13.6 | 13.6 SFS |
| Maltotetraose | 20.7 | 2.1 | 5.7 | 25.2 | 24.9 | 24.9 NFS |
| Higher sugars | | 24.7 | 21.0 | | | |

RFS - readily fermentable sugars (Glucose, Fructose, Sucrose, Maltose)

SFS - slowly fermentable sugars (Maltotriose)

NFS - non-fermentable sugars (Maltotetraose and higher saccharides)

Addition of sugar at 12½% of total extract to the wort in the copper increases the percentage of 'RFS' from 61.5% to 66.7% of total carbohydrate. Brewers yeast is unable to ferment maltotetraose or higher polymers (23); thus the theoretical fermentability of the carbohydrate spectrum of a wort may be defined as $\frac{\text{RFS + SFS}}{\text{total carbohydrate}}$. This theoretical value is seldom attained; some maltotriose and maltose usually remains at the end of fermentation. In general, lower mashing temperatures and the more highly diastatic malts give the more fermentable worts. MacWilliam (23) mentions that small amounts of other sugars are also found in malt worts:-

| | | |
|---|---|---|
| Free Pentoses | Xylose<br>Arabinose<br>Ribose | 1.5 mg/100 ml wort<br>1.4 " " "<br>0.2 " " " |
| Disaccharides | Nigerose, maltulose<br>Isomaltose | Less than 0.2 mg per 100 ml wort |
| Trisaccharides | Gluco-di-fructose | Less than 0.2 mg |

During fermentation of wort by yeast, sugars disappear in the following order: sucrose, fructose, glucose, maltose. Maltotriose is slowly fermented and is thus important during 'secondary fermentation (26). Glucose and fructose are incorporated by facilitated diffusion (27) (28). Maltose and maltotriose require active transport and must be hydrolysed within the cell before fermentation can occur (28), their fermentation requires the synthesis of two permeases and maltase, both inducible enzymes.

The sugars added to the copper are traditionally invert or sucrose, but a range of syrups of complex carbohydrate spectra is now available. Moreover the extract cost of some syrups is lower than that of invert, sucrose or mash-tun grist.

Maize syrups may satisfactorily be used (29) as substitutes for invert sugar, leading to savings. They have also been used (3) in place of flaked maize, at 30% malt replacement, with no evidence of quality deterioration. Saletan (31) compared the use of 20% wheat-flour on extract basis in the mash tun as against 20% wheat-flour syrup added to the copper. The wheat-flour syrup brew was satisfactory and gave a more highly fermented beer. Harris (3) reported that beers brewed at 30% malt replacement by wheat syrups gave normal analyses and no evidence of the adverse effects found with wheat-flour.

Brewing trials have been made with syrup derived from unkilned malt (32). At over 50% malt replacement the flavour of the beer produced was noticeably different though not necessarily inferior. Beer brewed from 100% syrup was hazy, but the haze could be removed by filtration and the finished beer was less susceptible to the development of 'non-biological' haze than traditional beer.

Imrie (6) listed barley, oats, wheat and rye as suitable raw materials for the production of syrups, and said that if malt were completely replaced the market for syrup would exceed 500,000 tons per annum (1967).

The available tonnages in the UK in 1967 were:

| | tons |
|---|---|
| Barley | 8,280,000 |
| Wheat | 7,879,000 |
| Oats | 1,234,000 |
| Rye | 33,000 |

Since oats and rye are not produced in sufficient quantity, barley and wheat were considered to be the most likely carbohydrate sources. Maize is also available in large quantities, mainly from N. America but also from the Continent.

Kirsop (33) broadly reviewed the different ways in which wort syrups may be produced by the activities of green-malt or foreign enzymes.
He said that green-malt syrup could be expected to give wort similar to traditional wort except for differences due to the absence of the embryo activity present in malting. These differences could be greater in barley syrup as 'foreign' enzymes are used and these might also produce small amounts of undesirable substances. Maize-starch syrups may be produced by the acid/enzyme process to give high dextrose-equivalent (DE) syrups. The enzyme can be either α-amylolytic and dextrinising, or α-glucamylase which converts starch direct to glucose. The enzyme action may be stopped prematurely to give relatively low DE syrups containing higher sugars and dextrins. The carbohydrate spectra of such syrups differ markedly from traditional wort.

In the dual-enzyme process the first stage may be effected by a bacterial α-amylase (30) followed by fungal α-amylase to give maltose-rich syrups similar in carbohydrate composition to wort. When amyloglucosidase is used in the second stage, however, the product is a syrup rich in glucose. Wheat- and maize-starch syrups may be prepared in this way. Maize syrups are produced free of nitrogen but wheat-starch syrups always contain some nitrogenous constituents.

Although malted barley is the starting material for the normal brewing process, as MacLeod (35) has said 'There is nothing natural about the malting process'. Therefore the use of enzymes similar to those found in malt but obtained from other sources can be considered for the production of wort from barley. Unless barley is malted there is a deficiency in amylolytic and proteolytic enzymes. The enzyme contents of several barleys and their malts are compared below

| | CAMBRINUS (malting) | α- amylase (ASBC) | β-amylase (relative) | Diastatic power | Proteinase |
|---|---|---|---|---|---|
| | Barley | 0 | 8.7 | 95 | Insufficient |
| | Malt | 36.2 | 6.5 | 240 | Sufficient |
| Wieg (36) | IMPALA (feed) | | | | |
| | Barley | 0 | 7.5 | 100 | Insufficient |
| | Malt | 38.6 | 9.7 | 290 | Sufficient |
| | CAMBRINUS | | | | |
| | Barley | 0 | 12 | - | 3 |
| | Malt | 35 | 7 | - | 6 |
| MacLeod (35) | DELISA | | | | |
| | Barley | 0 | 13 | - | 3 |
| | Malt | 50 | 7 | - | 7 |
| | | After Klopper | | After Sandegren | |

The proteolytic activity of the raw grain is insufficient for the production of adequate supplies of amino-acids for yeast nutrition. The diastatic power of raw barley is poor, alpha-amylase activity being developed in the malting process. Furthermore the β-amylase of barley is less extractable than that of malt (35). When preparing worts or syrups from barley it is therefore desirable to add α-amylase, proteolytic enzyme and β-amylase usually as malt, as has been described in a commercial process for the production of barley syrup (36).

Rainbow (35) compared the properties of two barley-syrups with conventional Pale Ale wort. The carbohydrate spectra were very similar and there were only relatively minor differences in the measured nitrogenous constituents. His results indicated that the HMW-nitrogen figures were more variable in the barley-syrup worts which might be reflected in the foam and haze forming potential of the beers prepared from them.

General scope of experimental work

The work reviewed in the preceding paragraphs falls into two main categories: 1) Laboratory-scale evaluation of raw materials by analysis and model-brewery trials. 2) Commercial scale brews. The gap between these two approaches was referred to in the Horace Brown Memorial Lecture in 1967 (37) when Mendlik drew attention to the problem of the relationship between the scientist and the production manager. The brewing scientist often devoted himself to research work of a fundamental and possibly abstruse nature, whereas the brewing manager gave his attention to the control of production. Kreiss (38) had said "For if research is to play its proper part in an industry, its results must be made understandable to those whose business it is to apply them; thus liaison between the fundamental scientist and the producer assumes extreme significance, and high qualities are required from those who will devise schemes of experimental work which will help forward the development of the industry". Hall (39) also drew attention to the gulf between advances in the laboratory and implementation in the brewery. He said that when so many new and often revolutionary materials were being offered by suppliers it was important not only to develop appropriate methods of analysis for these materials, but to assess their influence on the brewing process and the quality of the finished beer. The most suitable method was to brew beer with them. Full scale trials, however, are hazardous from the standpoints of both the brewing scientist and the production manager on the following counts:

1. It is not usually possible to risk use of the experimental material at high levels initially; thus progress is slow.
2. It is difficult for the technologist to exert sufficient scientific control in a large brewery in which may different departments and operators are involved.
3. 'Negative' results can lead to loss of beer, if unpalatable, and cause production hold-ups which are extremely costly in terms of productivity and production-scheduling.

The broad aim of this experimental work is to bridge the gap between laboratory assessment of brewing raw materials and commercial-scale experience. Materials will be evaluated in a comparatively large pilot brewery in which the problems of scale of smaller model-breweries are minimised. The pilot brewery will be fully equipped with the conditioning, carbonation, chilling, cold storage and filtration equipment which is important in the production of a commercially acceptable beer. Facilities for racking into keg, cask and bottle will be provided, and the laboratory and engineering facilities of a large commercial brewery made available.

The main stages in the technological study of raw materials will be:-

1. Selection of the raw materials for trial on the basis of availability, cost and likely technical suitability.
2. Pilot-brewery trials of selected mash-tun adjuncts at levels of 10%, 17% and 25% of the malt grist, and of selected syrups at 33%, 67% 100% of total extract.
3. Supplementary work designed to overcome the technical difficulties encountered in pilot-brewery trials.

It has been mentioned that Excise Duty represented as much as 62% of the wholesale beer price (1966). Any discussion of raw material costs would therefore be incomplete without consideration of the Excise Duty levied on the extracted solids. A mass-balance is presented in Part II providing a link between raw material and Duty costs. Thus the relative importance of raw-material cost reduction and the savings made by improved utilisation of wort solids can be shown.

# METHODS

## a) DESIGN AND OPERATION OF THE PILOT-BREWERY

### 1. Initial Design Considerations

#### a) Budget

A budget was agreed for the project, of which 35% was for building costs.

#### b) Size

Pilot breweries of 5 brl capacity are capable of producing satisfactory beer but the problem of scale-up would be considerable when translating the results to production breweries. A 60 brl brewery would be capable of small production runs but would require a sizeable building. The existence of some 15 brl fermenters made it attractive to decide on a 30 brl brewery so that each brew could be split into 2 fermenters. Finally it was agreed to build a 30 brl plant based on 1045° OG wort to be used exclusively for experimental work.

#### c) Site

The site chosen was in the precincts of a London brewery where supply of raw materials, laboratory control, labour, services and means of disposal of surplus beer were available. Space was available on the 2nd and 3rd floors of a building which previously housed a bottling store. The area was opened up by removing a section of the 3rd floor, and the elevation required for the grist case to command the lauter tun was supplied by creating a small penthouse on the roof.

### 2. Design of the Major Brewing Plant

Commercially available small-scale 'packaged' plants were considered but rejected in favour of conventional plant on the grounds of, 1) Cost: Installed cost approx. 30% higher than estimates for conventional plant. 2) Inherent inflexibility of operation.

In discussing the conventional plant required, the following systems were considered:

a) Mash tun + Copper/Hop-back/mash mixer

In design, however, the multipurpose vessel proved too complicated

b) Mash-mixer + Lauter tun + Copper/Hop-back + Whirlpool trub separator

The operation of a copper/hop-back would have been difficult, especially at different experimental hop rates. It was decided to use a simple hop-strainer and to retain the whirlpool separator to provide an extra means of wort clarification.

c) Copper/mash-mixer + lauter/mash-tun + hop strainer + whirlpool

This system was finally agreed, providing flexibility of operation in that the grist could be mashed direct into the mash tun, or into the mash mixer and transferred to the lauter tun later.

3. Details of Plant

a) Malt handling

An electric hoist is used to lift bags of malt to the 3rd floor where it is weighed into a malt hopper. The malt is screened and ground in a 2-roll mill. A bucket elevator lifts the ground malt to the grist case which commands the lauter tun and copper/mash mixer. A vibrator is attached to the grist case. A vibratory feeder is used to feed adjuncts into the malt at the foot of the grist elevator.

b) Liquor backs

Liquor is supplied from 2 x 40 brl liquor backs. These are lagged and steam coils used for heating. Treatment is added batchwise. An integrating flow meter and a flow indicator measure the quantity and rate of flow of liquor.

c) Lauter tun/Mash tun

The lauter tun was fabricated to our own design in stainless steel. The vessel is 6 ft. dia., has conventional slotted plates, annular V-channel bottom with 4 draw-off points, and fixed sparge nozzles. The tun is designed for 4.0-4.5 qr malt, giving an operating bed depth of 25-30 in and drained depth of 17-19 in. The tun is equipped with retractable knives which rotate at fixed speed. Grain-discharge bars can be slotted on to the knives supporting bar, to allow spent grain removal. A Steeles masher is used for making the mash.

d) Copper/mash mixer

The copper/mash mixer was also made in stainless steel by Burnett & Rolfe and is also 6 ft. dia., with a conical bottom. The copper is designed to hold a maximum charge of 35 brls. There are 3 steam-jacketed heating zones, the whole vessel being lagged. The annular heating gives an inward-roll boiling action, and an annular baffle, above the surface, helps to deflect the boiling wort towards the centre. A central drive shaft supports two paddles for mash-mixing at two speeds.

e) Hop Strainer and Whirlpool separator

The hop strainer is a simple perforated steel basket. The whirlpool separator is a stainless steel, cylindrical vessel, 6 ft. diameter. The wort enters tangentially through a venturi nozzle at a point 1/3 of the way up from the bottom. The bright wort is aerated and cooled through a plate heat-exchanger.

f) Fermenters

There are 5 x 15 brl. Meura fermenters and the working depth is 5 ft. Cooling coils with chilled liquor are used for cooling and as these vessels are small, temperature can be raised or maintained by appropriate ambient temperature (normally ~ 70°F). After fermentation only 5 brls is processed further, the remainder being blended in the main brewery. Two horizontal Porter-Lancastrian tanks are used for conditioning. These vessels are equipped with stirrers, temperature and pressure gauges, and thermostatically controlled by external jacketed cooling from individual refrigeration units.

g) Cold Room

The Experimental Brewery has its own cold room, where the conditioned beer is further processed to keg and bottle. The beer is carbonated and then chilled through a plate heat exchanger against brine into 5 brl. Fairey stainless steel tanks. The beer is held at ~1°C for 7-10 days normally and then powder-filtered into bright beer tanks. Keg beer is racked direct from the bright beer tanks. Bottled beer is further sheet filtered and bottled using a single-head Meadowcroft machine. Bottles are crowned using a Crown Cork hand-crowner and pasteurised at 59°C for 20 min in a tank pasteuriser.

b) LABORATORY METHODS

Malt and adjuncts were analysed by the methods recommended by the Institute of Brewing (40). The methods used were:

Extract, Cold Water Extract (CWE), Diastatic Power, Colour, Total Nitrogen.

Sieving test: 150 g sample were sieved using two screens of square mesh, aperture sizes 1.41 mm and 0.149 mm side, in an Endcott test-sieve.

Moisture: Except where stated otherwise, solids content of materials were determined after drying 18 hr. at 105°C.

Spent grain: Loss of extract in spent grain was determined by the method of Lloyd Hind (41).

Sugar composition of wort, beer and syrups was determined by gas-liquid chromatography of trimethyl silyl derivatives (42).

Amino-acid analyses were made by the methods of Spackman, Stein and Moore (43) using a Technicon automatic amino-acid analyser (at Spillers Technological Research Station, Cambridge).

Viscography: A Brabender Amylograph (Brabender Corporation, Rochell Park, N. Jersey) was used in the study of viscosity changes of flour slurries. The methods are described by Whistler (44). The work was done at Spillers Technological Research Station, Cambridge.

α-amino nitrogen was determined by the method of Satake (45).

Amylase activity of enzyme preparations and flours were determined by the methods of Sandstedt, Kneen and Blish (46), and Farrand (47).

Alcohol was determined by distillation and reference to Spirit Tables (48); OG by reference to the 'Original Gravity Tables' (49).

AL was determined by measurement of the SG of beer fermented by an excess of yeast (8g/200 ml) at 28°C with continuous agitation on a reciprocal shaker.

Head Retention was determined by the Rudin method (50).

Ash content of wort, beer or yeast was determined after ashing the dried material 2 hr at 600°C in a muffle furnace.

Carbon analyses of dried malt, adjunct, spent grain, yeast and wort, and yeast nitrogen content were determined by Microanalytical Laboratories, Oxford.

Volatiles etc. Dimethyl sulphide, iso-amyl acetate, ethyl acetate, diacetyl and acetaldehyde were determined by gas chromatography, using an F & M Model 400 chromatograph with a 1 : 1 split between flame ionisation and electron capture detectors. Details of gas chromatography have been described by Button (51).

# PART I. EVALUATION OF RAW MATERIALS

## SECTION 1. SELECTION OF EXPERIMENTAL RAW MATERIALS

Raw barley has been a popular mash-tun adjunct for many years as Maiden (52) reminded us when he referred to a book (53) published in 1832 in which the author recommended the use of barley meal or unmalted corn at the level of 20%. Taxation and legislation militated against the use of adjuncts in the nineteenth century, however. Imrie and Martin (7) pointed out that the use of sugar was banned in the period 1688-1847 so as to protect the barley growers. The use of raw grain was also forbidden in brewing, and in 1855 millstones were outlawed, smooth rolls only allowed, so that it was difficult to mill raw barley in the brewery. These laws were enforced until 1880. Maiden (52) tells us that in 1883 a book entitled "Brewing with Raw Grain" was printed, but brewers were slow to adopt such practices, as revealed in H.M. Customs & Excise returns (9), which showed that in the forty-year period up to 1965 the average grist was 80% malt, 5½% mash-tun adjuncts, and 14½% brewing sugar, excepting the abnormalities of war periods.

It was mentioned in the 'General Introduction' (p. 13) that only barley and wheat are available in the UK in sufficient tonnage to merit consideration as possible raw materials for adjuncts. To these should be added maize, which is imported in considerable quantities from America. Maize starch has a high gelatinisation temperature so that the use of maize grits in a brewery requires the use of a separate cooker. Flaked maize is a comparatively expensive adjunct and so it was decided not to include maize products in this work.

Wheat and barley, both in the form of raw grain and flour, are comparatively inexpensive sources of carbohydrate (see Section Ib, Part II).

Furthermore previous work, reviewed in the 'General Introduction', has established their technological suitability. Wheat is readily available in this country in the form of "straight run" or "air-classified" flour, as has already been mentioned. Barley is available in many different forms. Raw barley can be milled in the brewery, using the wet-milling technique, or can be purchased as ground barley of variable fineness of grind and husk content. There is also a choice between high quality low nitrogen malting barley and feed barley which is less expensive. As in the case of maize the popularity of the use of a separate conversion vessel for liquefaction of the starch in raw grain declined with the development of the flaking process. Flaked barley is prepared by moistening the grains and squashing them between steam heated rolls, and the resulting flakes are then dried (9). In this process it is unnecessary to dehusk and de-germ the barley before flaking, although in a more recent innovation (7), flaked pearled barley, the husk, most of the germ and the outer layer of protein are removed from the grain. Even more recently, a bacterial alpha-amylase spray has been used to coat the flakes prior to drying (54). The advantage of this enzyme treatment lies in the reduction of viscosity of the barley flake extract which might otherwise cause run-off difficulties in the mash tun.

Since the use of intact raw grain in the brewery would have required the installation of hammer-mills or wet-milling plant, and it was required that successful work should be of direct applicability in production plant, wheat and barley flours and flaked barley were the chosen mash-tun adjuncts. Syrups were also included in this work on account of their low price (wort syrups), and usefulness in extending production capacity. These materials are dealt with in the following order:

1. Wheat flour
2. Barley flour
3. Flaked barley

The experimental brewery work on these materials led to the development of starch slurrying processes:-

1. For use in the mashing process
2. For preparation of a syrup in the brewery

This led to the study of commercially available syrups which are dealt with in the final section of Part 1.

1. Sugar syrups
2. Wort syrups
3. Barley syrups

The mass-balance and economics of carbohydrate raw material utilisation in the brewery are dealt with in Part 2.

## SECTION 2. MASH-TUN ADJUNCTS

### a) WHEAT FLOUR

#### Analysis of wheat flours

Brewing flours are generally selected from low protein soft wheats (8). Since the nitrogen content of such flours may vary from 1.5% to 2.6% on solids it is difficult to achieve nitrogen contents of 1.4 - 1.5% by wheat- and mill-stream selection with any consistency. By the air-classification process, however, flours of nitrogen content no greater than 1.2% solids can consistently be produced. Two major flour-millers each offer two grades of flour differing in nitrogen content in this way:-

| Miller | Product | Nitrogen Specification (on solids) |
|---|---|---|
| J. Rank | "Silver Crest" | 1.2% maximum |
| | "Summit" | 1.4% average |
| Spillers | "Brumore" | 1.1 - 1.2% average |
| | "Attraction" | 1.5 - 1.6% average |

These and other flour samples were analysed in the laboratory, and the results were as detailed in Table 1.

#### Malt Analysis

Malts and adjuncts were analysed by the methods recommended by the Institute of Brewing (40). Results of these analyses are recorded in Table 2. The variability of extract of the malts used, as determined in the laboratory, could be explained either by the varying quality of the malt, or by variations in the determination. Comparison of the results obtained when the same malt sample was analysed on separate occasions revealed only slight variability in the laboratory figures. Duplicate determinations on average varied ± 0.5 brewers lb. from the mean, occasionally differing by 1.0 brewers lb. The differences in extract between the malts are therefore real and the laboratory-extract figures give a fairly accurate comparison of the potential extracts of the different malts. The extract figures are expressed in terms of brewers pound per quarter of 336 lb. of malt or adjunct.

Screening test for ground malt

The fineness of grind of the malt in the brewery mill is important in two respects. Firstly size reduction must be sufficient to allow penetration of mash and sparging liquor, otherwise the extract yield would be reduced. Conversely the malt should not be so finely ground that run-off from the mash-tun would be impeded. In these experiments, in which wheat flour is blended with the ground malt, these points are particularly important. The particle size-range of the wheat flour itself was 20-50 microns for the air-classified low nitrogen flours, and 0-150 microns for the other flours. Thus the wheat flours used can be considered as being in the same particle size range as the flour fraction of the brewery-milled malt.

A conventional malt mill, with two pairs of rolls, was used in the experimental brewery. A sieve test was devised using an Endcott test sieve in which ~ 150 g. of sample was sieved using two screens of square mash, aperture sizes 1.41 mm and 0.149 mm. Tests were made in which the roll setting were varied and the results showed that the setting of the top (first) pair of rolls had most effect. Table 2.

Analysis of production-brewery ground malt revealed a particle-size distribution corresponding to a relatively coarse grind on the experimental mill and so this mill was set to give similar results. Malt grains prepared from different barleys show intervarietal size differences. A smaller grained malt would tend to pass through the mill rolls without being crushed. It was therefore necessary to examine the ground malt for the presence of unbroken grains and to check the sieve analyses. The results for the experimental grists are listed in Table 4.

Grists

The experimental and control-brew grists were based on a production-brewery grist for Pale Ale of Keg Bitter:

| | |
|---|---|
| Standard pale malt | 88 quarters (336 lb/qr) |
| Crystal malt | 5 quarters (272 lb/qr) |
| Flaked maize | 7 quarters (336 lb/qr) |

On a weight-percentage basis, allowance must be made for the lower weight of a crystal malt quarter. The total carbohydrate for keg, or draught pale ales is made up of the malt outlined above and sugar which is added to the copper. The copper sugar, a liquid sucrose product, represents 12½% of the total extract, the remainder being being provided by the malt grist. The total grist of a production brew may thus be represented as shown in Table 5 in which the grist compositions of production brewery, experimental and control brews, are compared. The experimental malt-grists included 10%, 15% and 25% wheat flour. At the 10% level of flour usage the flaked maize was not replaced, only the standard malt percentage being reduced. At 15%, 17% and 25% levels of flour, the flaked maize was totally replaced, together with a part of the malt.

Brewing procedure

The total amount of malt grist used in each experimental-brewery run was 3.972 qr. This amount was accurately weighed, using an Avery platform scale, into the malt hopper, roughly blending the crystal with the pale malt. The malt was milled 15 hr. before each brew, dust and malt culms being removed at the screens and the wheat flour blended with the ground malt, using a vibratory feeder, as it left the mill. Further mixing occurred in the screw-conveyer which carried the materials to the grist case. Brewing liquor was treated with calcium sulphate, sodium chloride and sulphuric acid, roused with air, heated by steam coils to the required temperatures for mashing and sparging, and held in two 35-brl. capacity lagged tanks. An integrating flowmeter and a flow indicator were used to record the volume of liquor used in each brewing operation and to indicate the liquor flow rate during mashing and sparging.

Provision was made for steam injection beneath the mash-tun plates so that the mash-tun could be heated prior to mashing. Before starting to mash the grist into the tun sufficient hot liquor was admitted to cover the plates; this is necessary to prevent an air-lock developing beneath the plates and to prevent blinding of the plate slots. Approximately 1.2 brl of liquor was required to cover the plates. A conventional Steele's masher was used to make the mash. Including the plate liquor, a total of 8.5 ± 0.4 brls of liquor at 71°C was used during mashing for each brew. This is equivalent to 2.14 ± 0.1 brls/quarter of grist. The mashed-in bed depth above the plates was 27 in. and the mash area 28 $ft^2$. The initial temperature of the bed was 65.0 - 65.5°C and the time taken in mashing was 8 minutes. The tun was equipped with retractable knives which rotate at fixed speed and preliminary experiments were made to determine their best use. It was found advisable to mash with the knives in the raised position to avoid the creation of channels through the bed by the vertical support bars. On completion of the mash it was found possible to level the bed by running the knives in the top 6 ins. of the bed. Use of the knives in the lowered position removed entrained air from the bed, causing it to settle prematurely on the plates, often blinding the slots and reducing the rate of wort run-off. In many production breweries it is the practice to "underlet" hot liquor beneath the plates shortly after mashing. This may have the effect of suspending any fine particles lodged in the slots and redepositing them within the bed thus creating more area for filtration. In the pilot brewery, however, no advantage was found, and on some occasions the rise of liquor up through the slots was uneven causing disarrangement of the bed. Another procedure, that of recirculation of wort at the start of run-off, was found to be impractical as the wort tended to bore a hole through the floating bed on re-entry into the tun. Neither of these practices were therefore adopted in the brewing experiments.

The period after mashing before commencing the run-off of wort from the tun is known as the "stand-time". In production breweries the stand-time usually given is one hour. Experiments were made in which the "stand-time" was eliminated so that taps were set immediately after the mash. The most obvious effect of eliminating the stand period was on the specific gravity (SG) of sweet wort leaving the tun. The period during which SG rose was much longer than usual (see Fig. 1 ).This may be explained by the incomplete mixing of plate liquor with the wort from the mash, so that diluted wort is first drawn off from the tun. When a stand period is allowed there is some natural circulation of the higher density wort from above the plates, displacing upwards the plate liquor from below. Diffusion also occurs, so that after a 1 hour stand period a considerable amount of mixing has taken place, and the density of the wort below the plates is little less than that above. In the pilot brewery the proportion of plate liquor to mashing liquor is higher than that of large production brewery tuns:-

| | Pilot Brewery | Production Brewery |
|---|---|---|
| Plate liquor | 45 gals | 20 brls |
| Plate + mashing liquor | 306 gals | 200 brls |
| Plate liquor % | 15% | 10% |

If the plate liquor is run off early then effectively less liquor is available for diffusion of dissolved solids from the mash and this reduces the efficiency of extraction of the grist. This effect would be less marked in the production brewery as proportionately less plate liquor is used. In a pilot brew, with zero stand-time, the utilisation of grist material was 95.5% compared with 97.2% for a 1-hour stand control brew. A further factor is the time dependent diffusion of dissolved material from within each particle of grist into the main body of wort. If insufficient time is allowed for the reduction of diffusion gradients within the bed then extraction will be inefficient. In the pilot brewery the reduction in utilisation is likely to be higher than in a production-scale tun where the proportion of plate liquor is lower, and the bed is deeper, giving a greater number of "theoretical plates", or extraction stages. Carbohydrate and nitrogen analyses of the worts and beers showed the enzymic conversions to be as complete as in control brews (see Tables 6 and 7). These results indicated that the length of stand-time was unimportant, but a period of 1 hour was selected as standard for subsequent brews.

In experimental work with wheat flour as a mash-tun adjunct the operations of wort run-off and sparging are critical. In brews using control grists it was found most satisfactory to start sparging at the commencement of run-off and to balance the rates of sparge and run-off so that the bed level remained constant. As leaching of the bed proceeded, the gravity of the wort leaving the tun fell, and when an SG of approx. 1.0220 was reached it was found that the grains slowly sank forming a bed on the mash tun plates. At this stage it was possible to reduce the level of the bed, by cutting the sparge rate, until the top of the bed reappeared. This did not reduce the rate of flow from the tun except in so far as the hydrostatic head was reduced. A shallower bed at this stage increased the efficiency of extraction of the bed with the remaining sparge. Also at this point it was possible to run the knives at the bed surface, without disturbing the porous structure, and helping to maintain an even bed depth over the whole tun area. After all the sparge liquor had been applied it was found helpful to run the knives slowly bringing them down through the bed to ensure that all parts of the bed were leached.

## Results of brews using 10%, 17% and 25% wheat flour grists

Preliminary experiments were made in which wheat flour was used at 10% by weight of the malt grist. The flour used had a moderately high nitrogen content (Table 1, analyses L, M). Although normal beers were produced from this grist, grist utilisation was poor, due to inefficient extraction in the mash-tun. Channeling of wort through the mash bed and partial blockage of the plates gave long run-off periods, high last runnings gravities, increased sparge requirements and low overall extract. In an attempt to overcome these problems, changes were made in the brewing procedure, as has been described. An air-classified low-nitrogen flour (Table 1, analyses N.O.P.Q.) was used in place of the higher nitrogen "straight-run" flour, as it was considered that the wheat-flour gluten might impede run-off from the tun.

Two brews were made at each of the flour usage levels. The grists are shown in Table 5. The flour was blended throughout the malt grist despite the recommendation (8) to mash the first 10 - 15% of the grist without wheat flour addition, since on the pilot scale tun it was found that there was considerable lateral movement of the "goods" during mashing so that it was impossible to arrange an all-malt layer above the plates.

At the start of run-off "taps" were opened gradually and the rate of sparge balanced the rate of run-off. Frequent samples were taken of the wort as it left the tun and the specific gravity and rate of run-off were recorded. The tap-setting and bed depth were also detailed. In Figs. 2 and 3 are shown the run-off rates of control brews and wheat-flour brews. In the controls the rate rose to 14 - 16 brls/hr whereas in 10% and 17% wheat-flour brews the maximum rate was generally 12 - 14 brls/hr, although one brew at 10% wheat flour achieved a rate of 20 brls/hr. The two brews at 25% resulted in set mashes. The mash-tun performance of one of these brews is shown in Fig. 4; a reasonable run-off rate was achieved after a second underlet, but the extract obtained was very low in both cases.

Worts produced from the wheat-flour grists were processed in the same way as worts from control grists. Worts were boiled 2 hours with Tutsham hops which were then strained in the hop-strainer and the hopped wort pumped into a cylindrical wort receiver. Trub was separated in the wort receiver by the "whirlpool effect" and the wort cooled through a plate heat exchanger to 16°C. Wort was aerated by injection of filtered air on the "hot side" of the heat exchanger. Worts were collected at 1038 - 1039° SG in batch fermenters, pitched with yeast and allowed to ferment at a temperature rising to 21°C. After the required degree of fermentation was achieved, usually 3 - 4 days, cold liquor was circulated through the attemperation coil and temperature reduced to 16°C. Five barrels of the fermented beers were then transferred to conditioning tank where auxiliary finings were added and the beer periodically agitated, venting at 5 psig. At the end of the 1 week conditioning period beers were chilled to 1°C and pumped to cold tank where they remained 14 days to allow precipitation of protein and fining action. After cold storage the beers were kieselguhr filtered into bright-beer tank. Keg beer samples were racked direct from these tanks against counter-pressure and then pasteurised (20 minutes at 59°C). Bottled beer was first sheet filtered and filled through a Meadowcroft single-head filler, and pasteurised 20 minutes at 59°C.

Worts and beers for the wheat flour and control beers were analysed during processing, and the results are shown in Table 7.

The trub remaining in the wort receiver after each brew was drained overnight and weighed. The trub comprised protein precipitated from the boiled hopped wort together with some hop seeds. On average rather more trub was precipitated from the wheat-flour worts (64 lb) than from the control worts (54 lb). The trub moisture-content was 75% so that no more than one fifth of total grist protein was removed as trub. Nitrogen analyses of worts and beers showed in general a slightly lower nitrogen content in wheat flour worts but very similar levels of nitrogen in the fermented beer.

Head-retention values were rather low, both for wheat-flour brews (average 87) and control brews (average 85). Hop utilisations were similar, wheat-flour brews showing a slightly higher average value. The relative proportions of individual fermentable sugars were similar in control and wheat-flour brews. Taste-profile evaluation revealed no significant differences between the beers.

Results of brews using 15% wheat-flour grists

In the previous series of brews it was found that at the 10% wheat flour level the brewery extract was equivalent to, or even rather higher than that of control grists. At 17% there was some evidence of reduced extract although this was not statistically significant. In the two brews at the 25% level set mashes resulted. Comparison of the analytical data and taste profile results showed few differences. These results indicated that wheat flour was a suitable mash-tun adjunct, and that the optimum level of usage was probably a little less than 17% of total grist weight. It was therefore decided to make a further series of brews at a level of 15% in which the extract yield from the grist, and mash-tun performance could be more closely examined.

The analyses of the wheat flour used are described in Table 1 (P) and the malt analyses in Table 2. The grist composition is described below. These figures show that the laboratory extract of the wheat flour was 103.3 brewers lb/qr whereas that of the malt was 98.5 (on average) and flaked maize 106. In the 15% wheat-flour grist the flour is replacing 7% of the grist as flaked maize and 8% as malt. The rise in potential extract in the replacement of the malt more than compensates for the loss of extract resulting from the replacement of flaked maize. In fact the potential extract of the wheat flour grist is 98.7 brewers lb/qr on average, a gain of 0.2 brewers lb/qr on the malt alone.

| | Lab. Extract (as is) | % Grist (weight basis) | Brewers lb per qr grist |
|---|---|---|---|
| Pale malt | 98.5 | 80.9 | 79.7 |
| Crystal malt | 86 | 4.1 | 3.5 |
| Wheat flour | 103.3 | 15.0 | 15.5 |
| | Predicted Lab. grist extract | | 98.7 |

The grist utilisation results are set out in Table 8a in the same way as for the previous wheat flour brews ( Table 7a ). In these tables, the column E represents the theoretical laboratory extract of the grist. Column C, on the other hand, shows the theoretical pilot-brewery extract of the grist if there were no spent-grain loss. The values shown in columns E and C are therefore independent estimates of the theoretical potential grist extracts and column F shows the average of these values;

it is this average value which is used in the calculation of pilot-brewery grist-utilisation, column G. Thus the grist-utilisation figures represent a comparison of the observed pilot-brewery extract with the theoretical available extract as derived by laboratory malt-analysis and spent-grain analysis. The results in Table 8a show a range of 97.2 - 98.0% utilisation, with an average of 97.6% which may be compared with the utilisations of 97.2% and 97.5% found for control brews and 10% wheat-flour brews respectively.

Spent-grain losses, Table 8b, again showed higher extract loss in the lower regions of the bed. The overall average loss was 3.0 brewers lb/qr which compares with previous results as below:-

Average spent-grain losses (brewers lb/qr)

| | |
|---|---|
| 10% wheat flour | 2.9 |
| 15% wheat flour | 3.0 |
| 17% wheat flour | 3.8 |
| Control brews | 3.4 |

The rates of run-off from the mash-tun for the 15% wheat-flour brews are shown in Fig. 5 in comparison with the data for the six control brews of the earlier experiments. It is evident that the maximum rate was lower for the wheat-flour brews. The rate reached 14 - 16 brls/hr in the previous control brews but averaged 12.5 brls/hr for the 15% wheat-flour brews. In this series of brews, however, the knives were used at the surface of the bed when the run-off gravity had reached 1.020° SG. This had the effect of sinking the bed a little earlier than usual so that the rate of run-off did not increase to the normal maximum. This explanation is supported by the fact that early on in mash-tun extraction the run-off rates were similar. The increase in run-off rate was curtailed when the surface of the bed was raked. Further evidence of this is given in Fig. 6 in which the run-offs of control brews made during the same period as the wheat-flour brews are shown. In these two control brews the knives were used in the same way as in the wheat-flour brews and the maximum run-off rate was 12.5 brls/hr. Thus in the four 15% wheat-flour brews no difficulty was encountered in mash-tun run-off. Full details of mash-tun performance for both these and the control brews are shown in Figs 7 - 12.

Hopped-wort sugar analyses are shown in Table 8c). It will be noted that a figure of 21% on total carbohydrate has been assumed for the dextrin fraction. This figure is an average of the published data for similar worts. Inspection of Table 8c) shows support for this approach. Firstly, the maltose content of the wheat-flour worts is very consistent when the calculation is based on a constant dextrin content. Secondly, the sucrose content is close to the expected level when it is remembered that liquid sucrose was added to the copper to the extent of 12½% of total extract. Thirdly, the proportions of the various sugars relative to the assumed dextrin figure agree with those published elsewhere (55). The results show a high level of consistency and reveal very similar sugar spectra for the wheat-flour and control worts. The level of maltose appeared to be slightly higher in the wheat-flour wort. This might be explained by a difference in amylose/amylopectin ratios in the wheat and maize starches.

The wort-nitrogen figures, Table 8d), show amounts of total nitrogen and alpha-amino nitrogen very similar to those previously reported for control brews. Head-retention values were low, averaging 76 for the wheat-flour and 68 for control brews. In all other respects the beer analyses were very similar to the controls. The beers attenuated to 10.0°, 8.2°, 7.3° and 7.7° SG for successive 15% wheat-flour brews, and after 5 days conditioning at 60°F, gravities were down to 8.8°, 8.0°, 7.2° and 7.2° respectively. The pH after conditioning was between 3.69 - 3.84. Residual nitrogen levels were similar to those previously recorded, Table 7d After conditioning the beer was chilled to 0°C and cold stored for 10 days. Bowser filtered beer was racked direct into keg and the beer scored higher on taste-panel evaluation than did the control beers. Table 8e.

Discussion

The results have indicated that there are two most important factors to be considered in the use of wheat flour in brewing. These are the achievement of a satisfactory rate of run-off from the mash - or lauter - tun, and a high level of efficiency in extraction of the grist. Royston (56) and Harris (57) have shown, however, that the conditions favouring extraction efficiency are the reverse of those favouring filtration speed.

Filtration speed, or run-off rate, was found to increase in both control and wheat-flour brews from approx. 7 brl/hr to 13 brl/hr during the period that the tap gravity fell from 1.098° SG to 1.020° SG, although the tap setting was not altered. It was also found that the viscosity of the wort at 1.098° SG was half that at 1.020° SG.

Now, Royston has pointed out that run-off rate is inversely proportional to the liquid viscosity; this would account for the increase in rate. The equation relating the important parameters in mash-tun filtration proposed by Royston (56) was

$$V = \frac{K.\Delta P}{L.\ u} \cdot d^2 \cdot F_{Re.f.} \ \frac{1}{f\ (\Delta P)}$$

V = volumetric flowrate

$\Delta P$ = pressure differential

L = bed depth

u = viscosity

K = constant

d = particle size

$F_{Re.f.}$ = factor dependent on bed porosity and particle shape

$f(\Delta P)$ = function of bed compression with increasing pressure differential

In the wheat-flour brews in general, the filtration rate V was slightly lower than that of control brews. The viscosity, $\mu$, of the wheat-flour wort was no higher than that of control worts. Raw barley contains glucan which increases viscosity, but air-classified wheat flour has much less (58). The viscosity was found to be related to specific gravity and temperature, and to be no greater than that of control worts. The average particle size in wheat-flour grists is reduced in proportion to the amount of flour used, and this is one reason for the use of a coarser malt grind than usual when using wheat flour. The extra flour present also tends to fill the spaces in between the malt husks in the mash bed. This reduces bed porosity and the overall bed depth, L. to a small extent. The pressure differential, $\Delta P$, across the bed is dependent upon the hydrostatic head and the extent to which the taps are opened. Birtwistle (21) experienced reduced filtration speed and loss of extract when using a 1.5% nitrogen wheat-flour. Attempts at pre-cooking of the wheat flour were unsuccessful and this was attributed to coagulation of the gluten. It is possible that undissolved gluten could block the pore spaces of the mash bed thus reducing filtration speed. The earlier wheat-flour brews in which higher nitrogen flours were used showed reduced run-off rates. Although the higher nitrogen flours are cheaper than air-classified flour this advantage is outweighed by its effect on filtration, and as Russell-Eggitt has pointed out (8) a rise in flour nitrogen of 0.2% is roughly equivalent to a drop of 1% in starch content and thus a potential loss in extract of 1 lb/qr.

Harris (57) has shown that in an infusion mash the bulk of the mash floats during the early stages of run-off leaving a relatively thin loose cake resting on the mash-tun plates. The mash is floated by the air entrained in the malt, aided by the high specific gravity of the wort, and the presence of flotation aids. Harris found that the suspended bed began to sediment when extraction was well advanced, as was found in the present work. Using wheat flour at 15%, the bed was less buoyant than at 10% or in control-grist brews. In the 25% wheat-flour brews the bed did not float, even immediately after mashing. It is considered that the bulk density of the grist is increased in proportion to the amount of wheat flour used, and air is displaced by the flour so that insufficient remains to float the bed.

Although a high rate of filtration can be achieved if the malt is coarsely ground, the rate of leaching is low from a large particle so that extraction efficiency may be impaired. As Royston put it (56) an increase in the rate of filtration without a corresponding increase in the mass-transfer rate will cause dilution of the wort and thus a reduction in extraction efficiency. The carbohydrates in the malt grains or wheat flour particles must first diffuse to the particle surface and then reach the mainstream of downward flowing sparge liquor. In a wheat-flour grist the proportion of small particles is increased so that extraction efficiency is unlikely to be reduced on account of particle size despite a slightly coarser malt grind. A more likely cause is the uneven distribution of sparge liquor through the bed. Flow will be fastest along the paths of least resistance through the bed, which may be created by imperfect blending of the flour in the grist. Regions in which the proportion of wheat flour is above average will be less porous, thus these regions will receive less than their share of sparge liquor and incomplete extraction will result. In the wheat-flour brews reported here, the precautions taken to ensure good mixing of the flour with the grist, and of the grist with the mashing liquor, were successful. The spent grain analyses (Tables 7b, 8b) showed a small constant amount of unextracted carbohydrate in different parts of the bed.

The bed depth was only 27 inches in the experimental mash tun. In a deeper production-brewery tun the number of theoretical extraction stages is larger so that a greater extraction efficiency should be possible. The extraction efficiencies of 97% - 98% achieved in the experimental tun using 15% wheat flour and control grists indicate that there should be no difficulty in this respect on a production scale. The progress of extraction from a 15% wheat-flour brew is compared in Fig. 13 with those published by Harris for a 20 inch mash depth in a lauter tun with a transferred infusion mash, and an 8 ft. infusion mash in a conventional mash tun. Although extraction is more rapid in the lauter-tun mash, the rate per unit area was greater in the experimental infusion mash as the following figures reveal:

| | Harris (57) | These experiments |
|---|---|---|
| | Lauter tun | Mash tun |
| Tun diameter (ft.) | 15.75 | 6.0 |
| Quarters mashed | 16.5 | 3.972 |
| Filtration area (ft.$^2$) | 190 | 28 |
| Quarters per ft.$^2$ | 0.087 | 0.142 |
| Extraction efficiency % | 100 | 97.6 |
| Extraction time (mins) | 135 | 150-180 |
| Brls collected | 165 | 31 |
| Liquor used (brls/qr) | 10 | 7.8 |
| Qrs/ft$^2$/min. | $6.3 \times 10^{-4}$ | $7.9\text{-}9.5 \times 10^{-4}$ |
| Bed depth (in.) | 20 | 27 |

In brews at 25% wheat flour, set mashes resulted. The mash did not float, probably largely as a result of the flour occupying the inter-particulate spaces between the malt grains which would otherwise have contained entrained air. At high levels of usage it is even more important that the flour should be evenly dispersed in the grist. Even if this had been achieved there would certainly have been a degree of separation of the flour particles from the malt husks as a result of their differing sedimentation rates when the mash settled on the tun plates. These considerations led to a study of the possibility of slurrying the flour with liquor and using this wheat-flour slurry as "mashing liquor" to make the mash with the ground malt. This approach, described in section 3a, was aimed at overcoming the difficulties of blending and separation of malt and flour.

## SECTION 2b). B A R L E Y   A D J U N C T S

### Analysis of barley adjuncts

In a recent review (59) MacLeod mentioned that starch and husk form 63 - 65% and 12 - 13% of the dry weight of barley respectively. Protein accounts for a further 10 - 15%. Hemicelluloses 1 - 3%, sucrose 2%, and lipids 2% are also present, ash and other minor components making up the remainder. The starch granules, as in wheat, are accumulated in the cells of the endosperm. The cell walls of the endosperm are formed from hemicelluloses some of which are soluble in hot water yielding high viscosity solutions. The yield of gums from raw barley is almost twice that from wheat (58). As in wheat the endosperm cells are held in a proteinaceous matrix. The embryo forms only 2 - 3% of the dry weight of the barley grain. The enzyme β-amylase is fully developed in the raw grain (60) together with some of the proteolytic activity which is only fully developed during germination when the β-glucanases and α-amylase are also formed.

The foregoing description applies to a 2-rowed barley of moderate nitrogen content. 6-rowed barley contains relatively more nitrogenous components and less starch. In the flaking process barley is commonly treated whole, but may first be dehusked and degermed. The raw barley may be ground more or less finely and the proportion of husk extracted in the milling process may be varied. The amount of barley milled in the U.K. is very small compared with the enormous quantities of wheat milled for bakery products. There is thus no barley product comparable to the air-classified wheat flours, and analyses are more varied. The materials chosen in this

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study were flaked whole barley and an 85% extraction barley flour, analyses of which appear in Table 9, together with those of flaked pearled barley (61) and a barley-meal.

The barley flour SF 85 is more finely ground than a barley meal; particle size analyses are shown in Table 10 . Most of the husk is removed from the SF 85 product in the milling process. Dehusking the barley can cause increased time needed for filtration (17) but increases the extract yield.

The experimental and control grists were of the same formulation as described in the work on wheat flour, except that in the 10% flaked barley brew no flaked maize was used, its place being taken by extra malt. Brews were made at 10%, 17% and 25% by weight of the experimental adjunct, and the brewing procedure adopted was the same as for the wheat-flour experiments.

Results of 10%, 15%, 17% and 25% barley flour grists

Preliminary experiments were made using the coarsely ground barley-meal. The utilisations, however, were consistently lower than those obtained in the control brews. More sparge was needed; the specific gravity of the last runnings from the mash tun was always higher and the evidence obtained from spent-grain analyses indicated incomplete conversion of the barley-meal. It seemed likely that there was insufficient penetration of the relatively coarse particles by the proteolytic and amylolytic enzymes. The protein matrix remained undissolved and the starchy endosperm was probably further protected by the highly viscous dissolved hemicellulosic material. The worts and beers obtained from these brews gave normal analytical results and no off-flavours were detected in taste-panel evaluations. These results led to trials with the more finely ground SF 85 barley flour from which much of the husk had been removed.

The rate of run-off of wort from the mash-tun reached only 10 - 12 brl/hr for brews at 10% barley flour, comparing unfavourably with the rates of 12 - 14 brl/hr obtained using air-classified wheat flour. At 17% barley flour the rate of run-off was extremely poor and it was necessary to underlet the mash with hot liquor to achieve a reasonable wort flow. At 25% barley flour set mashes resulted, several underlets being required to obtain sufficient wort for a single 15 brl. fermentation.

The utilisations of the grists were determined in the same way as in the wheat flour work, and these are shown in Table 11a . The utilisation of extract material was lower than that of wheat-flour or control brews. At 10% barley flour overall extract utilisation was reduced by 1%, and in the 17% brews by 6 - 7%, as the figures summarised below reveal:-

| | Barley flour | Wheat flour |
|---|---|---|
| | SF 85 | "Brumore" |
| Control brews | 97.2 | 97.2 |
| 10% flour | 96.2 | 97.5 |
| 17% flour | 90.6 | 95.8 |
| 25% flour | very low | very low |

(% extraction efficiency)

The loss of extract at the higher levels of barley-flour usage can be accounted for in the spent grain analyses. These are set out in Table 11b and indicate that although the barley starch is eventually converted to sugars the extract is not properly leached out of the grains bed during run-off.

The hopped-wort sugar analyses shown in Table 12 show rather more variable results than obtained for the wheat-flour brews. Furthermore there appeared to be a tendency towards a higher dextrin proportion the greater the level of barley flour in the grist. For these reasons two sets of figures are set out. Firstly are the quantitative gas-liquid chromatography figures obtained by measurement of the peak areas and secondly the figures adjusted to an assumed level of 21% of total carbohydrate as dextrins, for comparison with the wheat-flour results. This comparison shows very little difference in the sugar spectra, except that the level of maltose was lower in the barley flour brews.

Wort and beer nitrogen levels, Table 13 were closely similar to those of wheat-flour brews. Head-retention values were slightly, if not significantly, higher than those of wheat-flour or control brews. Hop utilisation was high in three brews using 1967 hops, but lower for the higher alpha-acid 1968 hops. Taste-profile results Table 14 showed that barley flour did not have a detrimental effect on beer flavour. In general the beers were fairly completely attenuated so that sweetness levels were low and the beers not "full-drinking".

Results of 10% and 17% flaked-barley grists

The laboratory analysis of the flaked barley used has already been described (Table 9). In the preparation of the flakes the barley was not dehusked but was moistened and passed through steam-heated rolls to form the flakes which were finally dried in a current of hot air.

The pattern of wort run-off from the mash-tun is shown in Figure 14 for a 17% barley-flake brew. The maximum rate of run-off was 10 - 12 brl/hr compared with the rates of 14 - 16 brl/hr for the control brews. The specific gravity of the last runnings was slightly higher than that of control brews, and coupled with the rather high loss of extract in the spent grain, Table 15a , indicated that the grains bed was not fully permeated by the sparging liquor.

The utilisation of extract material, Table 15b, was lower than that of wheat-flour or control brews. At 10% flaked barley overall extract utilisation was reduced by 0.3% and in the 17% brew by 2.4% with respect to control brews.

Analyses of the wort and of the beer during conditioning are set out in Table 15c, together with taste profile results 15d. The poorer attenuation of the 10% barley-flake beer gave rise to a sweeter and slightly fuller beer. The higher level of bitterness in the 17% brew was noticed by the taste panel, and some remarks were made that the beer was slightly harsh. The overall assessment of quality was satisfactory.

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## SECTION 3. USE OF STARCH SLURRIES

### a) USE OF STARCH SLURRIES IN THE MASHING PROCESS

The experimental brewery work on the use of wheat and barley flours, described in the preceding section has shown that these materials may be used at a level of 15%, in a conventional infusion mash. At higher levels set mashes resulted, partly due to the difficulty of blending the flour with the malt, separation of the flour in the grist case, and to the uneven and reduced porosity of the grain bed. Macey (5 ) has recently confirmed that 10 - 15% wheat flour is the maximum practical range for use in infusion mashing where the flour is blended with the grist in the dry state. It was thus decided to attempt to overcome these problems by making a homogeneous slurry of the flour and using it as "mashing liquor" to give improved blending with the malt. There is, however, ample evidence (17) (52) that there is sufficient enzyme activity in malt to cope with much higher levels of flour. Cereal starch is rendered susceptible to enzyme attack by malting, fine grinding, gelatinisation or pre-soaking (15). The wheat and barley flours described earlier were finely ground, and readily hydrolysed by the malt enzymes, but the possibility remained of obtaining a more rapid action by suspending the starch granules in hot liquor and perhaps partly gelatinising them before blending with the malt in the mash tun.

The normal mashing rate for infusion mashes is 2.0 - 2.4 brl/qr. In a 25% flour/75% malt grist a proportion of the mashing liquor could be used to make a flour slurry which would later be blended with the ground malt and the remainder of the liquor at the masher. The proportion of liquor used to make the slurry could be varied. If all the liquor were used in making the slurry this would then form the medium for mashing the malt. Alternatively the slurry could be made at the normal mashing rate, reserving the remainder of the liquor so that the malt could also be mashed at 2.0 - 2.4 brl/qr., the flour slurry being introduced to the mash tun during or after mashing. These considerations require that the mashing rate for the flour slurry should be within the range 2.0 - 8.0 brl/qr (2.14 - 8.56 l/kg).

A preliminary laboratory experiment was made using a domestic food mixer to prepare a flour slurry in an ordinary mixing bowl. The maximum liquor rate of 8.56 l/kg was used, the flour being slowly added to the liquor in the bowl over a period of 4 minutes with a constant slow rate of stirring. The initial liquor temperature was 58°C and this was reduced to 50°C by the time the slurry was made. The slurry was then heated in a water bath to 65°C and the viscosity measured using a Brookfield viscometer. The viscosity indicated was 6,800 centiPoise (cP), though this is not a true viscosity value as a flour slurry is non-Newtonian. The slurry was heated further to 68°C and the viscosity was reduced to 40 cP. During the experiment it was noticed that the slurry thickened as the temperature approched 65°C and became much less viscous as the temperature was increased to 68°C, but even at its most viscous state it would have been easily pumpable. The viscosity changes in this experiment are due to the successive gelatinisation and liquefaction of the starch. If the normal mashing liquor temperature of 71°C were used in making such a slurry in the brewery the final slurry temperature would be approximately 69°C and the starch would be gelatinised with partial liquefaction. The degree of liquefaction would depend on the starch-liquefying enzyme-content of the flour and on the time available. The liquefaction process could be speeded by adding an appropriate enzyme, but the process would have to be almost instantaneous if the use of an intermediate liquefaction vessel prior to the mash tun were to be avoided. An alternative approach is to make a more concentrated starch slurry using 1/2 - 1/4 of the total liquor at sub-gelatinisation temperatures and using the remaining 1/2 - 3/4 of the liquor at a high temperature to make the final malt/flour-slurry mash and achieve the normal 65 - 66°C overall mash temperature. In the first case, in which the whole of the mashing liquor is used to make a partially liquefied slurry, no further temperature adjustment would be necessary at the malt-mashing stage.

Sufficient liquefaction might be achieved by:

a) natural flour enzymes;

b) added enzymes e.g. bacterial α-amylase, or diastatic malt flour;

c) sufficient dilution to prevent the development of high viscosity levels.

It was therefore necessary to study the viscosity characteristics of flour slurries during heating at different flour/liquor ratios with or without added bacterial amylase or malt flour. Preliminary laboratory tests were made to determine the range of enzyme concentration required to reduce the viscosity of a 2.14 l/kg liquor/wheat-flour slurry to water-like consistency within a short time interval. A bacterial α-amylase preparation, Bacterase CF (activity 620 SKB units (46) per g) was used in a slurry of the air-classified wheat flour, Brumore, at 72°C. The results are recorded below:-

| % Bacterase CF (on flour weight) | time to liquefy (mins) |
|---|---|
| 0.75 | 2 - 3 |
| 0.50 | 3 - 4 |
| 0.30 | 6 |
| 0.15 | 12 |
| 0.07 | 18 |

In subsequent experiments it was decided to use enzyme concentrations of up to 0.20% only, since the enzyme cost at a higher concentration would be prohibitively high in a production process (1969) *

* α-amylase prices are now (1971) much lower: see Part 2 Section 1b.

A Brabender Amylograph was used in the study of changes in viscosity of flour suspensions during controlled heating. In the Amylograph tests the flour was mixed with 450 mls. of water and heated, whilst agitating, at a rate of 1.5°C/min. The flour/water ratios used were within the range considered possible for a brewery slurrying process, and are listed below:-

Flour/water ratios

| Amylograph | cgs units | Brewing units |
|---|---|---|
| (Flour rate too high at 450 ml/210 g.) | 2.14 ml/g. | 2 brl/qr. |
| 450 ml/150 g. | 3.00 ml/g. | 2.8 brl/qr. |
| 450 ml/100 g. | 4.50 ml/g. | 4.2 brl/qr. |
| 450 ml/52.6 g. | 8.56 ml/g. | 8.0 brl/qr. |

The enzyme preparations used were "Bacterase CF" (ABM Industrial Products Ltd.), and a highly diastatic malt flour (Edme). The activities of these preparations were 620 and 65 SKB units per gram respectively. The flours used are listed below:-

Test flours

| Flour | Type | Particle size |
|---|---|---|
| Wheat flour A | Air-classified low-nitrogen brewing-flour | 20µ - 50µ |
| Wheat flour B | Higher nitrogen baking-flour | 0µ - 120µ |
| Barley flour P | 85% extraction of 1968 barley | 0µ - 180µ |

The chosen temperature cycles were from 40 - 77°C and from 50 - 77°C.

The Amylograph results are shown in Figures 15-22 . In all but one case gelatinisation commenced at 55 - 57°C as evidenced by a sharp rise in viscosity. At peak viscosity at 61 - 72°C the rate of liquefaction began to exceed further gelatinisation. The decrease in viscosity through liquefaction was more or less rapid depending on the conditions used. At high flour rates, as in Figure 15, the addition of 0.1% (on flour weight) Bacterase CF substantially reduced peak viscosity, and 0.2% accentuated this effect. Reducing the flour rate from 150 g/450 ml water to 100 g/ 450 ml, as in Figure 16 , resulted in much reduced peak viscosities. Bacterase appeared to be more effective than malt flour even at equivalent concentrations of enzyme in terms of SKB units. Increasing the start temperature from 40°C to 50°C had no effect on the Amylograph curves. The Amylograph curve for a second flour, Wheat flour B, of higher protein content, was almost identical (Fig.19). Peak viscosities were reduced to quite low levels using higher levels of malt flour. At low wheat-flour rate (Fig. 18) only a low level of viscosity was developed which gradually fell with temperature rise. In Fig.20 the Amylograph of wheat flour is compared with that of a wheat/barley flour mixture and a barley flour alone. A lower level of viscosity was developed by the barley flour probably due to its higher natural amylolytic activity. The peak viscosity of the barley-flour Amylograph was further reduced by the addition of enzyme (Fig.21).

The most important single factor in reducing the peak viscosity was the flour/water rate. At 53 g wheat flour/450 ml water (8 brl/qr) peak viscosity was lower than for any enzyme treatment at higher flour/water rates. Addition of 0.1% Bacterase reduced viscosity considerably but increased quantities had less pronounced effect. These facts are summarised in Figure 22 in which the peak viscosities of different flour suspensions at various flour/water rates and enzyme treatments are compared.

In any slurry process to be considered for use in a brewery it would be desirable to avoid the development of a high level of viscosity as this would reduce the rate of mixing and increase process time. There would also be a build up of gelatinised starch on heat-transfer surfaces reducing the overall heat-transfer coefficient. It would be difficult to pump the more concentrated slurries (2 - 3 brl/qr) during gelatinisation although these could easily be handled if sufficient α-amylase were used to prevent the development of a high peak viscosity. The amylograph results have shown that 55°C is the lowest temperature for the start of gelatinisation of wheat starch. It would therefore be practical to add the flour to the stirred liquor at this temperature without fear of "lumping". The mixing action could be continued during heating in the presence of added enzyme. Without enzyme the slurry would form a thick paste at 64°C (Fig 15), and it would be necessary to cease heating to avoid "baking" the paste on the heat-transfer surface, but there would be sufficient liquefaction after 10 minutes for heating and mixing to be continued. If α-amylase is added, then heating and mixing can be continued throughout, as high viscosity levels are not developed. In the experimental brewery a suitable mixing action was achieved using a Silverson mixer-emulsifier with a disintegrating head and a down-thrust propeller on the central rotating shaft. The enzyme treatment was added to the liquor immediately before the addition of the wheat flour and temperature raised from 55°C to 75°C. This treatment yields a completely homogeneous liquid which can easily be blended with the malt and remaining mashing liquor, which is at a reduced temperature to give the correct overall "mash heat" at the mashing machine.

The alternative approach is to use all the mashing liquor to make the slurry. In this case the peak viscosity without added enzyme is only 50 Brabender units, Fig. 18. It is therefore possible to envisage an in-line brewery process in which the flour is mixed with the mashing liquor en route to the mashing machine. A Silverson in-line mixer-emulsifier could be used for this purpose.

The Amylographs (Figs 15 - 22) show that malt flour can successfully be used to speed the liquefaction of the gelatinised starch. It was previously shown, Table 4, that in the brewery milling of malt approximately 5 - 8% of flour is produced. This malt flour could be separated by sieving from the coarser fractions of the ground malt and mixed with the flour. If the malt flour used in this way was 5% of the malt then in a 25% wheat-flour grist the malt-flour/wheat-flour level would be 15%, the malt flour supplying more than sufficient α-amylase for a rapid liquefaction of the slurry. A flow diagram for such a process is proposed in Fig 23.

The work described above showed that bacterial amylase could successfully be used to reduce viscosity and partially liquefy wheat-flour slurries. It was hoped that by the addition of a proteolytic enzyme it might be possible to hydrolyse the wheat-flour gluten which could impede normal mashtun run-off. When wheat flour is mashed together with malt, the proteolytic enzymes of the malt partially solubilise the nitrogen without hydrolysing it to any extent. It was hoped that it might be possible to effect a more extensive hydrolysis by adding the extraneous proteolytic preparation "Novo Alcalase 1.5". In this investigation a wheat-flour slurry was compared with one to which "Alcalase" was added. (The properties of Alcalase are described in the Appendix, p. 63)

A 2 brl/qr wheat flour/liquor slurry was prepared using the bacterial amylase Novo 264 (The properties of Novo 264 are described in the Appendix, p. 62):-

1. Add bacterial amylase Novo 264 (0.025%)*

   Raise to 85°C

   Hold at 85°C for 30 mins.

   Cool to 65°C

2. Adjust to pH 7.0 using calcium hydroxide

3. Add "Novo Alcalase 1.5" (0.025%) *

Hold at 65°C for 90 mins.

* Based on flour weight.

A similar slurry was prepared without the addition of Alcalase. The liquefied slurries were kieselguhr filtered, boiled 5 min, stored at 0°C for 3 days and refiltered. Solutions were made up to 1 litre and pasteurised at 65°C/30 mins. The nitrogen analyses of the liquefied slurries are shown in Table 16 The amino-acid analyses revealed that very little alpha-amino nitrogen was liberated in the wheat-flour slurry, despite the proteolytic activity of the amylase preparation. Addition of the proteolytic enzyme preparation, Alcalase, under optimum conditions for activity, had no apparent effect. These findings confirm those of Leach (19) on malt enzymes; he concluded that malt solubilised some of the wheat-flour protein of malt/wheat-flour grists during mashing without any significant degree of proteolysis. Jones & Pierce (20) (62) also found that wheat flour did not contribute free amino-acids to wort.

b) USE OF STARCH SLURRY IN THE PREPARATION OF A SYRUP IN THE BREWERY

It was seen in the previous section how a wheat or barley flour slurry might be used to increase the proportion of flour usage in a conventional mash tun. The slurry could be made at low temperature, without gelatinisation, merely to improve the degree of mixing with the ground malt. Developing from this was the possibility of gelatinising and partially liquefying the slurry before mixing it with the malt, using hot liquor and relying on the natural amylolytic activity of the flour, or on added malt flour or bacterial amylase. The logical extension of this work was to consider the use of a further saccharifying stage to prepare a syrup of carbohydrate spectrum similar to malt wort and thus bypass the mash tun.

It has been seen that both malt and bacterial amylases can be used to increase the rate of liquefaction of wheat and barley-flour slurries. The action of the α-amylases is to split the α - 1,4 - links in the starch molecule, thus reducing viscosity and providing more chain ends for the saccharifying enzymes to attack (63). Malt α-amylase is most active in the pH range 4.5 - 5.5, being more stable to high temperature at pH 5.6 - 5.8. In brewery mashing conditions, where the pH is around 5.0 a temperature of more than 70°C will inactivate the enzyme. Bacterial α-amylases, on the other hand, have a pH optimum for activity of 6.5 and temperature optimum of 70°C, and will retain much of their activity after 2 hours at 75°C. In the Brabender Amylograph experiments it was seen that the natural raw cereal enzymes allowed a slow rate of liquefaction. This action is due to the β-amylase content of the flour, but this enzyme is inefficient at hydrolysing starch as it cannot act beyond the α-1,6-links of starch and is impeded by anomalous links in amylose (64). Nevertheless the β-amylase activity of barley is greater than that of malt (60) and reduces viscosity by splitting off maltose at the α - 1,4 - links from the non-reducing ends of the molecule. The β-amylase of barley is made up of at least four components of different molecular size, but in malting, the larger components are broken down so that malt retains only the smallest component (65) (66). In recently developed commercial processes for the preparation of syrups from raw barley the extra-cellular α-amylase from Bacillus subtilis is a preferred liquefying enzyme (67) (68) (69). This enzyme is suitable on account of its price, stability and activity at high temperature. The α-amylases are more stable in the presence of calcium ions and enzyme survival is favoured by a high concentration of mash or slurry, due to the stabilising action of starch and dextrins (70).

The amylolytic activities of some of the amylase-containing preparations used in this work are compared below:-

| Material | Activity |
|---|---|
| Malt flour | 60 SKB units (46) |
| Amylozyme B | 400 SKB |
| Novo 264 | 5,000 SKB |
| Nervanase CF 18 | 1,200 SKB |
| Bacterase CF | 620 SKB ≡ 100,000 Farrand units (47) |
| Bread flour | 20-25 Farrand |
| English wheat flour | 20 Farrand |
| Brumore brewing flour | 15-10 Farrand |
| Imported wheat flour | 5-10 Farrand |

In raw barley, proteolytic activity is only half-developed (59) and barley/enzyme wort preparations are deficient in nitrogen unless a proteolytic enzyme preparation is used. In using raw barley the increased viscosity due to the presence of glucan can be ameliorated by the use of preparations having β - 1,3 and β - 1,4 - glucanase activity. Bromus extract has a high level of glucanase activity, but lower levels of activity are also obtained in some α-amylase preparations, such as Bacterial Amylase Novo 264, which acts on the glucan at a pH optimum of 7.5 and temperature range 50 - 55°C. The manufacturers therefore recommend a glucanase pause at 52°C for 10 - 20 mins at the start of the barley brew. Collier (71) has also recommended the use of a lower temperature premash or addition of viscosity reducing enzymes, to degrade the gums.

In conventional malt brewing the saccharification of the liquefied starch is achieved by the action of malt β-amylase. In barley brewing, however, much of the β-amylase activity has been lost at the high temperatures required for the liquefaction stage. Malt, or vegetable, β-amylase preparations are expensive, so fungal α-amylase is preferred. The α-amylase from Aspergillus oryzae or A. niger converts much of the liquefied starch to maltose and the optimum conditions for its activity are 50°C and pH 5.0. Some glucamylase activity is usually found in fungal α-amylase preparations, so that the worts produced will also contain a certain amount of glucose.

The possibilities of using a dual enzyme process to produce wort from raw cereals, in place of the traditional malt-mashing process, is under serious consideration by brewers and allied traders (36) (72). Raw barley is preferred to wheat as it is considered to be a more "natural" brewing raw material, and the protein is more easily degraded. It was thus decided to take the slurrying concept a stage further in considering the preparation of a syrup from the slurries.

A wort syrup was prepared by a dual enzyme process on barley flour. The powdered enzymes used were:-

1) Bacterial amylase Novo 264 - 0.1 % on flour weight

2) Fungal α-amylase Novo 11 - 0.05% on flour weight

Properties of these two enzymes are described in the Appendix pps 62-3.

A 2 brl/qr barley-flour/liquor slurry was used and the conditions for the successive enzymic hydrolyses were:

1) Add bacterial amylase

| | |
|---|---|
| 60 mins. at 50°C | Protease activity |
| 90 mins. at 65°C | Beta-amylase activity |
| 30 mins. at 80°C | Alpha-amylase liquefaction |

2) Add fungal amylase

| | |
|---|---|
| 90 mins. at 50°C | Saccharification |

The barley-enzyme wort was kieselguhr filtered and boiled 5 mins. The wort was stored at 0°C for 3 days and refiltered, made up to 1 litre and then pasteurised 65°C/30 mins. Samples for amino-acid analysis were deproteinated by ultra filtration.

Amino-acid analyses were made by the methods of Spackman, Stein & Moore (43) using a Technicon automatic amino-acid analyser. Total nitrogen was determined by the Kjeldahl method, and alpha-amino nitrogen by the method of Satake (45). Sugar analyses were made by gas liquid chromatography of trimethyl silyl derivatives (42). Analytical results are shown in Tables 17-19.

The sugar analyses show that both the overall fermentability of the syrup and the relative proportions of the individual sugars were similar to those of traditional malt wort.

As is evident in Table 18, the overall nitrogen compositions of the barley-enzyme wort and the malt wort were very similar. The fate of the original barley or malt nitrogen is illustrated in Fig.24 and Table 17 The degree of proteolysis was similar, although rather more alpha-amino nitrogen was present in the malt wort. The amino-acid compositions of the two worts were similar, except for two notable amino-acids. The level of proline in the barley wort was much lower than that of the malt wort, whereas with valine the reverse was the case. The low level of proline in the barley wort supports the suggestion (62) that malt proline is not derived directly from the endosperm, but by synthesis from precursors in the germ. Valine is implicated in diacetyl formation, and the presence of valine in wort is thought to be important (36).

It is concluded that sufficient assimilable nitrogen is liberated from barley-flour by the action of crude preparations of bacterial amylase and fungal amylase. The proteolytic enzymes associated with the bacterial amylase, and present in the barley flour, were sufficient to release similar quantities of amino-acids to those of malt wort. Valine was liberated in greater, and proline in lesser, quantity.

APPENDIX TO SECTION 3

## BACTERIAL AMYLASE NOVO 264

Heat stable alpha-amylase preparation prepared from a strain of Bacillus subtilis. The same enzyme can be obtained in liquid form: Bacterial Amylase Novo liquid 60 and Bacterial Amylase Novo liquid 120. These preparations contain 60,000 Novo units/g and 120,000 Novo units/g respectively. The price per enzyme unit is somewhat lower than that of the powder product.

Activity. Bacterial Amylase Novo 264 contains an activity of 264,000 Novo Alpha-amylase units/g, corresponding to approx. 5,000 SKB units/g (at pH 5.7).

Influence of pH and temperature. Optimum pH range: 5.7 - 7.0, depending on the temperature. Temperature optimum: 70 - 85°C, depending on the concentration of stabilizers, particularly starch and dextrins. The stability is also improved by the presence of a certain amount of $Ca^{++}$.

Proteolytic activity. Besides the alpha-amylase activity, Bacterial Amylase Novo 264 contains a proteolytic activity of 0.25 - 0.30 Anson units/g. according to the Anson haemoglobin method (78).

Beta-Glucanase activity. Bacterial Amylase Novo 264 is able to split the 1 - 3 and 1 - 4 glucosidic linkages of barley beta-glucan. The optimum conditions for this activity are pH about 7.5 and temperature about 45 - 50°C.

→

FUNGAL ALPHA-AMYLASE NOVO 11

An enzyme derived from a strain of Aspergillus oryzae. The action of Fungal alpha-Amylase Novo 11 on gelatinized starch may roughly be compared to a combination of bacterial alpha-amylase and beta-amylase, resulting in a breakdown of starch to dextrins and maltose. Prolonged action results in the formation of large amounts of maltose. Further a certain amount of dextrose is formed, due to the presence of some amyloglucosidase activity in the product.

Activity. The enzymatic activity is higher than 42,000 SKB units/g at pH 4.7.

Influence of temperature and pH. The pH optimum is about 5.0 and the temperature optimum is 50°C. The enzyme is not stable at higher temperatures and is rapidly destroyed at temperatures exceeding 60°C. The stability in solution is improved by the presence of $CaCl_2$.

NOVO ALCALASE 1.5

Heat stable proteolytic enzyme preparation manufactured by the submerged fermentation of a species of the genus Bacillus.

Activity. Splits up to 20 - 30% of the peptide bonds in all parts of the protein molecule. Activity 1.5 Anson units (78) per gram.

Influence of pH and temperature. Stable in aqueous solution, pH 8.5, at 50°C and retains 50% activity after 1 hr at 65°C.
Stable and active over the wide pH range of pH 5.0 - 10.5.
Independent of $Ca^{++}$ for stability.
Optimum temperature for activity is 60°C.

Suggested rate of use. A range of 0.05 - 0.1% Alcalase based on the dry weight of protein.

## SECTION 4. COMMERCIAL SYRUPS

In the previous section it was shown how wheat or barley flours could be used to prepare a wort of similar composition to that of malt-grist wort. Although these experiments were made on a laboratory scale it was mentioned that allied traders were developing such processes, and in some cases they had already reached production-scale for barley and green-malt syrups. It was therefore decided to use the available products in experimental brews in order to assess their brewing properties, and the relative economics of using them on a commercial scale in comparison with a brewery barley/enzyme process, since syrup manufacturers have to bear additional evaporation, purification and transport costs which may largely be avoided if the syrup were made at the brewery.

In the past, syrups were often prepared by the acid hydrolysis of starch. Unfortunately bitter components such as formic acid, levulinic acid hydroxy methyl furfural, gentiobiose and polymers were formed during the process, following dehydration and recombination of glucose (7). Despite the improved methods of purification, these bitter flavours were still prevalent, but the development of the more specific dual-enzyme hydrolysis overcame this problem. Further improvements of the acid hydrolysis process have been incorporated into modern production methods so that acceptable brewing syrups are now produced by acid, acid/enzyme and dual-enzyme hydrolysis of starch. Sucrose syrups are now also popular, having recently gained ground for economic reasons from invert sugar. The syrups used in brewing can conveniently be classified (73) into sugar syrups e.g. sucrose or invert, wort syrups and barley syrups. The wort syrups are prepared by acid, acid/enzyme or dual-enzyme hydrolysis of wheat or maize starch and contain only small amounts of nitrogenous components. The barley syrups are prepared by solely enzymic processes, and are similar to malt-grist worts, containing adequate nitrogenous compounds to support yeast growth during fermentation.

Macey (5) pointed out that allied traders could supply barley syrups at prices competitive to that of traditional malt wort, but it would be necessary to establish the commercial acceptability of barley syrups before venturing the capital to provide the necessary large-scale production facilities. One of the aims of the experimental work described here was to make such an assessment of the available barley and wort syrups.

At the time that these experiments were made, only two commercial barley syrups were available in any quantity. These were ABMG (Syrups) Ltd. "Barley Syrup" and Crisp Malt Products "Brewmalt". Only pilot-scale quantities of Corn Products Ltd. "Total Wort" were available.

Production methods for barley-syrups have not been revealed in any great detail, although Clayton made some reference to them at an Institute of Brewing meeting in July 1969 (68). Using coarsely-ground dehusked barley it was possible to use a mash tun, adding 0.5% each of bacterial $\alpha$-amylase and protease at mashing-in. The proteolytic stand was 1.5 hr at 50 - 55°C, mash temperature then being raised to 75°C and held at this temperature for 15 - 30 mins to allow starch liquefaction. It was then reduced to 63°C and 5 - 10% of ground highly diastatic malt added for a saccharification period of 0.5 - 0.75 hr at that temperature.
Alternatively, the barley was finely ground and stirred tanks used for the enzyme stages, the syrup being recovered by centrifugation and filtration. In a Kroyer plant process finely ground dehusked barley is slurried with bacterial amylase and liquefied in a tubular reactor at 85 - 90°C, the

reaction being continued in stirred vessels for a period of 2 - 5 hr. The liquefied slurry is cooled and the pH adjusted before entry into stirred jacketed saccharifying tanks where protease and ground malt are added. Solids are finally removed in a filter press and the syrup concentrated by evaporation.

It has been considered that the degree of grinding necessary dictated the use of a conversion vessel (74) and clarification by centrifugation rather than grain-bed filtration. In a recently commissioned plant (75), however, a lauter tun is used, the barley being coarsely ground and the husk used to provide sufficient porosity in the grain bed. An alternative method of barley wort separation is the use of vaccuum-belt filters and counter-current washing; in which case a fine grind can be used to ensure maximal extraction. In R & W Paul's "Liquid Malt" process for the production of syrup from green malt an automatically controlled solid bowl centrifuge is used for primary mash separation (32).

In considering the potentialities of various syrups for use in brewing, both the physical and chemical properties must be considered. Barley syrups are very viscous at low temperatures, but at elevated temperatures browning reactions can cause unacceptable colour development. A suitable compromise is to store them at 27 - 32°C (73). The highly fermentable wort syrups should be stored at 43 - 49°C to prevent crystallisation of glucose. Syrup concentration should be around 79% RI Brix to inhibit osmophilic yeast growth (71).

Rainbow compared worts prepared from conventional 10% wheat-flour malt-grist with barley syrups (35). He found that the carbohydrate spectra were closely similar, but variations in the HMW nitrogenous components suggested that barley-syrup beers might be less consistent in terms of protein haze and foam. The proline content of the barley syrup was low, but in general the free amino acids showed satisfactory correspondence.

The barley syrups were not deficient in phosphate or d-biotin and nine serial repitchings of yeast showed no loss of crop.

Analysis of syrups

It was said in the introduction to this section that syrups may be classified as barley or green-malt syrups, wort syrups, or sugar syrups. In the experiments to be described, all four types of syrups were used, and the carbohydrate analyses of the syrups are shown in Table 20. Analyses reported earlier (Tables 8c, 12, 19) were of worts to which 12½% of sucrose had been added. In order to make a valid comparison with the sugar analyses of the syrups, these figures have been adjusted by deducting the proportion of sucrose added in the copper, Table 21 . The total and $\alpha$-amino nitrogen contents of the various syrups are shown in Table 22 together with results of Lundin fractionation.

a) WORT SYRUPS

The available wort syrups are prepared from maize or wheat starches. The syrups considered in these experiments were WS1 and WS2, manufactured by ABMG (Syrups) Ltd. The syrup WS1 is prepared by an acid/enzyme process. Ground wheat is attacked at a low pH and high temperature to yield a glucose-rich syrup. A proteolytic enzyme preparation is used to convert the relatively small amount of protein into lower molecular weight compounds. The more fermentable syrup WS2 is derived from WS1 by a further enzymic stage, glucamylase being used to convert part of the dextrin fraction to glucose.

The carbohydrate compositions of WS1 and WS2 shown in Table 20 may be compared with that of malt-grist wort, Table 21 . The fermentability of the wort syrups can be assessed by consideration of the dextrin content, Table 23, and reveals that WS2 is more fermentable, and WS1 rather less fermentable, than malt grist wort. Also of note is the difference in the relative proportions of glucose and maltose, the wort syrups being rich in glucose and poor in maltose content.

In view of the rather similar degree of fermentability of WS1 and malt-grist wort, the former can be considered for use as a partial malt-grist replacement. In the experimental brews in which trials of ABMG WS1 syrup were made, two different grists were used. In one grist, (33 WS), the liquid sucrose product LP1 was totally replaced, together with part of the malt grist. In the other experimental grist, (33 WS + S), the LP1 was retained at 12% of total extract, part of the malt grist only being replaced by WS1. These and the control grists are described in Table 24

The fermentabilities of WS1 and malt-grist wort have already been compared, Table 23, that of WS1 being 72% of total carbohydrate, and malt-grist wort 76%. Combining this data with that of the grist compositions, Table 24 , allows predictions to be made of the fermentabilities of the experimental and control grists, Table 25. These figures suggest that the overall carbohydrate fermentabilities of (33 WS) and (33 WS + S) grists would be reduced by 4.4% and 1.5% respectively, compared with malt-grist wort.

The nitrogen content of an early WS1 sample was as low as 0.11% of dry matter. In later samples, including those used, the nitrogen content was nearer to the manufacturer's specification at 0.23%. Normal brewery worts of SG 1040 contain 65 - 75 mg N/100 ml, Table 7c . This SG is equivalent to 10% solids so that the nitrogen content is equivalent to 0.72% (approximately) on dry matter. Thus the wort syrup has only 1/3 or less of the normal nitrogen content of wort. Reference to the data on lundin fractions, Table 22 , shows that the molecular-weight distribution of the N-compounds is similar to that of normal wort, so these should be equally assimilable.

In a laboratory investigation of the properties of WS1 a trial fermentation was made. The syrup was diluted and sucrose added at 12½% of total extract and this was boiled with hops to yield hopped "wort" at S.G. 1041°. The →

hopped wort was cooled and pitched at the normal rate with brewery yeast and fermented at 16°C in tall tubes for 6 days. An identical brew was made using a barley syrup (Brewmalt) of nitrogen content 0.6% on dry matter, in place of WS1. The barley-syrup beer fermented to 1010.5° and yielded a good yeast top-crop but the WS1 beer had attenuated to only 1025° with a poor crop of yeast. The low nitrogen content of the WS1 wort seemed to be the likely cause of the poor attenuation. The possibility that yeast growth and fermentation had been limited by nitrogen deficiency was investigated further.

Yeast will utilise ammonium ions as sole N-source, and has no requirement for preformed amino-acids, although it will utilise these if available

Ammonium chloride was used as the supplementary N-source in five test flasks which contained the same hopped WS1 wort but with varying amounts of supplementary nitrogen. In this experiment the wort was prepared by boiling with hops, as before, for 3/4 hour. The hops were strained off, the wort cooled, sterile M/10 ammonium chloride solution added, and each flask pitched at half the usual rate of yeast. The flasks were loosely plugged and incubated at 21°C for 4 days. The final gravity of the beer was then recorded. The available nitrogen was supplied a) by the WS1 amino-acid and polypeptide fractions (about 75% of the total nitrogen) and b) by the added ammonium chloride. Details of the available nitrogen and attenuations are recorded in Table 26 .

These results indicate that WS1 is deficient in nitrogen and this limits the degree of attenuation by yeast. The effect was more pronounced in tall fermenters probably due to the sedimentation of the yeast. Full attenuation was made possible by supplementing the nitrogen to a level of 10 mg assimilable nitrogen per 100 ml of wort. It is unlikely, therefore, that there would be any deficiency of nitrogen unless the syrup were used at extremely high levels of malt replacement. At lower levels of usage the effect would be a slight reduction in wort nitrogen.

The standard brewing-procedure was adopted for each grist to produce similar brew lengths. In the (33 WS) and (33 WS + S) brews, with a smaller proportion of malt grist, the mash-tun bed-depth was smaller and thus extraction time was reduced, Fig. 25.

The sugar analyses of the worts produced are detailed in Tables 27-8; as expected sucrose was absent from (33 WS) worts but present at approximately 12% in the (33 WS + S) worts due to the addition of LP1 sucrose at the copper stage. The maltose content of the wort-syrup worts was generally reduced but, as predicted, the glucose content was higher. The proportions of fructose and maltotriose were similar. The dextrin content was assumed from the figures quoted in Table 25 , and the assumed values are supported by the fact that sucrose, which acts as an internal standard, was present in the expected amounts.

The wort-nitrogen levels are shown in Tables 29,30, 31. The nitrogen analyses of wort syrups are detailed in Table 22, showing that the nitrogen content was only 1/3 that of malt-grist wort-solids. It is to be expected therefore, that the nitrogen levels in the wort syrup brews would be reduced in proportion to the level of malt-grist replacement by wort syrup. If the total nitrogen of control wort is taken as the standard it is possible to predict the wort-nitrogen levels as % of standard for (33 WS) and (33 WS + S) grists. The predicted nitrogen levels for the wort-syrup brews are compared with the actual levels obtained in Table 32, the results achieved being close to the predicted values.

The fermentation charts (Fig 26-8) for the wort-syrup brews do show rather poor attenuations, but attenuation in the control brews was also poor. The circled figure on the charts is the present gravity of the beer after conditioning. In these experimental brews a racking gravity of 1011° from FV was aimed for, and a further drop to 1009° during conditioning. Temperature control in FV was rather crude, however, which could account for some variations in attenuation. Despite this, a racking gravity of 9.6° was recorded from one FV in a (33 WS) brew, and a gravity of 9.7° after conditioning in a (33 WS + S) brew.

Results of "taste profile" tasting of the experimental wort syrup and control beers are set out in Tables 33-5, and show that (33WS+S) beers were similar in taste profile to control beers, and were equally acceptable. The (33WS) beers were more variable.

→

b) BARLEY AND GREEN MALT SYRUPS

A preliminary trial was made, using ABMG (Syrups) Ltd. Barley Syrup. It was decided to use a high level of malt replacement in order to emphasise any flavour changes or effects on fermentation. The grist used is detailed in Table 36.

The producer's analysis of barley syrup D2 gave the total nitrogen as 0.92% of solids; this figure was confirmed in our own laboratory. The alpha-amino nitrogen content was 0.19% of solids. As suggested in the previous work on wort syrup, this level of nitrogen is even higher than that of normal wort and should be more than sufficient for yeast nutrition. The wort-nitrogen levels of the experimental barley syrup brews are compared with those of control brews in Table 37 . Fermented beer nitrogen-levels are also compared.

The fermentation charts (Fig. 29) for the barley-syrup brews are to the same scale as those for control and wort syrup brews (Fig.26-8) and may therefore be directly compared. Fermentation was sluggish in the first brew, but in the second, fermentation was similar to that of control brews. In both brews attenuation was incomplete, the SG after conditioning being 12.6° and 11.2° for the first and second brews respectively.

The taste-panel results from the first barley-syrup brew were invalidated by inadvertent contamination. The results for the second brew are recorded below:-

| | |
|---|---|
| Bitterness | 3.9 |
| Sweetness | 4.2 |
| Hop aroma | 2.6 |
| Fulness | 4.2 |
| Off flavour | + |
| Overall assessment | 5.0 |

→

This result suggested that a reasonable taste profile could be achieved using a 67% barley-syrup grist.

Previous work included trials using wort syrup at 33% and barley syrup at 67% of total extract. It was decided that further work should be done using barley and green-malt syrups at 100% rather than at partial replacement levels, so that any differences from malt wort would be emphasised. The three syrups now available on a commercial scale were used, together with a barley syrup from Corn Products which is not yet marketed:-

| Manufacturer | Product | Type |
|---|---|---|
| ABMG | "Barley Syrup" | Barley Syrup |
| Crisp's | "Brewmalt" | Barley Syrup |
| Corn Products | "Total Wort" | Barley Syrup |
| Paul's | "Liquid Malt" | Green-malt syrup |

The four brews were all made within a period of a fortnight and the syrups were delivered within 2 or 3 days of brewing so that there was no time for any deterioration.

The syrups are designed to provide wort as close as possible in composition to malt wort. Not only should the relative proportions of sugars and dextrins be similar, but also sufficient assimilable nitrogen should be available for yeast nutrition. Laboratory analyses of the syrups are set out in Tables 20, 22.

The syrups were used at 100% replacement of the malt grist. It was decided to use the normal level of copper sugar so that the overall wort fermentability would be similar to normal wort. Furthermore, as the sugar analyses reveal, the barley syrups were all devoid of sucrose. The grist make-up was therefore as detailed below:-

| Material | % of total extract |
|---|---|
| Barley or green-malt syrup | 87.5% |
| Manbre LP1 liquid sucrose | 12.5% |

The syrups were dissolved directly into the copper which was made up with normally treated liquor to the usual level. A two-hour boil with Tutsham hops was given. In each case the formation of hot-break was very poor and the amount of trub separated in the whirlpool was only 25% of the normal level for control brews.

| Brew | Trub Separated (lb) |
|---|---|
| Paul's liquid malt | 14 |
| ABMG barley syrup | 14 |
| Corn Products total wort | 12 |
| Crisp Brewmalt | 14 |

Furthermore, a considerable amount of fine trub was carried through to the fermenting vessels, and the hop seed filters became blocked with trub.

Fermentation details are shown in Figs 30 - 1 Corn Products "Total Wort" and Paul's "Liquid malt" brews fermented more slowly than the other two syrups, and less extensively. The gravity at rack for the former was approx 1010°, and for the latter 1008°. In all cases the yeast crop was much lighter than usual.

Beers were conditioned at 16°C for 4 days. The beers produced from barley syrups were all of high pH, whereas the green-malt syrup had a more normal pH level. Results are recorded in Table 38.

Taste-profile evaluation indicated that the beers were generally less acceptable than normal control beer. Beer from ABMG Barley Syrup was found to be slightly harsh perhaps because this beer was more extensively fermented. The results are recorded in Table 39.

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SECTION 4 - COMMERCIAL SYRUPS - DISCUSSION

The analytical results and experimental-brewery fermentations have shown that the fermentabilities of the wort syrups WS1 and WS2 are slightly less, and rather more than that of malt-grist wort respectively. The fermentabilities of the barley syrups were also similar; in both cases the fermentability can be controlled by regulation of the enzymic or acid hydrolyses employed in the manufacture of the syrups. A barley syrup recently described (73) has the following sugar composition:

| | |
|---|---|
| monosaccharides | 9% |
| disaccharides | 55% |
| trisaccharides | 17% |
| dextrins | 19% |

Wort fermentability may also be varied by changing the proportion of sucrose used, or by altering the proportions used of syrups of differing fermentability. Most of the sucrose of malt is produced by the barley embryo from the products of endosperm starch breakdown, but in the preparation of barley syrups there is no embryo growth so that sucrose is not formed. Unless sucrose syrup is used in increased proportion, therefore, the level of this sugar in the wort will be reduced with possible effects on beer flavour. The high level of glucose present in many wort syrups is also likely to affect flavour; the glucose may repress induction of maltase and maltose permease until nitrogen is limiting for yeast growth so that yeast may then not very readily use maltose. This may in part explain the rather slow fermentation and incomplete attenuation achieved in the 33% wort syrup brews. The glucose/maltose ratio of the barley syrup worts was more similar to that of malt grist wort and attenuation was more extensive.

The nitrogen levels in the barley and green-malt syrups were closely similar to those of malt-grist wort, but the wort syrups contained only one-third the normal malt-grist wort-nitrogen level, although the molecular-weight distribution was similar and the nitrogen equally assimilable. The wort syrups could therefore be used as nitrogen diluents to improve non-biological stability, or used in conjunction with malts which yield more soluble nitrogen. A decrease in the ratio of assimilable nitrogen to fermentable carbohydrate may alter the extent of fusel alcohol formation (76), but there was no evidence of this in the 33% wort-syrup brews in which the wort-nitrogen level was reduced to 74% of normal. The low nitrogen content of such wort syrups does, however, set a limitation on the extent to which they can be used, but not in the case of green-malt or barley syrups.

It has already been possible for manufacturers to produce barley syrups that contain all the nutrients required by yeast. Rainbow (35) has shown that for two commercial barley syrups the content of nitrogen compounds did not vary in any important respect from that of malt wort, the content of D-biotin and inorganic phosphate also being similar. Furthermore, nine serial pitchings of yeast in barley syrup wort showed no reductions of yeast yield or viability. The experimental brewery trials showed that little of the yeast produced was carried to the surface of the fermenter to form a yeast head. This reduction of yeast head is probably due to increased amounts of "head-negative" substances especially phospholipids (77). After processing, however, there was no reduction in head retention with respect to malt-grist beer. The reduced yeast head can embarass the brewer when the yeast required to pitch subsequent brews is collected by skimming, but in the modern fermentation systems using conico-cylindrical vessels, or continuous fermentation, the problem does not arise.

The taste-profiles of the 100% barley-syrup brews showed that adjustments in syrup manufacture or brewing procedure are still necessary to achieve a profile comparable to that of malt-grist beer. It is recognised that small differences in wort composition can significantly alter beer flavour. Alcohols and esters are the by-products of yeast synthetic processes, any alterations in which will therefore influence the amounts of these flavour components. A change in the source of nitrogen, for instance, may affect higher alcohol formation, in addition to the change due to the conversion of the different amino-acids to the correspondingly different alcohols by the Ehrlich pathway. The pH of the barley syrup beers was also found to differ from that of the malt-grist beers, suggesting that modifications to liquor treatment would be necessary. It has thus been seen that such differences as exist between barley syrups and malt-grist wort are slight and should not prove difficult to overcome, so that barley syrup could be used to produce beers almost identical in character to those produced from conventional malt-grist worts.

In the experimental brewery the normal brew length of 31 barrels was used, so that the amount of malt grist used in the mash tun was less than normal. Extraction was thus more rapid and a higher sparge-rate was used (Fig.25). In a production brewery of given mash-tun capacity, brew length would be increased to 160% and 130% respectively for (33 WS + S) and (33 WS) grists. There might be further advantages in the brewing of high gravity beers, a higher sparge rate than normal being possible, the extra gravity being added as syrup to the copper. The advantages in using a wort syrup are summarised as follows:- 1) Wort-nitrogen dilution 2) allows the use of high -N malt 3) allows adjustment of overall wort fermentability 4) cost saving in raw materials 5) increased mash-tun capacity 6) high gravity beers.

The barley syrups are more expensive than wort syrups and would therefore be used only in circumstances where wort syrups would prove inadequate. It has been shown that WS1 can be used at 33% malt replacement, but at higher levels there would be a lack of suitable nitrogen, and the glucose/maltose ratio would be high. At such high levels as 70% malt replacement it would be sensible to use at least a proportion of barley syrup to supply the necessary nitrogen and redress the sugar balance. It is difficult, however, to envisage such a grist making economic sense in the long term, as all the mashing equipment and processes would have to be retained for the proportion of malt grist that was used. Two uses for barley syrups are apparent. Firstly the syrup could be used as a small proportion of the grist at times of peak production, if milling or mashing were the bottle-neck. Secondly, new breweries could be built without mill or mash tun, the beer being produced entirely from a barley syrup. As the cheaper acid, or acid-enzyme converted syrups could fulfill most requirements it would seem that complete malt replacement will be the aim for barley syrups. The syrup manufacturers are confident that there willbe an increased demand for barley syrups, as evidenced by the recent announcement of new barley-syrup plants in the U.K. and in Denmark (73). The extent to which syrups will be used in brewing remains an open question; much will depend on the relative economics, which are discussed in Part 2.

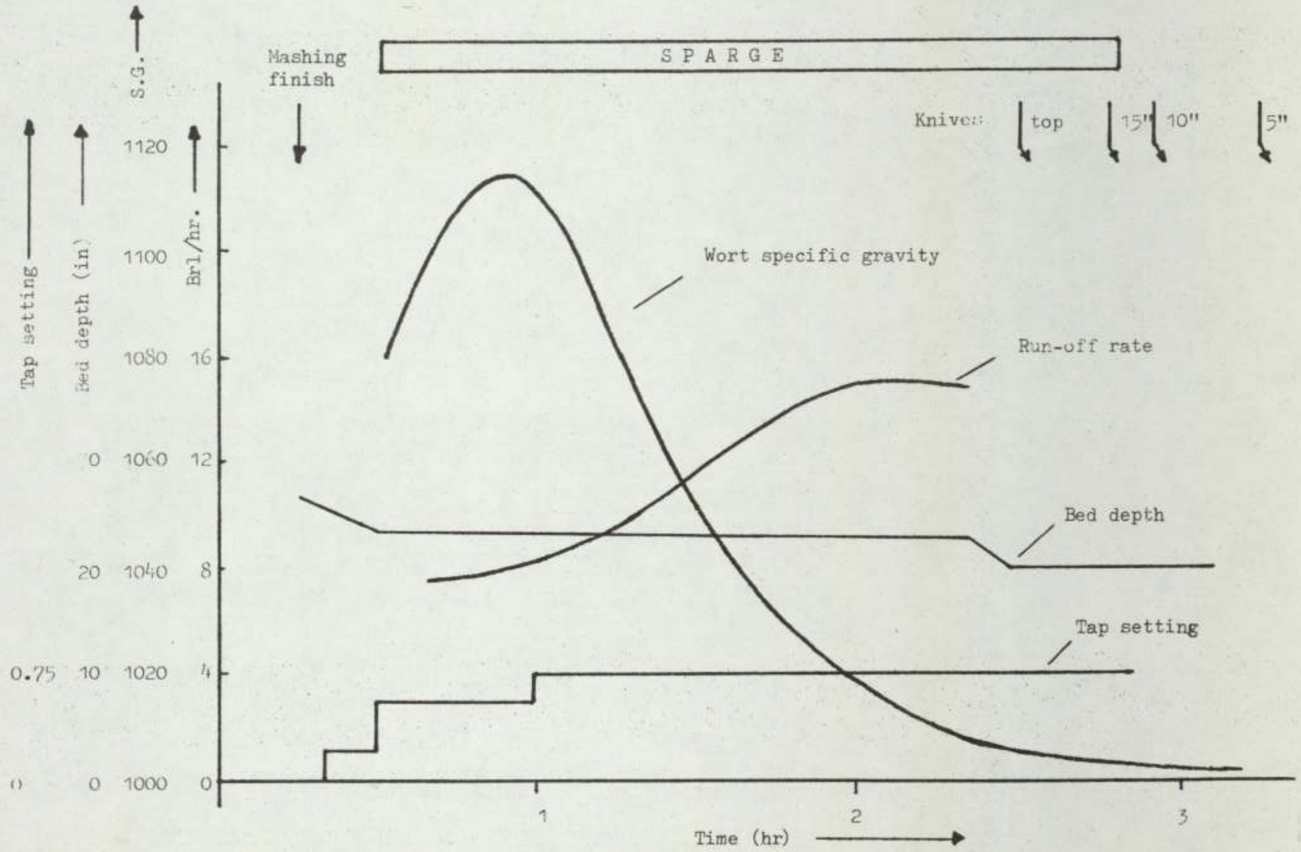



Fig. 1. Extraction of malt grist, zero stand time

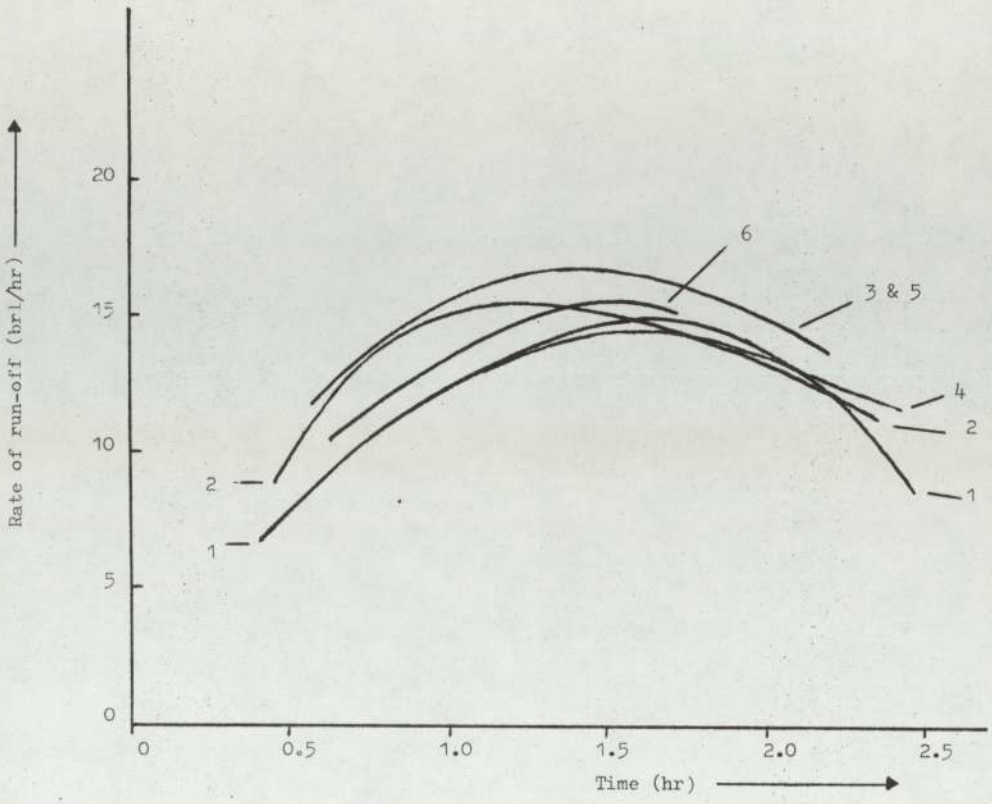



Fig. 2 Extraction of malt grist, control brews, CB 1-6.

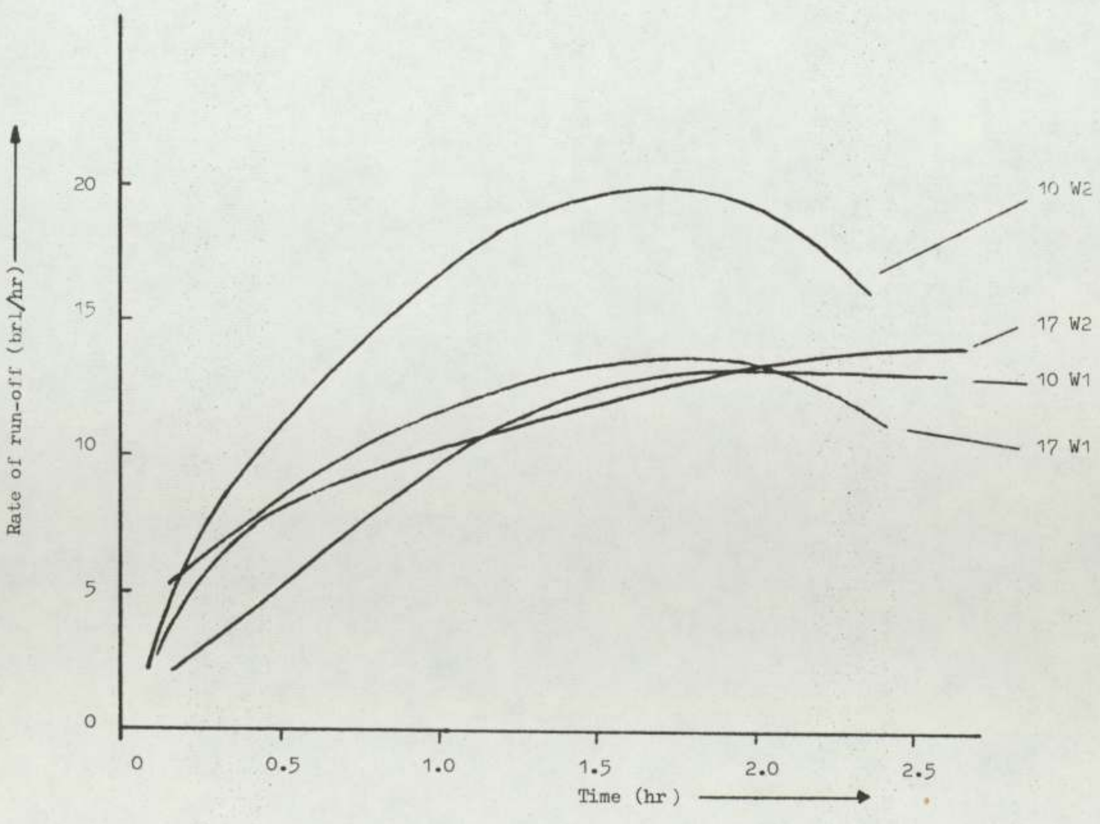



Fig. 3 Extraction of grist, wheat-flour brews

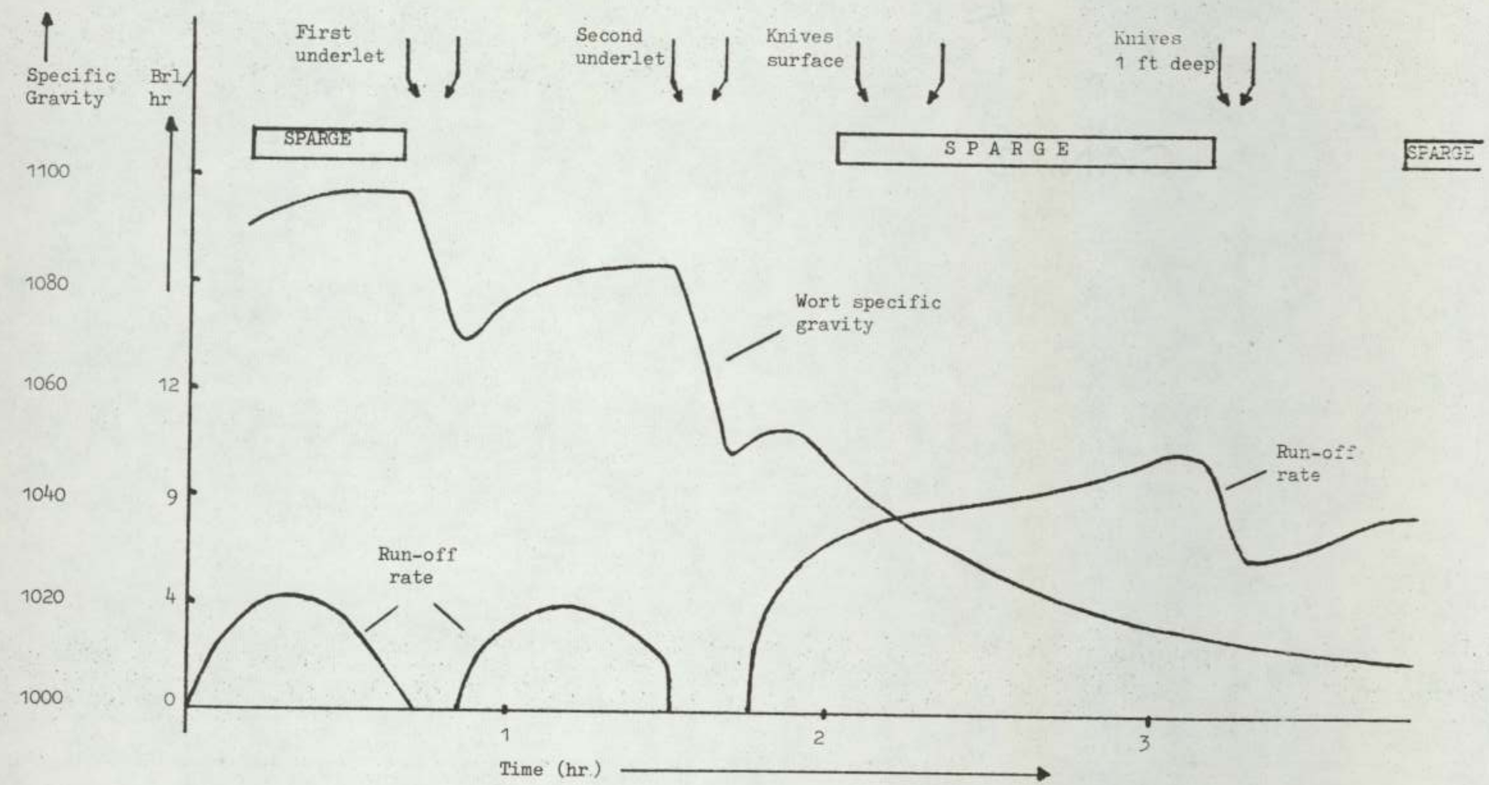



Fig. 4 Extraction of 25% wheat-flour grist

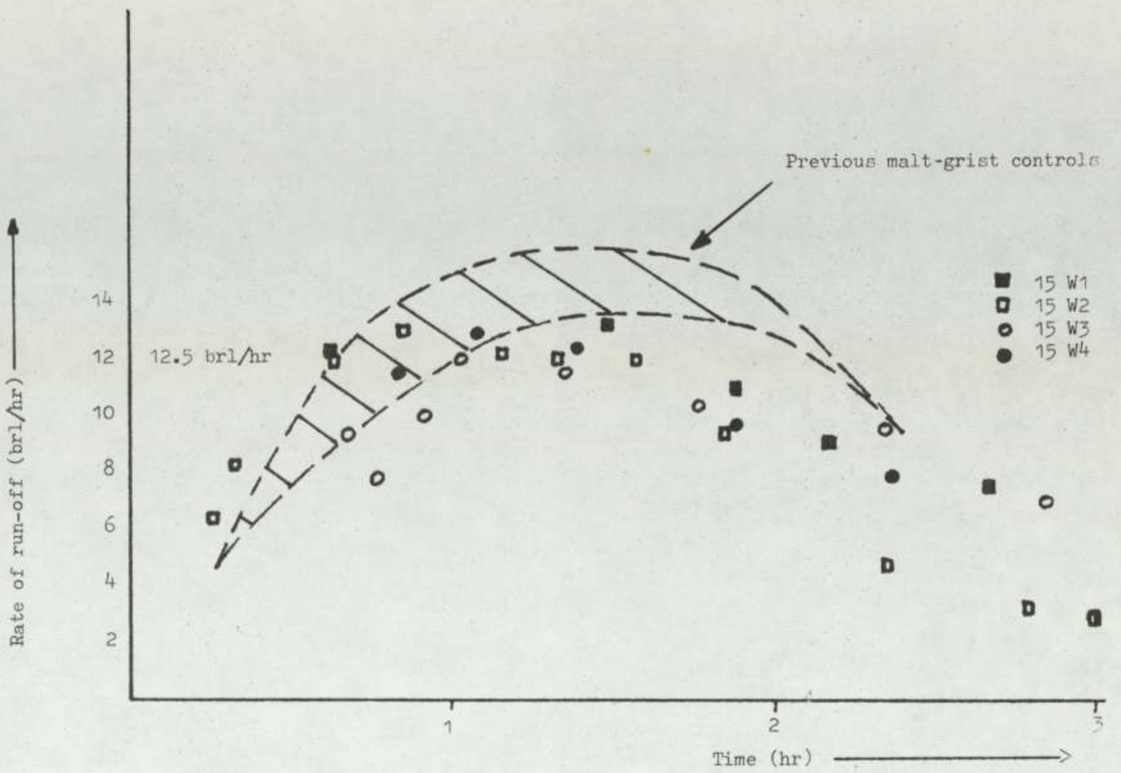



Fig. 5 Extraction of grist, 15% wheat-flour brews.

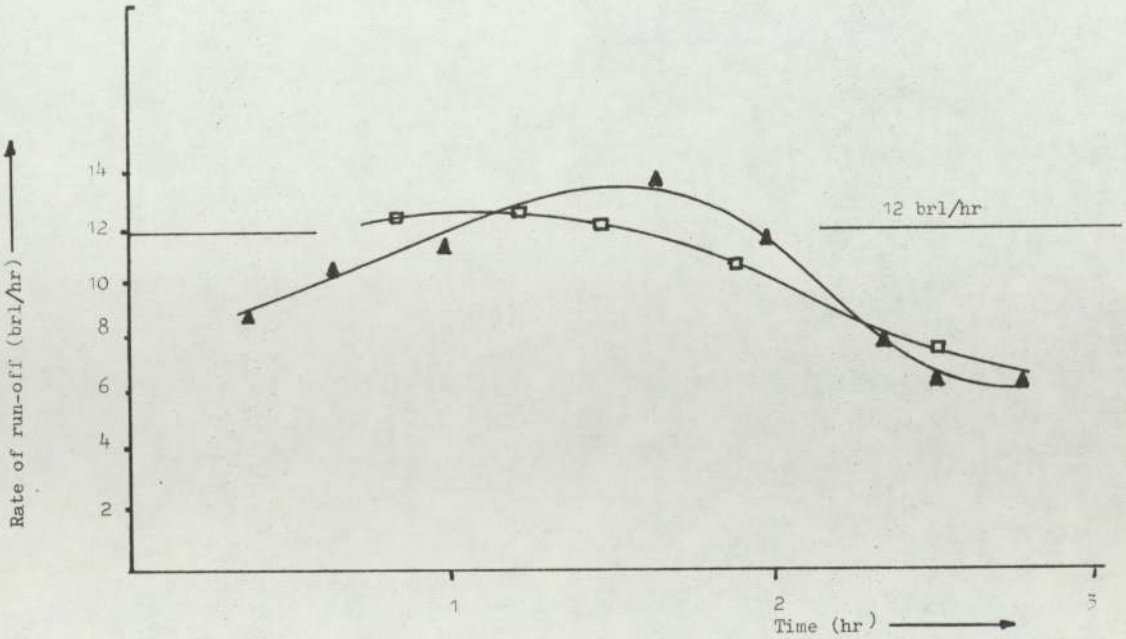



Fig. 6. Extraction of grist, control malt-grist brews

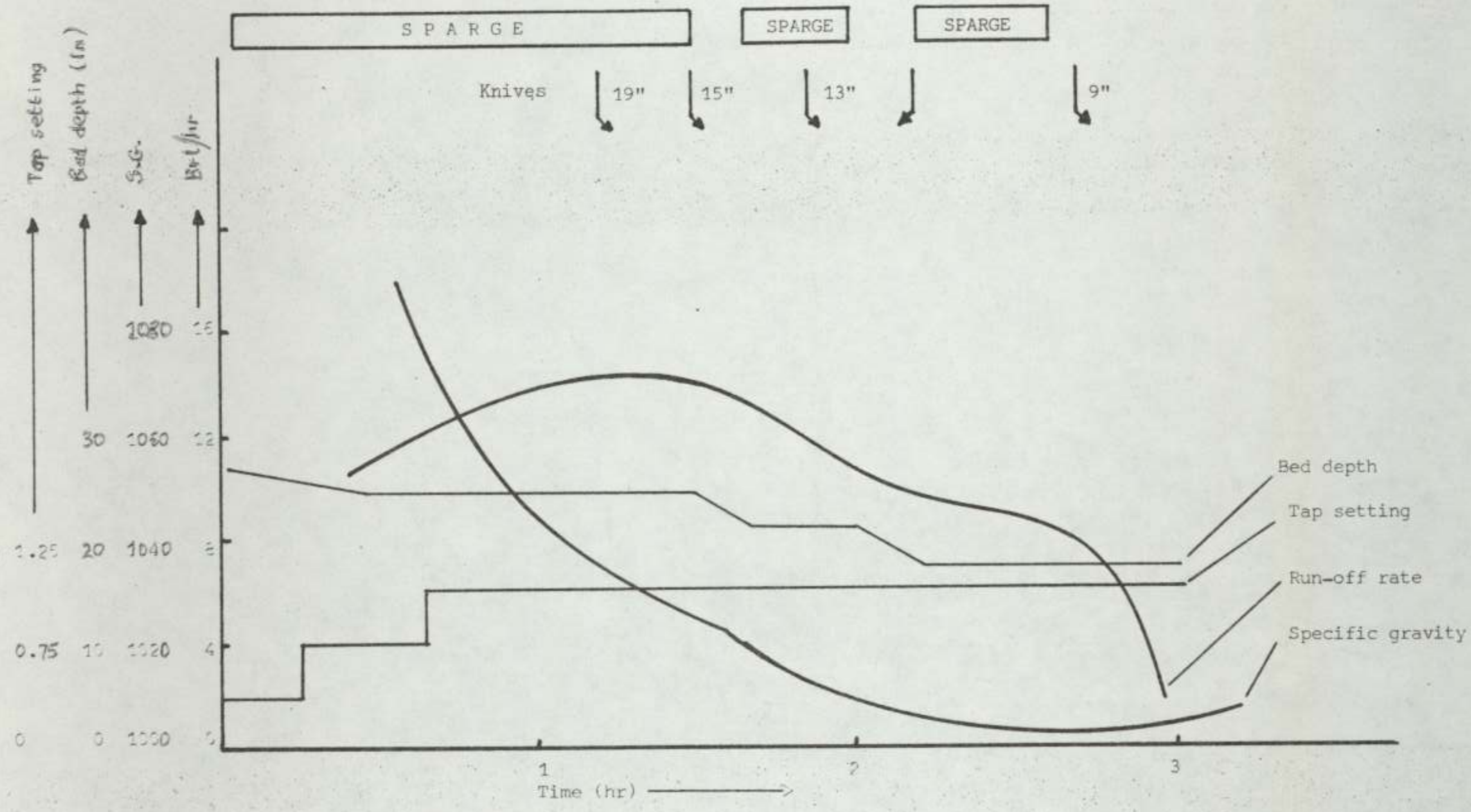



Fig. 7 Extraction of 15% wheat-flour grist 15 WFM

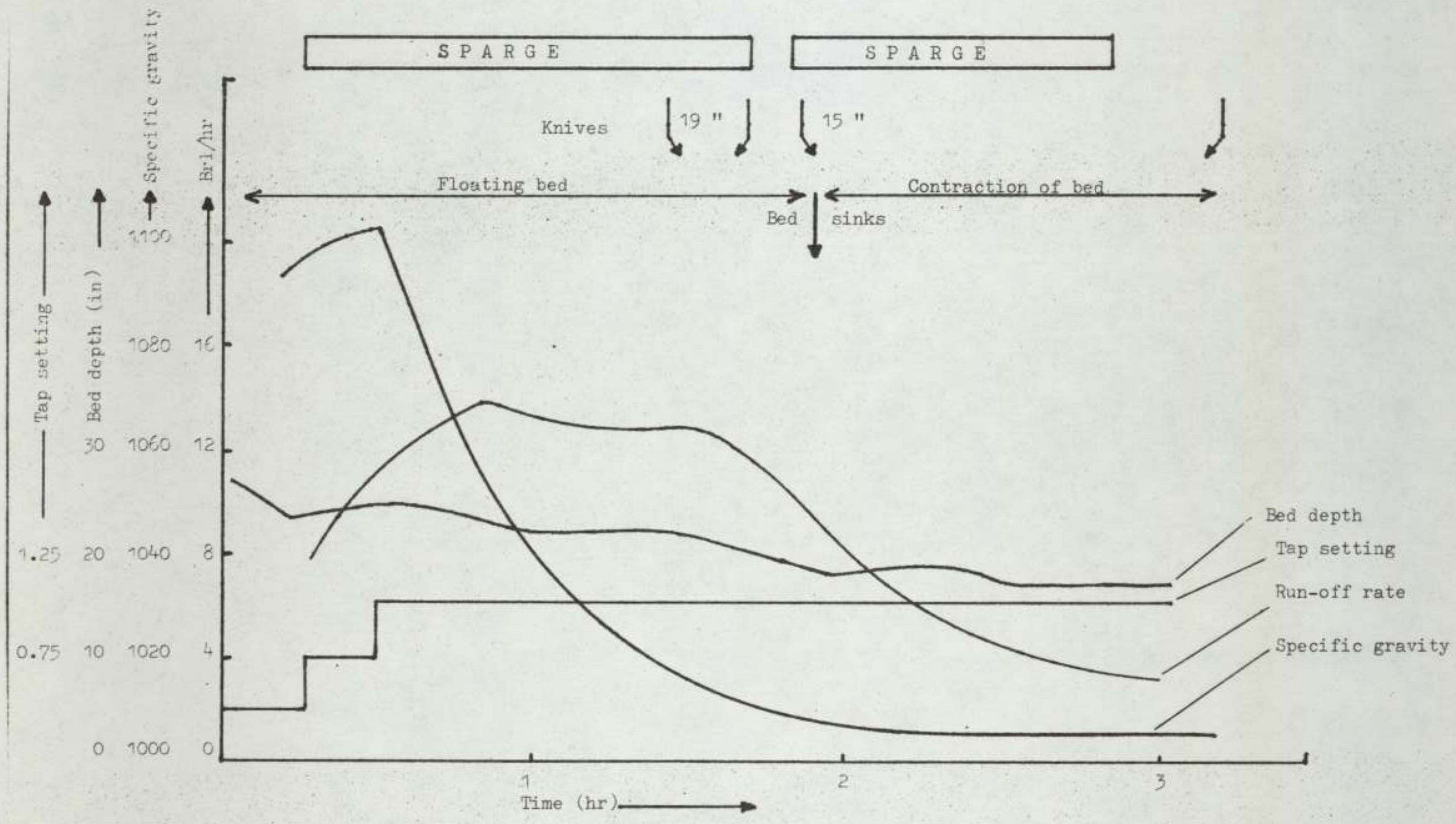



Fig. 8. Extraction of 15% wheat-flour grist , 15 WF2

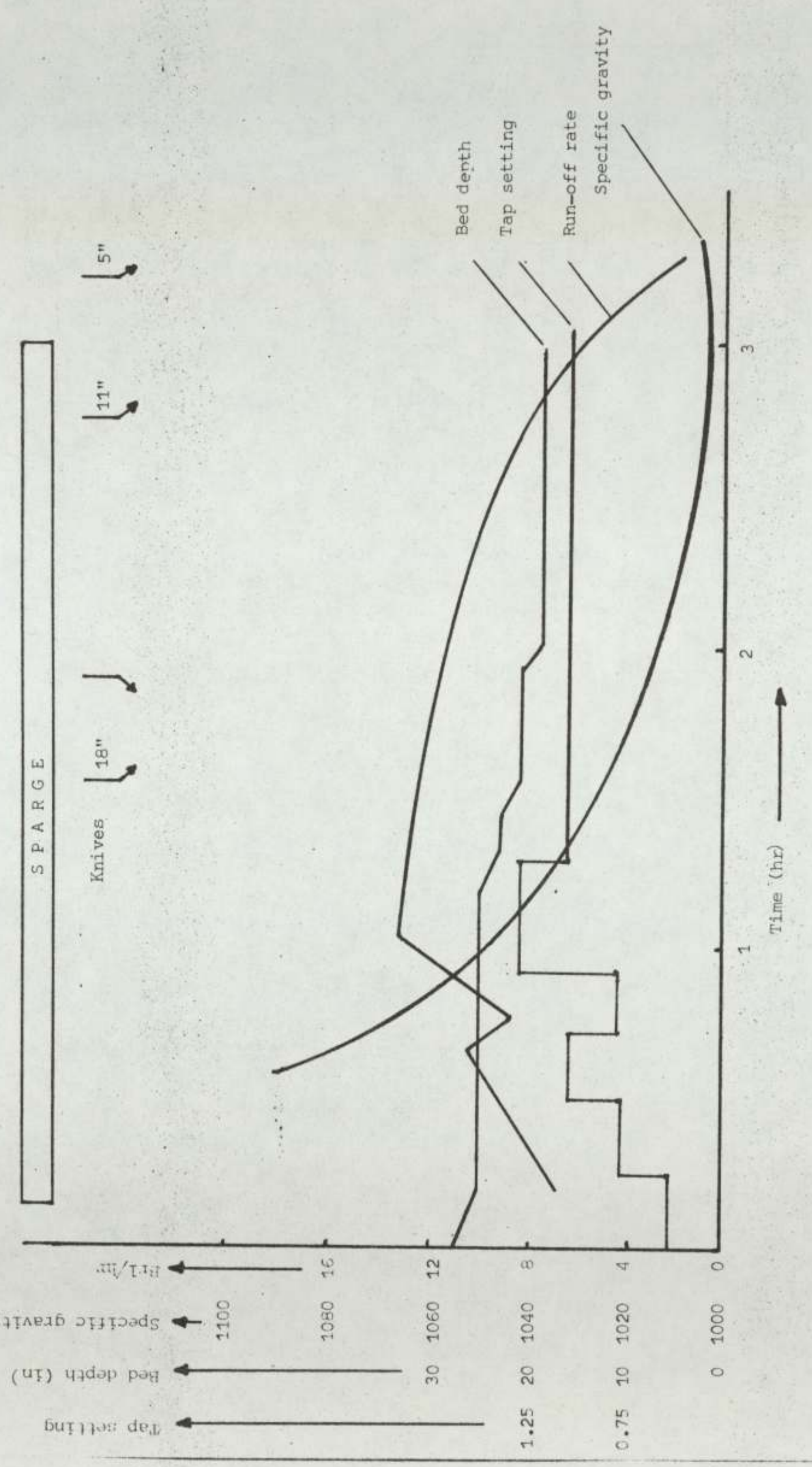



Fig. 9 Extraction of 15% wheat-flour grist, 15 WF3

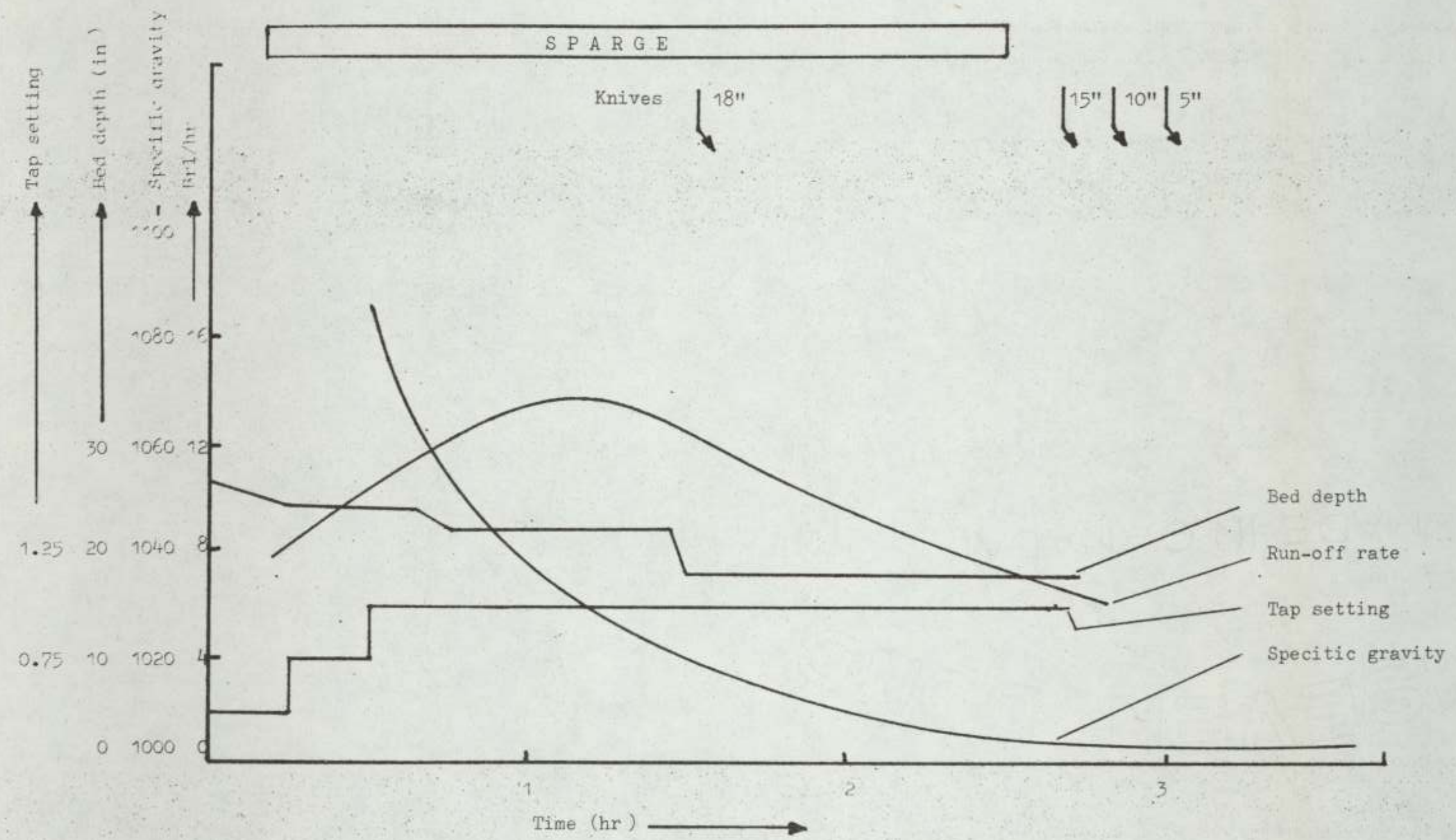



Fig. 10 Extraction of 15% wheat-flour grist, 15 WF 4

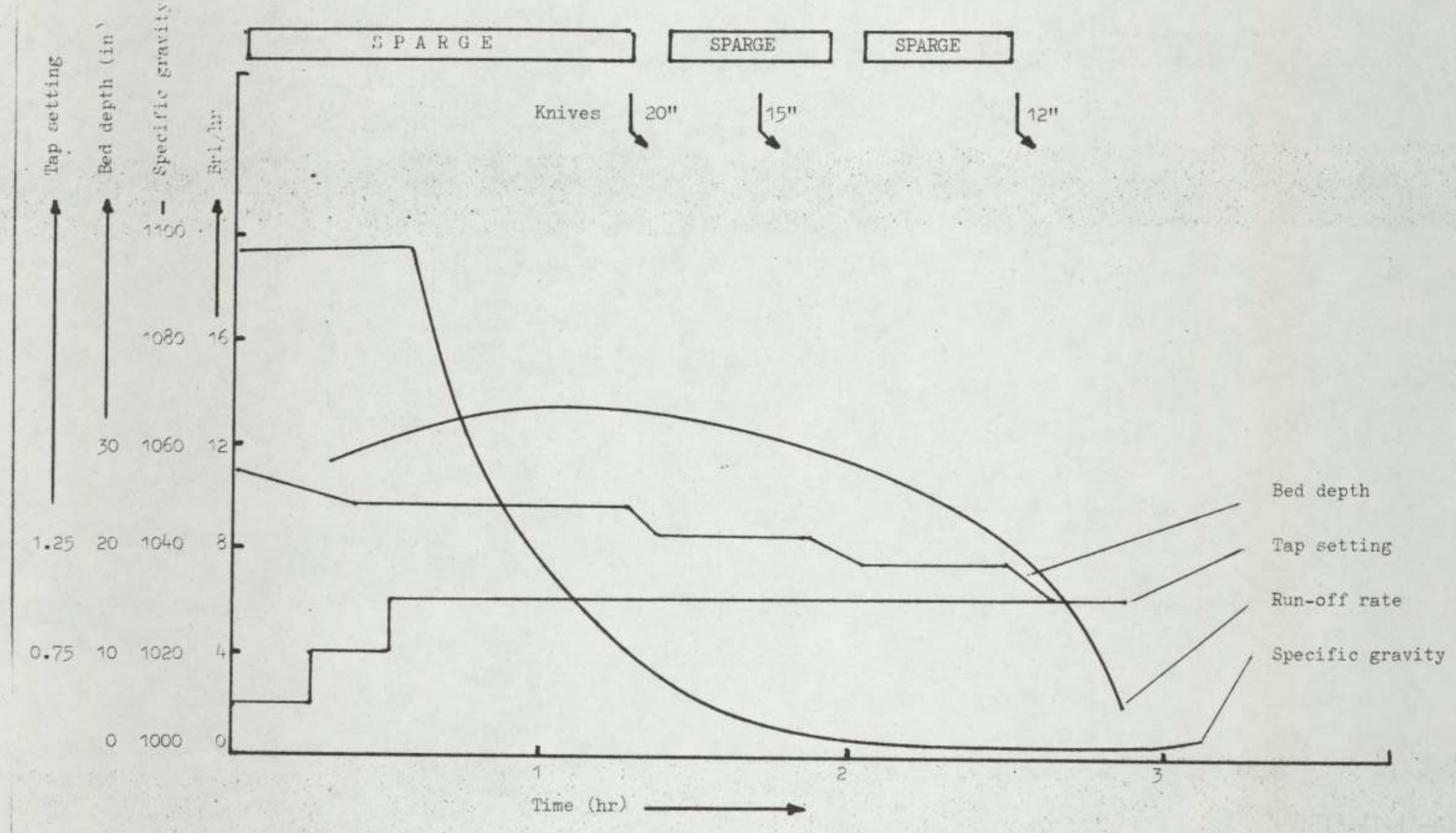



Fig. 11 Extraction of malt-grist, control brew CB 1

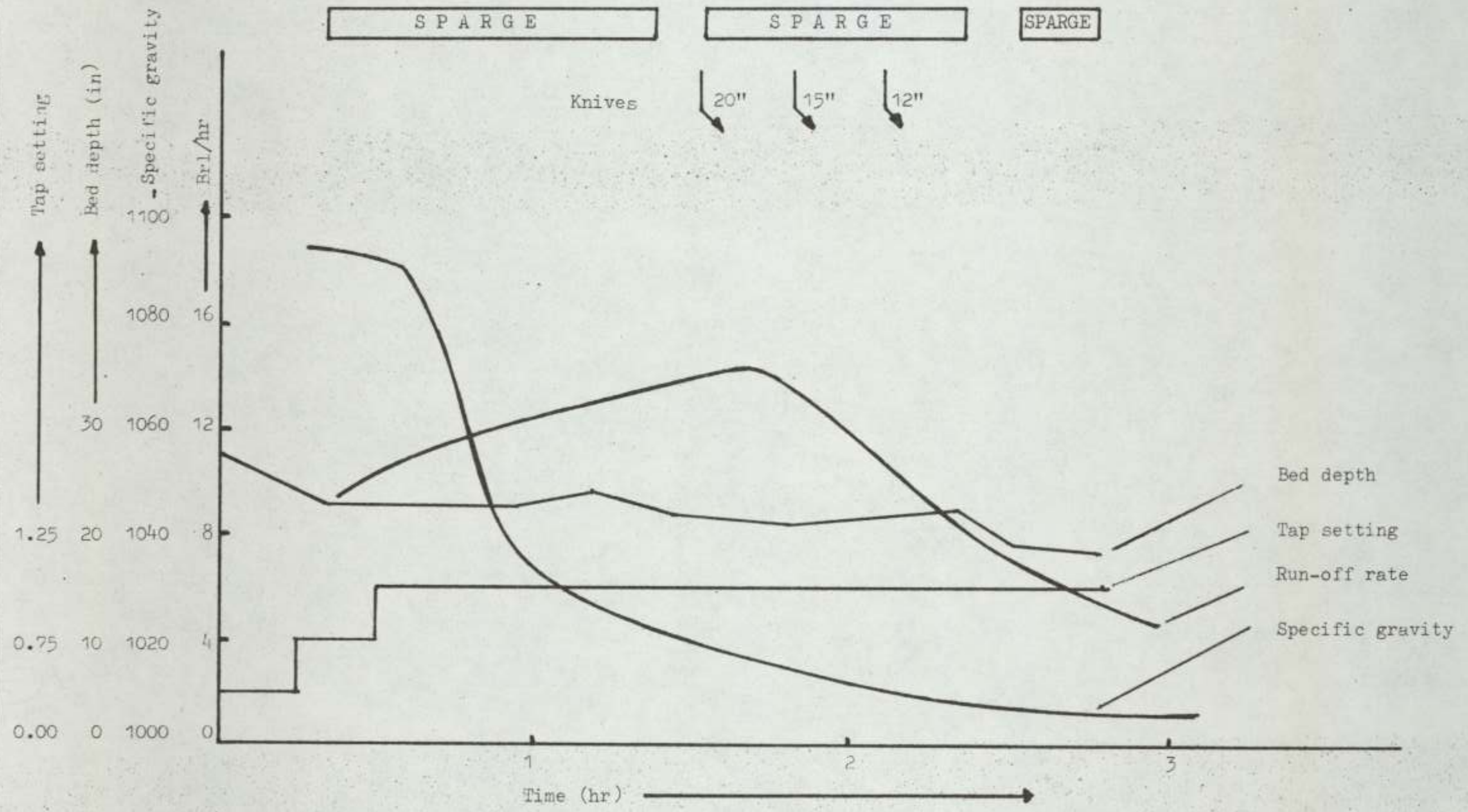



Fig. 12 Extraction of control malt-grist. CB 2

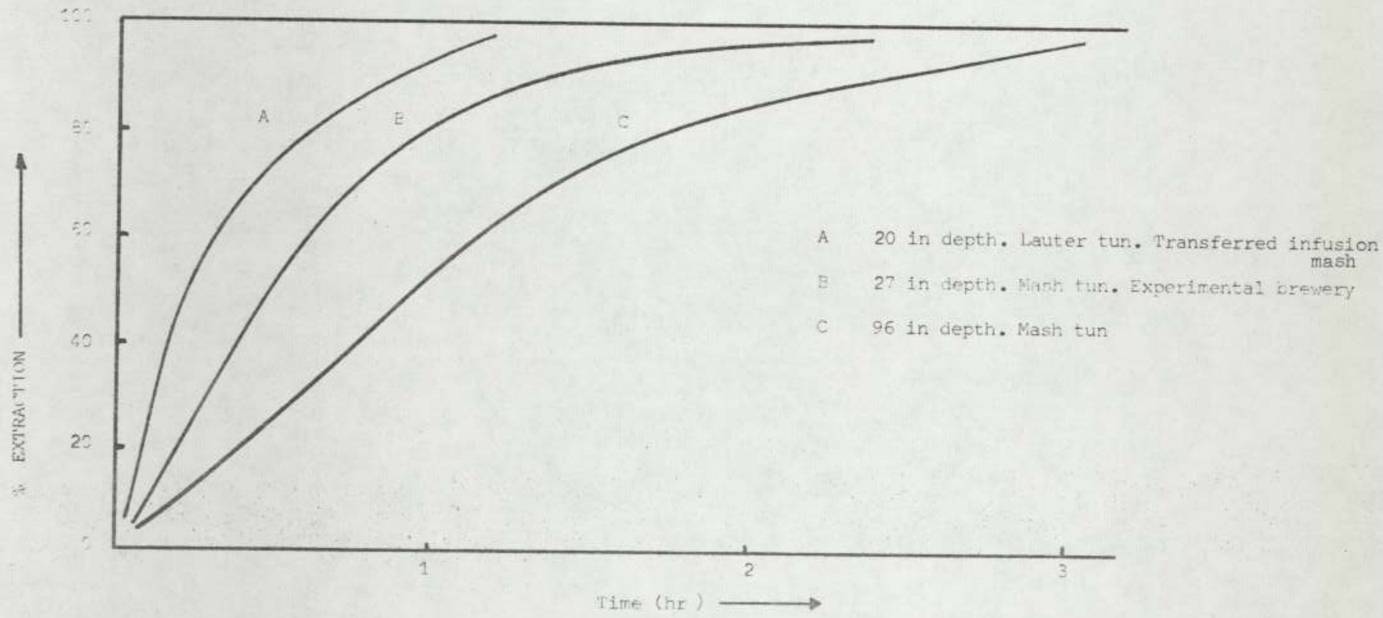



Fig. 13 Extraction rates of malt grist in different tuns

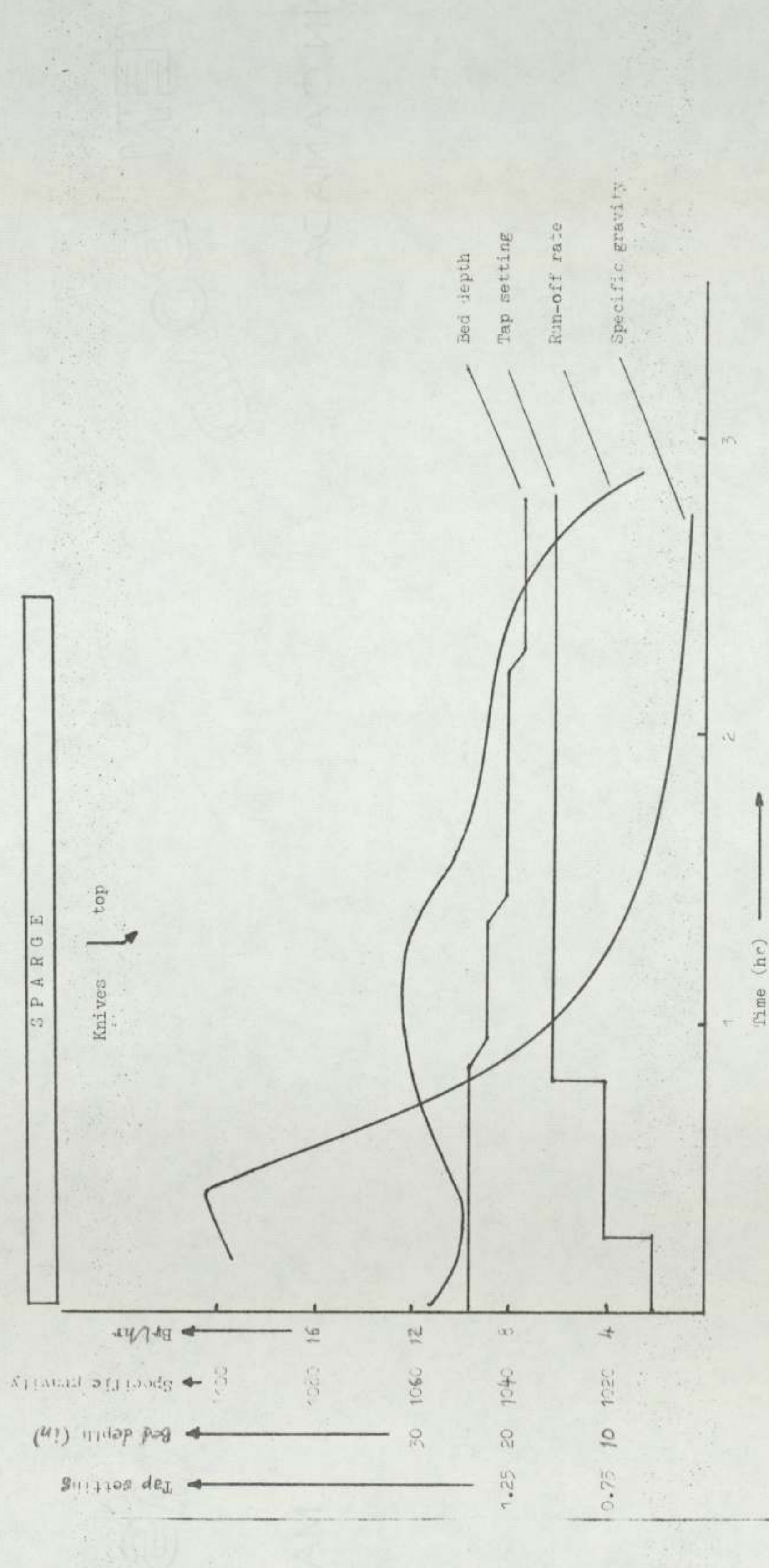



Fig.14 Extraction of 17% barley-flake grist

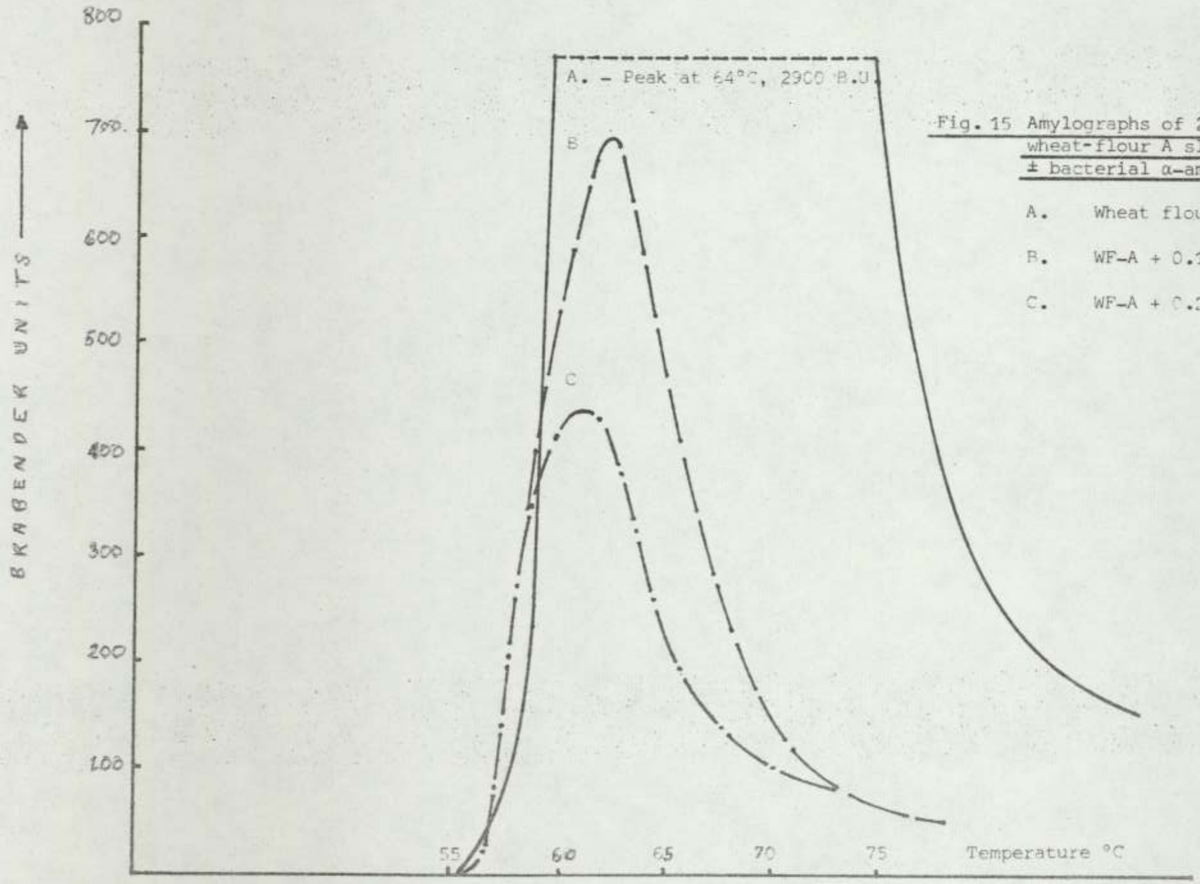



Fig. 15 Amylographs of 2.8 brl/gr wheat-flour A slurries ± bacterial α-amylase.

A. Wheat flour A slurry (WF-A)

B. WF-A + 0.1% α-amylase

C. WF-A + 0.2% α-amylase

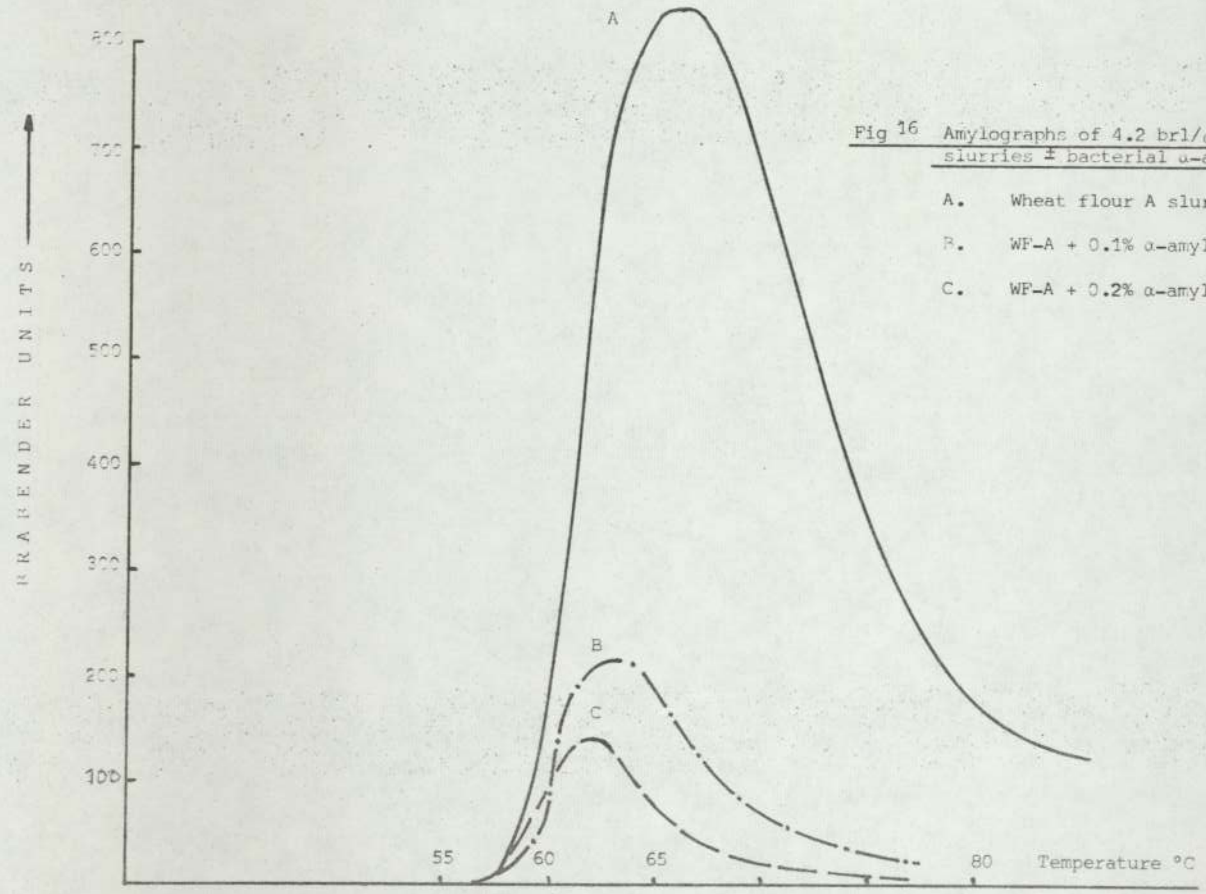



Fig 16 Amylographs of 4.2 brl/gr wheat-flour A slurries ± bacterial α-amylase

A. Wheat flour A slurry (WF-A)

B. WF-A + 0.1% α-amylase

C. WF-A + 0.2% α-amylase

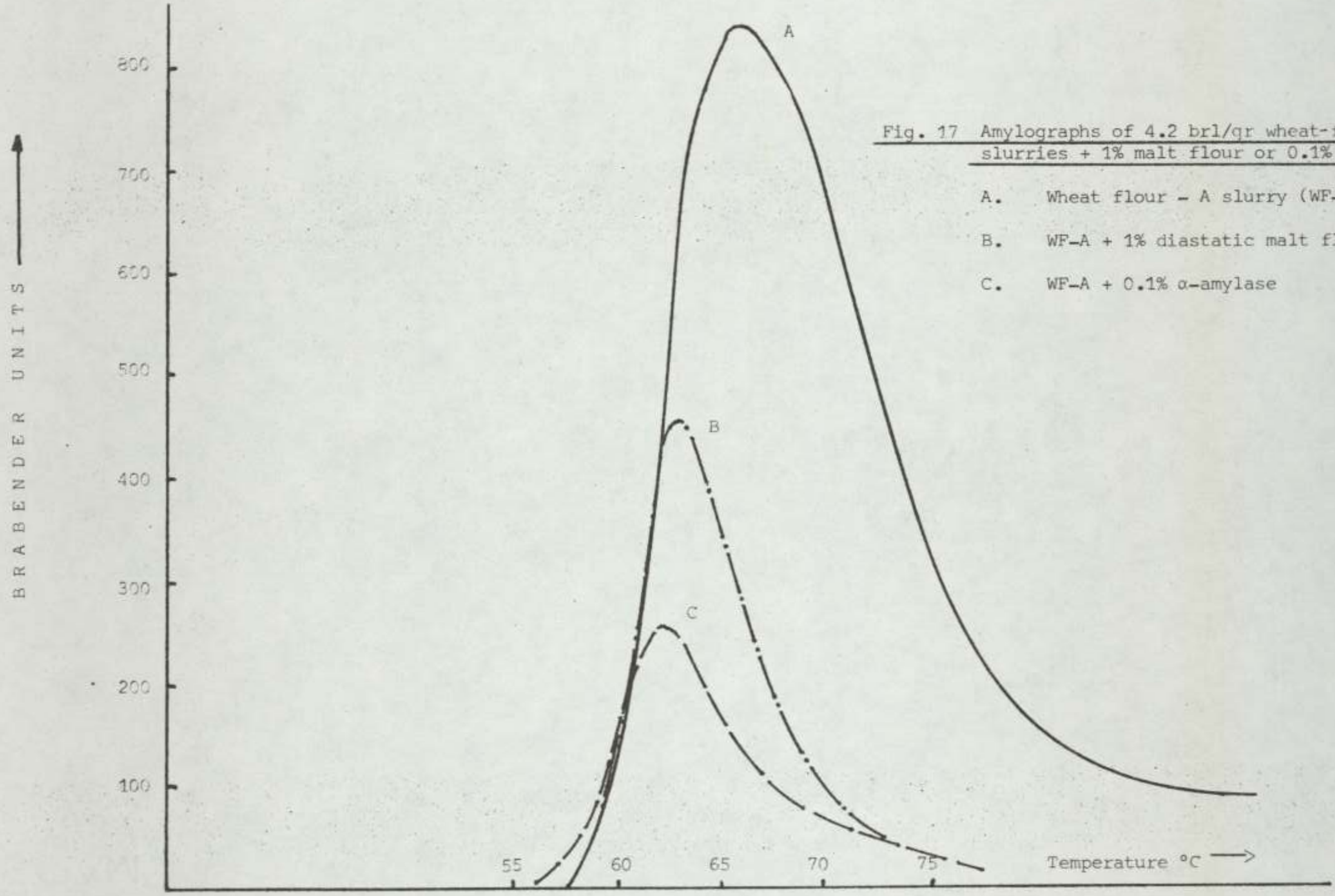



Fig. 17 Amylographs of 4.2 brl/gr wheat-flour A slurries + 1% malt flour or 0.1% α-amylase

A. Wheat flour - A slurry (WF-A)

B. WF-A + 1% diastatic malt flour

C. WF-A + 0.1% α-amylase

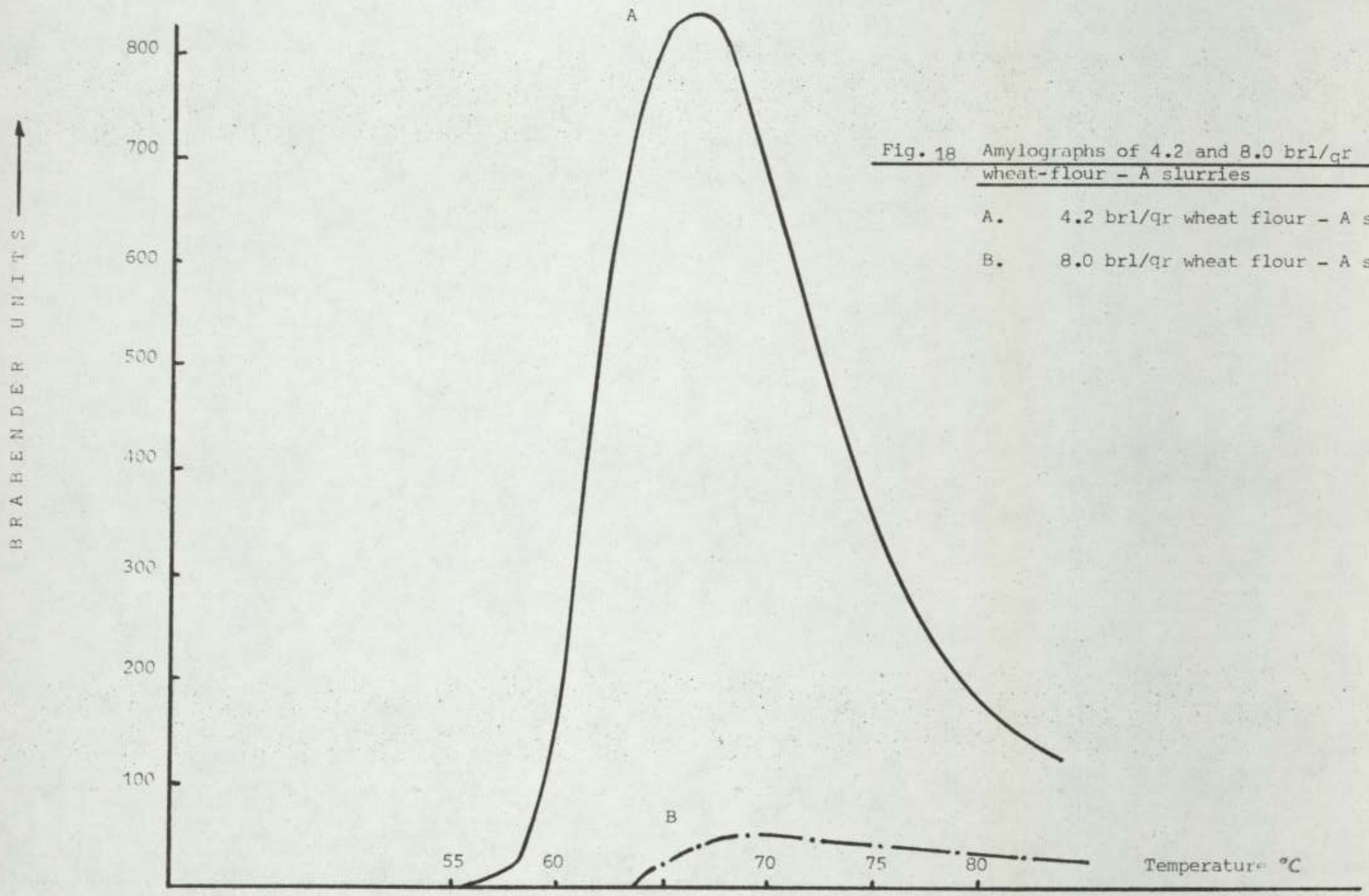



Fig. 18 Amylographs of 4.2 and 8.0 brl/qr wheat-flour - A slurries

A. 4.2 brl/qr wheat flour - A slurry

B. 8.0 brl/qr wheat flour - A slurry

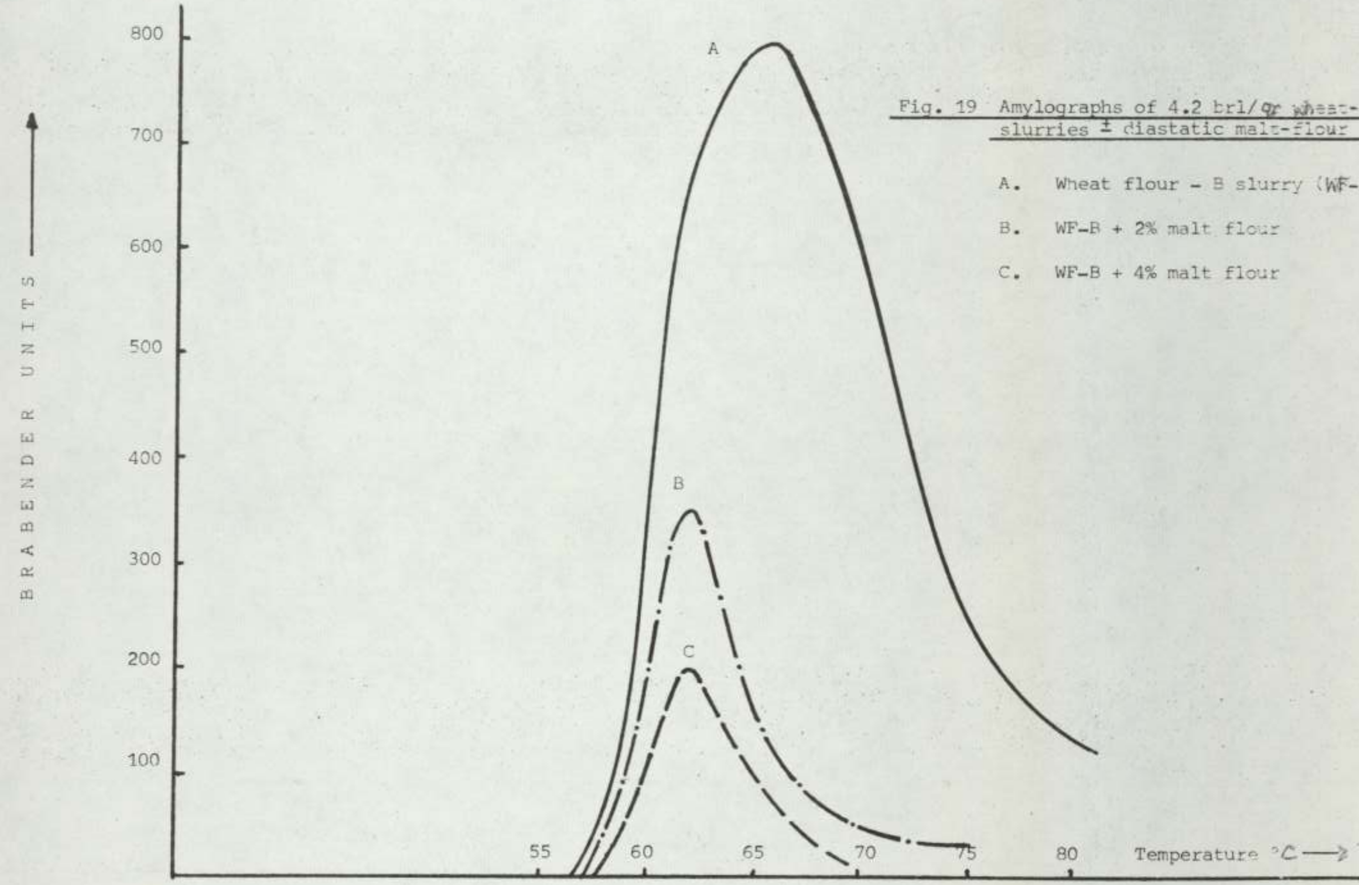



Fig. 19 Amylographs of 4.2 brl/gr wheat-flour B slurries ± diastatic malt-flour

A. Wheat flour - B slurry (WF-B)

B. WF-B + 2% malt flour

C. WF-B + 4% malt flour

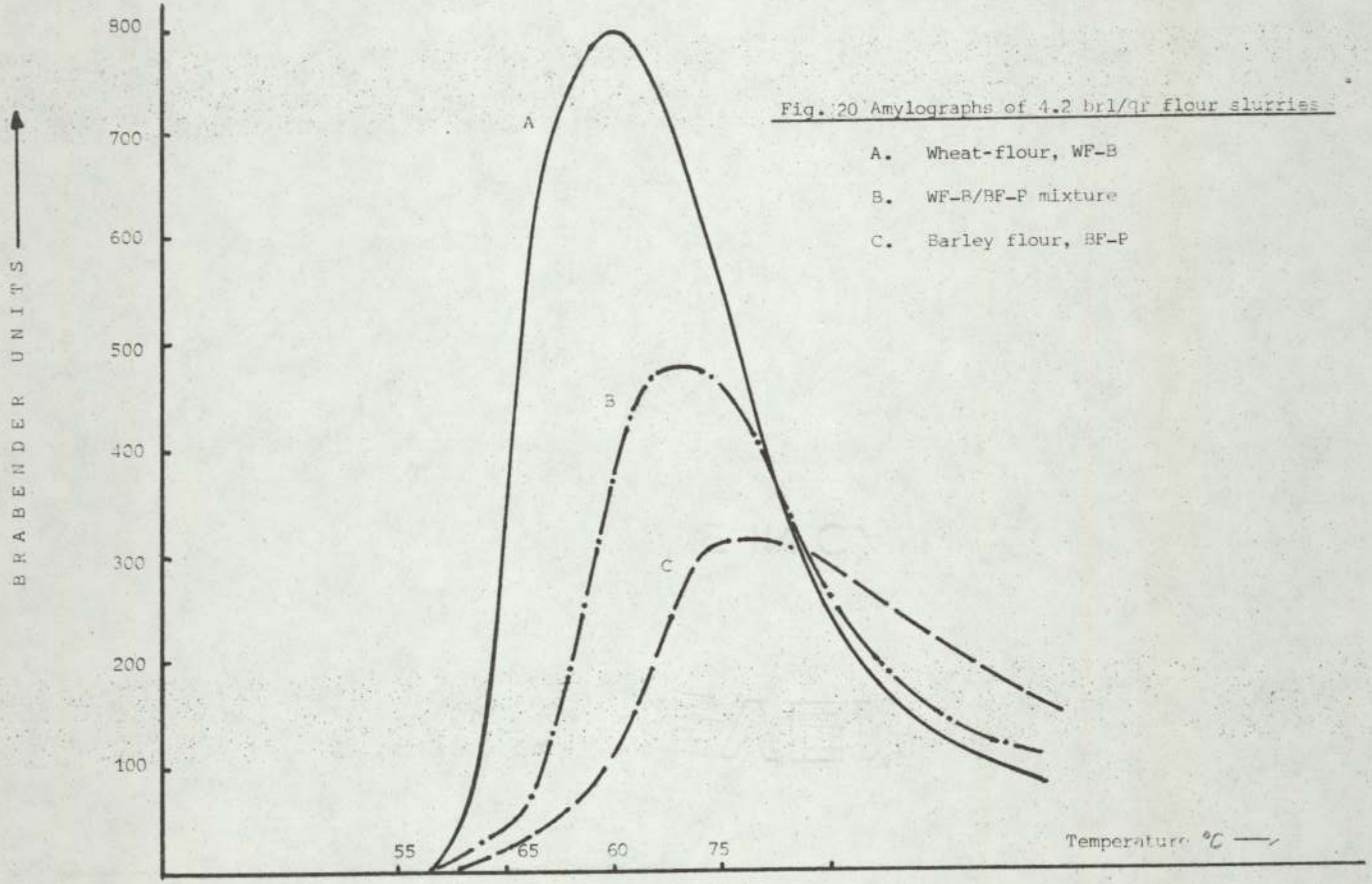



Fig. 20 Amylographs of 4.2 brl/qr flour slurries

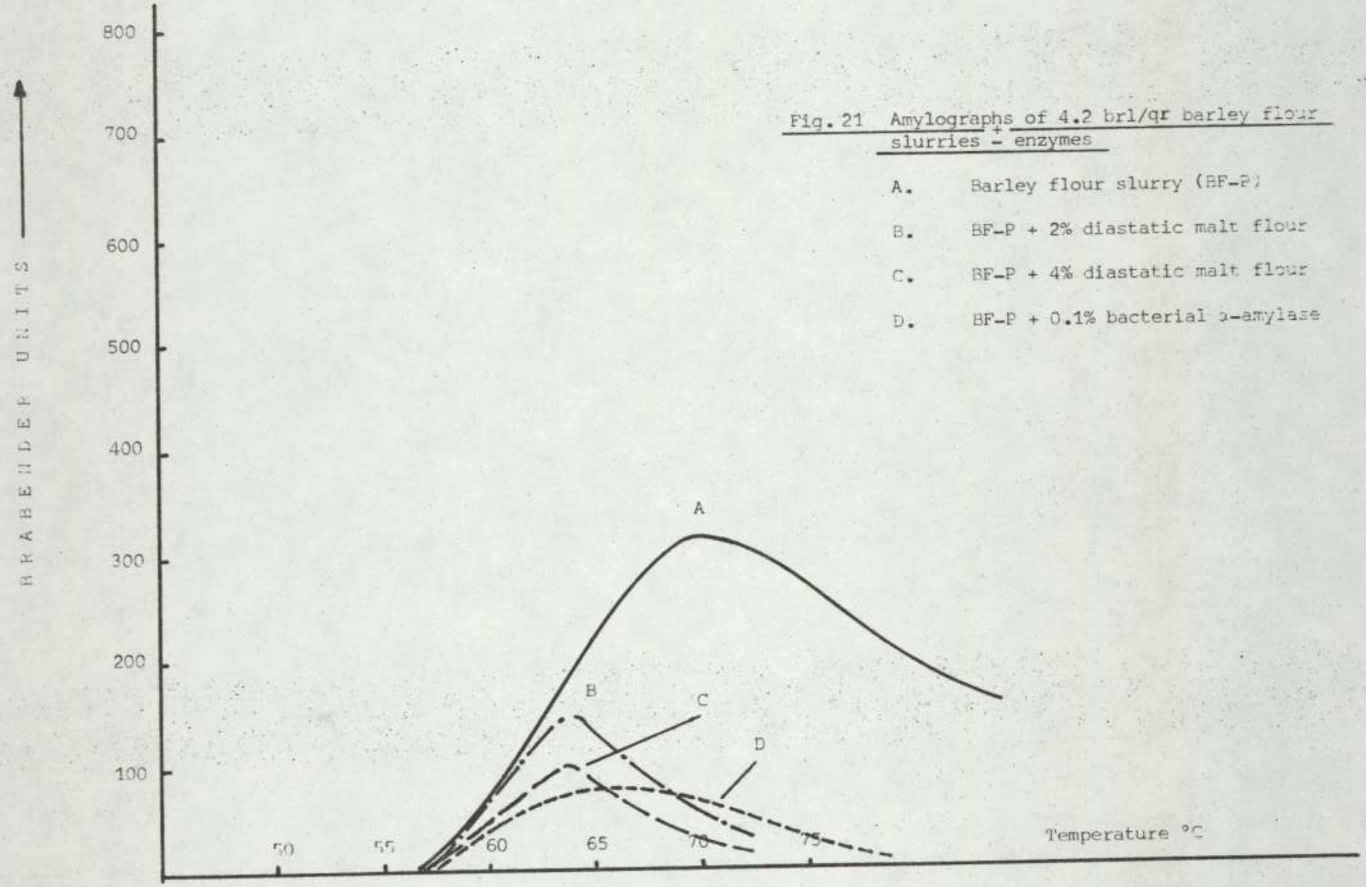



Fig. 21 Amylographs of 4.2 brl/qr barley flour slurries + enzymes

A. Barley flour slurry (BF-P)

B. BF-P + 2% diastatic malt flour

C. BF-P + 4% diastatic malt flour

D. BF-P + 0.1% bacterial α-amylase

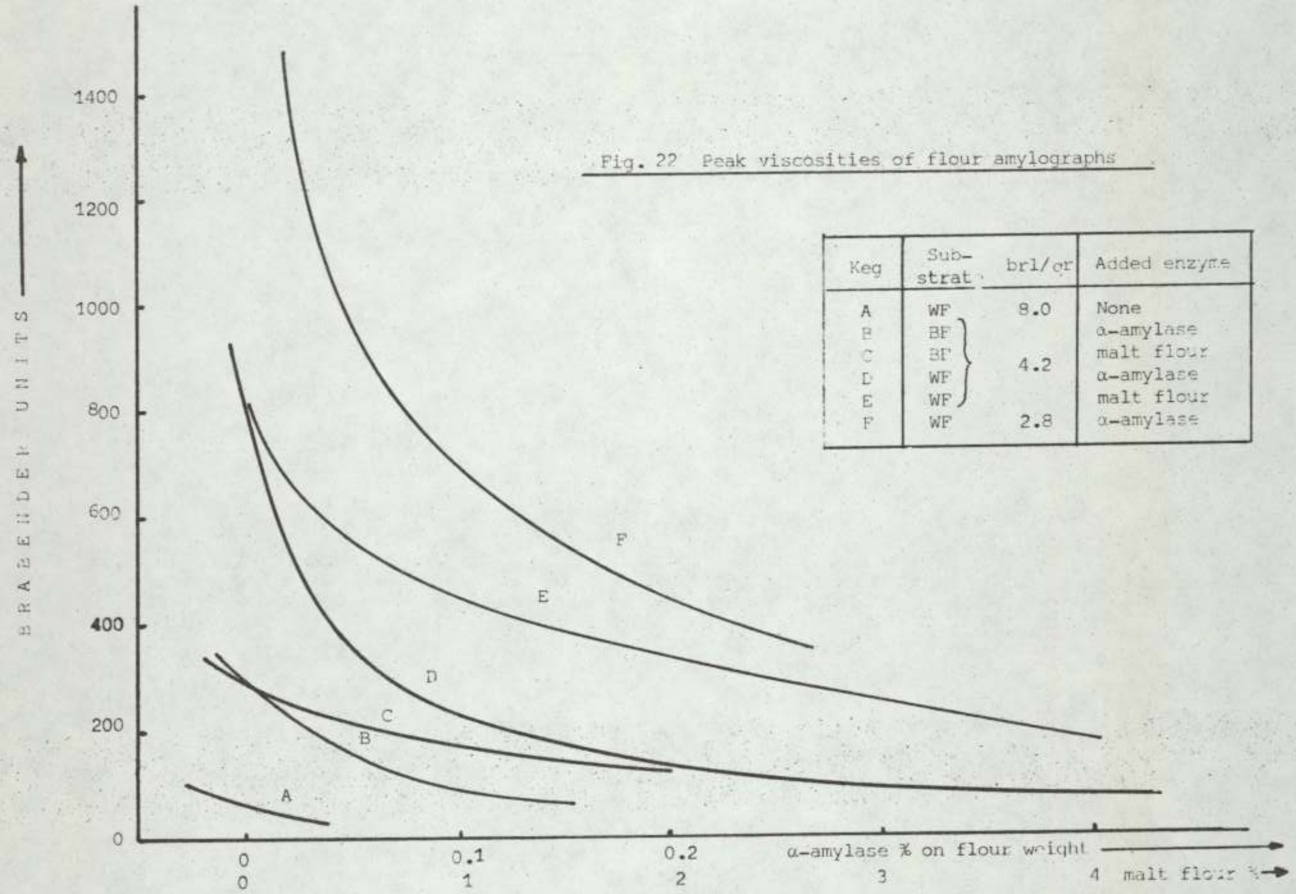



Fig. 22 Peak viscosities of flour amylographs

| Key | Sub-strat | brl/gr | Added enzyme |
|---|---|---|---|
| A | WF | 8.0 | None |
| B | BF | 4.2 | α-amylase |
| C | BF | 4.2 | malt flour |
| D | WF | 4.2 | α-amylase |
| E | WF | 4.2 | malt flour |
| F | WF | 2.8 | α-amylase |

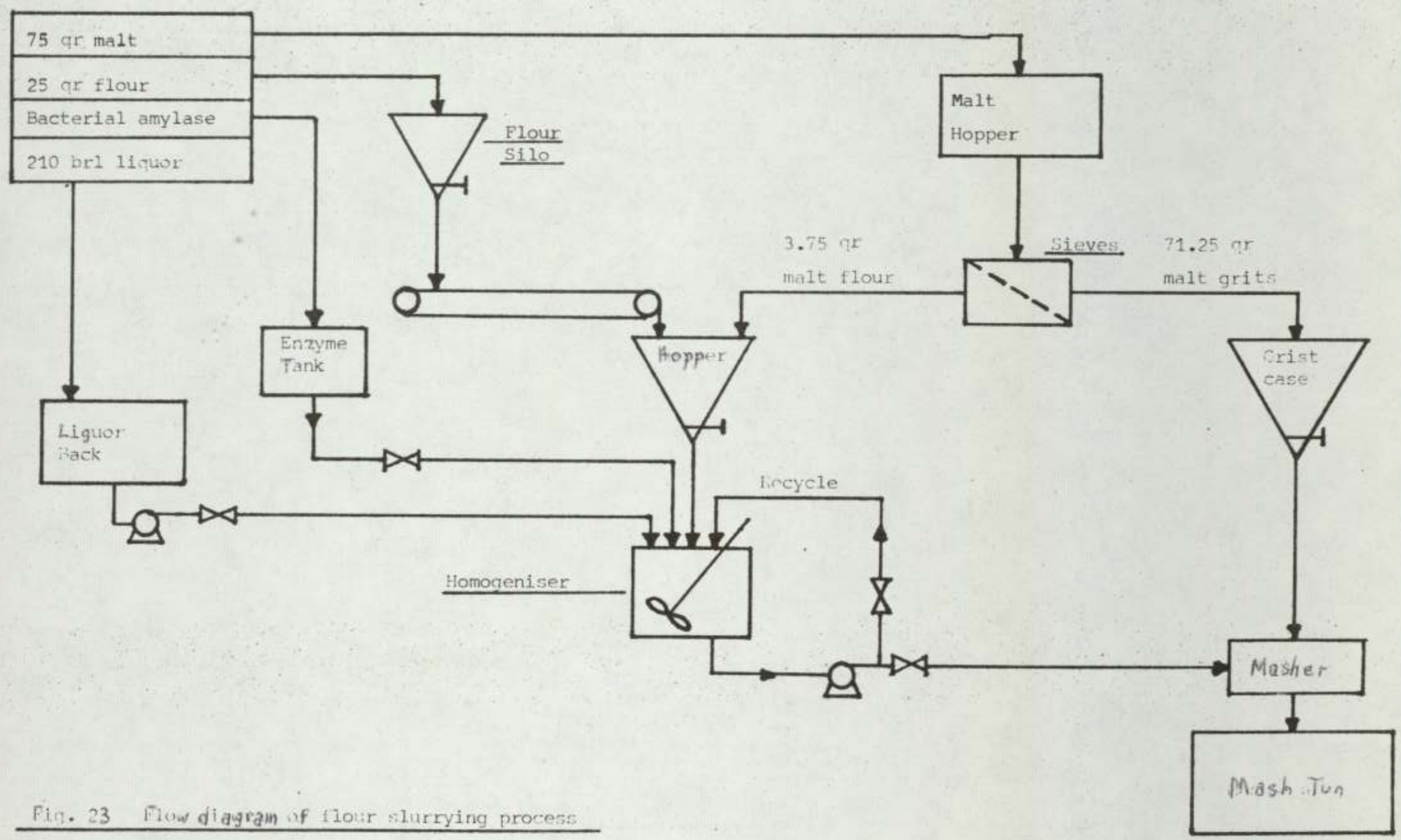
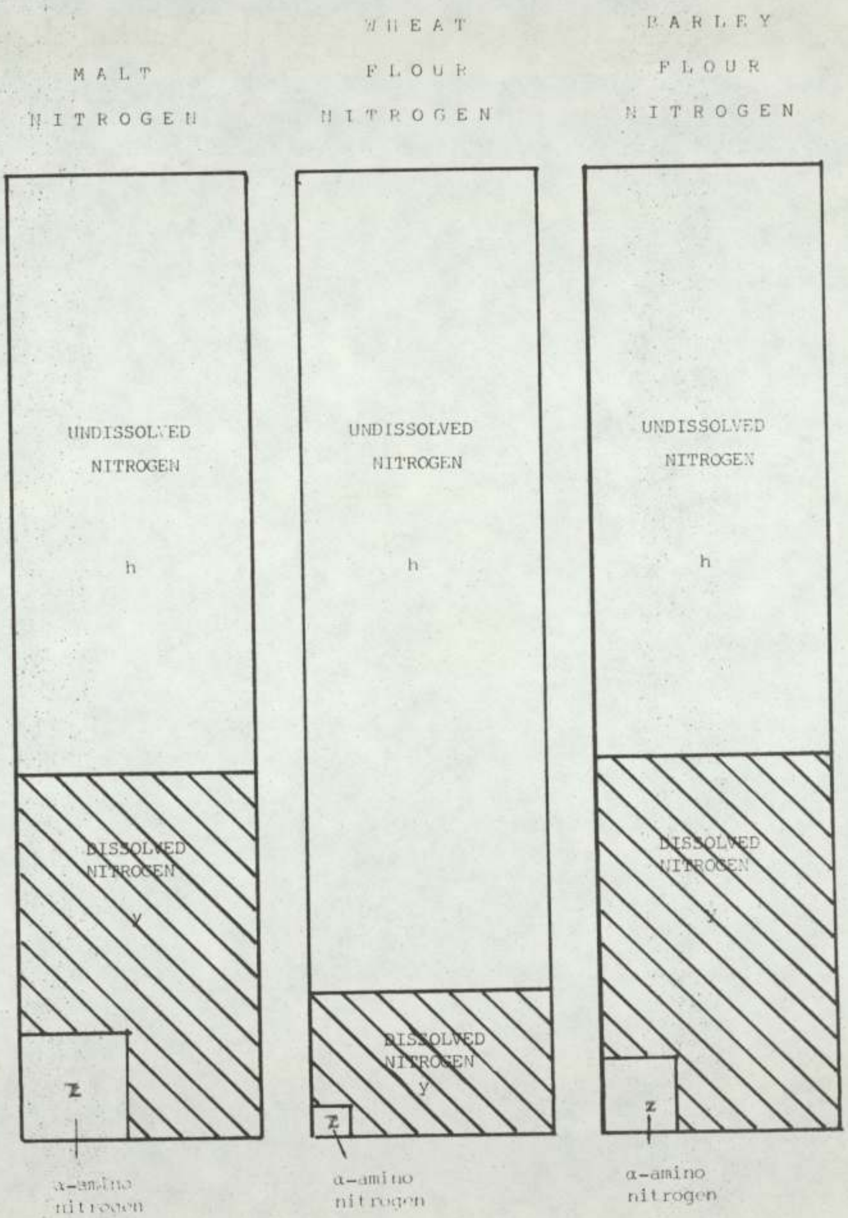



Fig. 23 Flow diagram of flour slurrying process

Fig. 24 Fate of cereal nitrogen




→

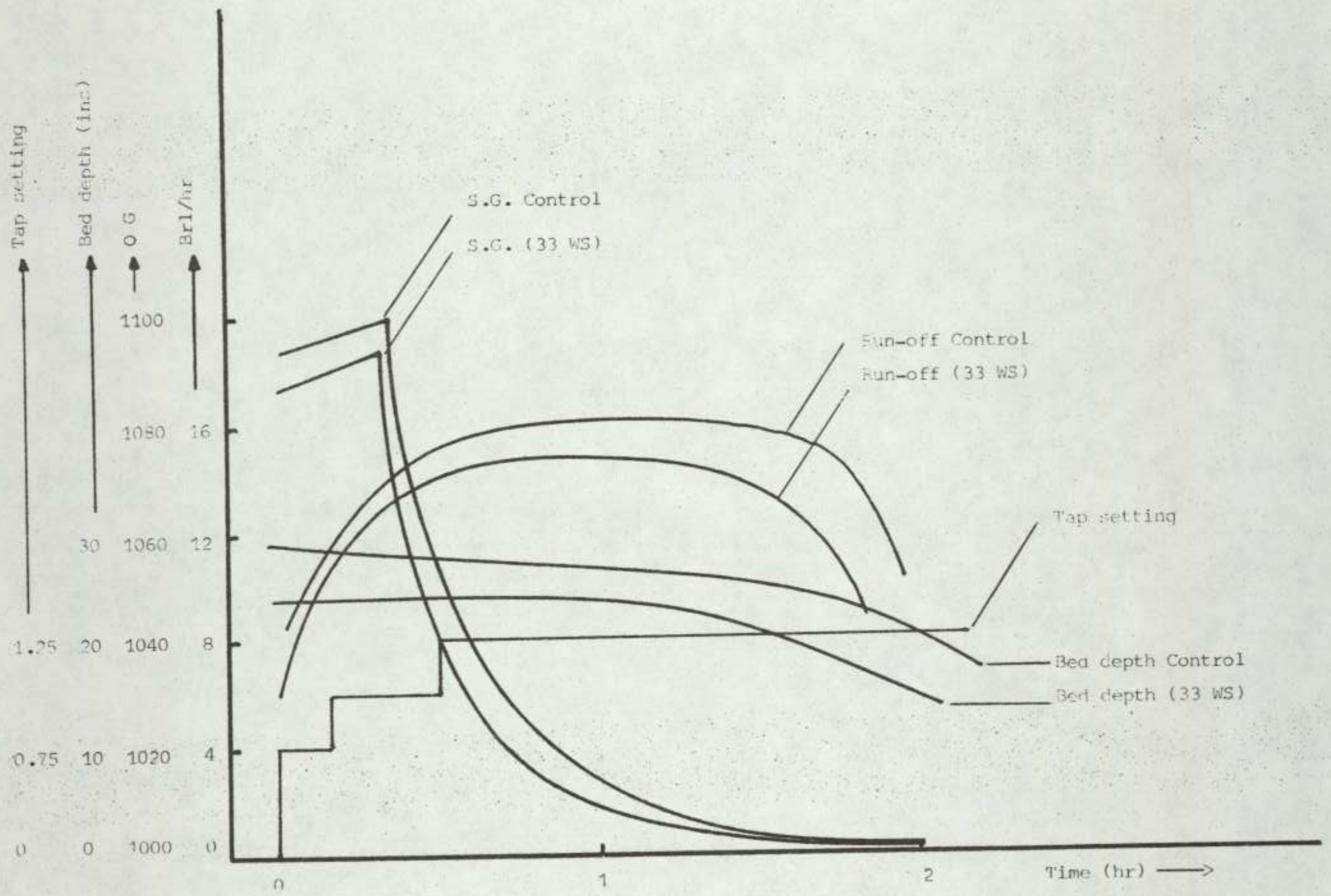



Fig. 25 Extraction of (33 WS) and control grists

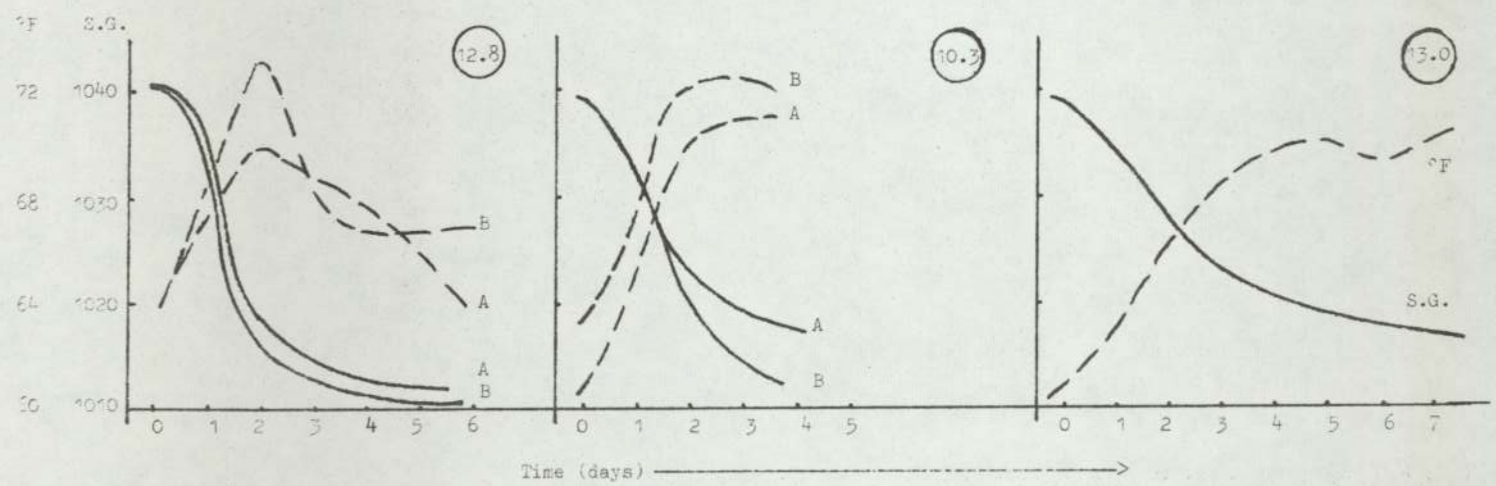



Fig. 26 Fermentation of 33% wort syrup brews (33 WS) 1 - 3

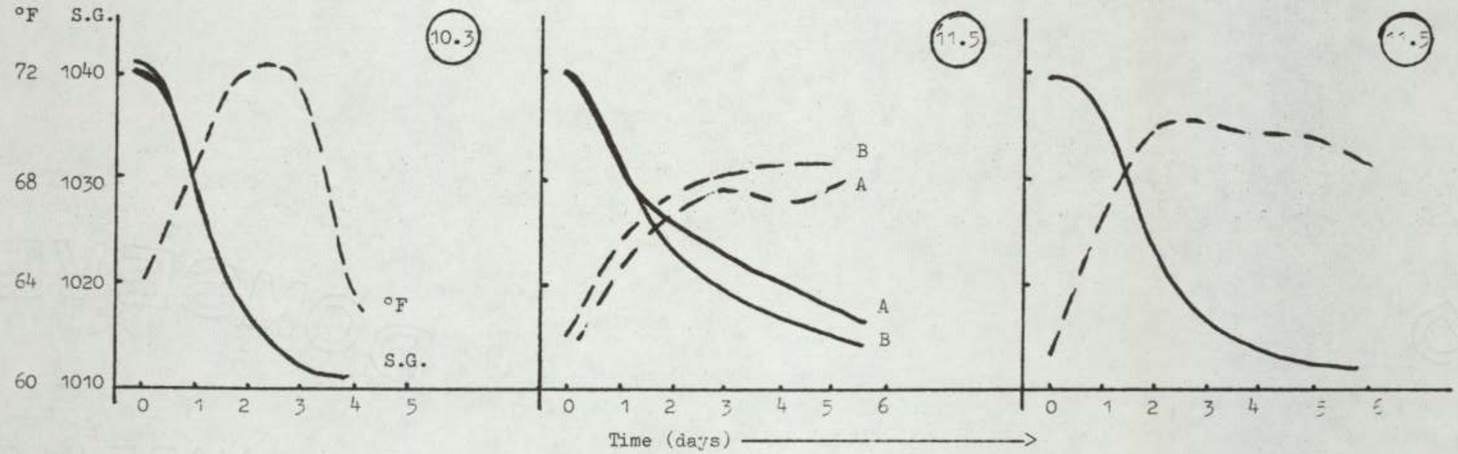



Fig. 27 Control brew fermentations 1 - 3

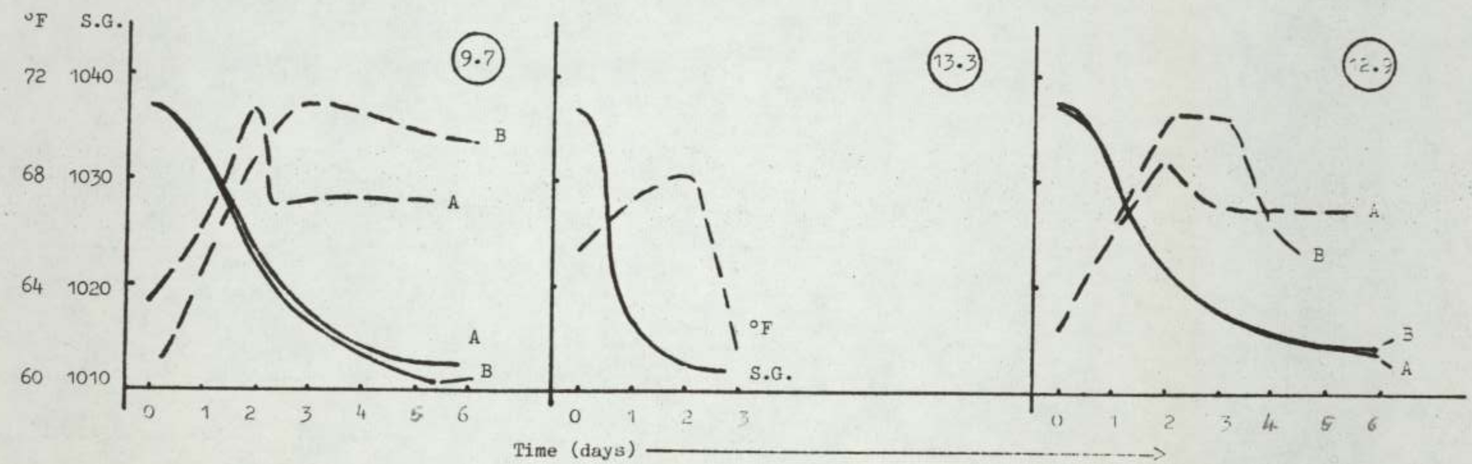



Fig. 28 Fermentation of 33° wort syrup + sucrose brews (33 WS + S)

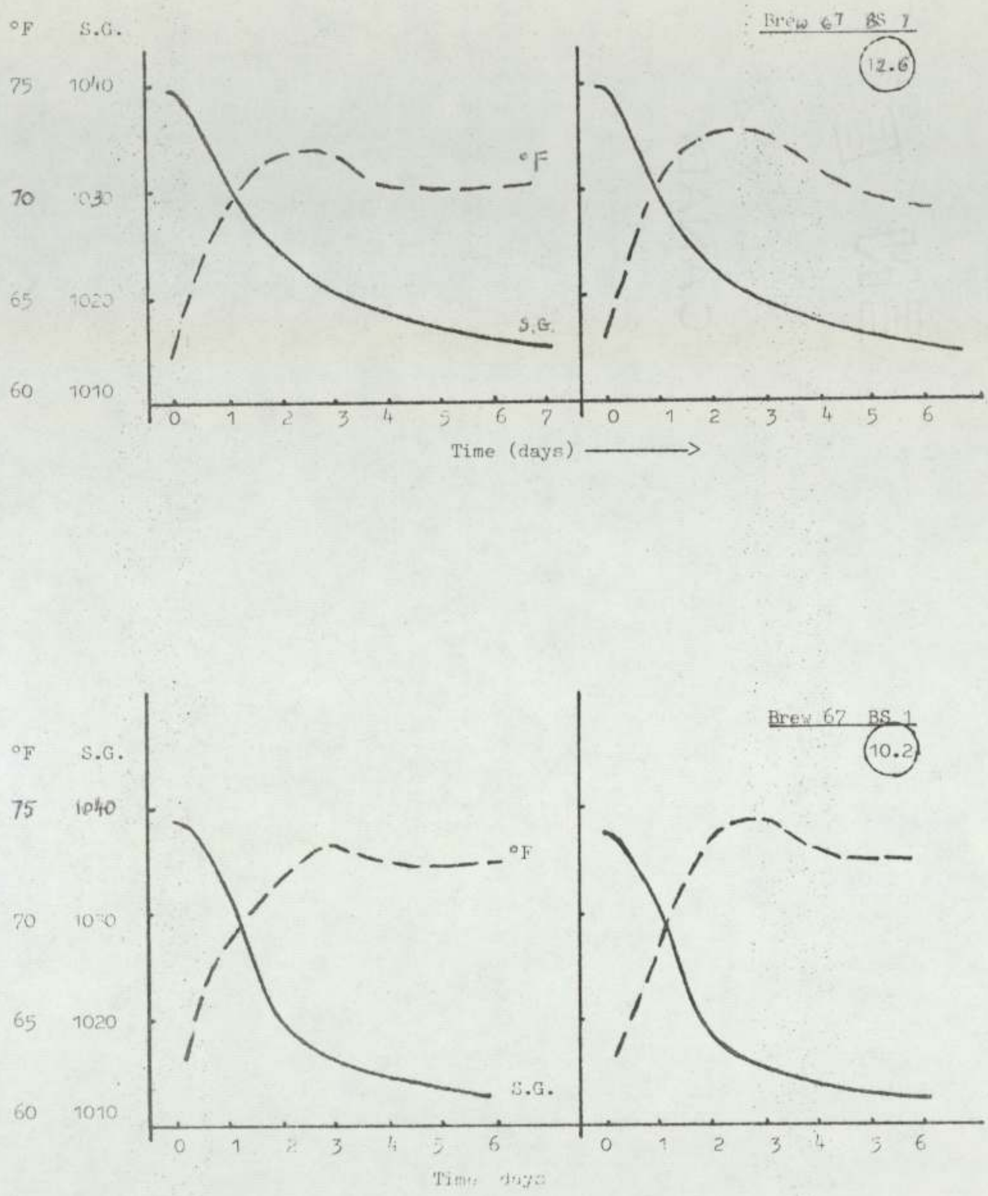



Fig. 29 Fermentation of 67% barley-syrup worts

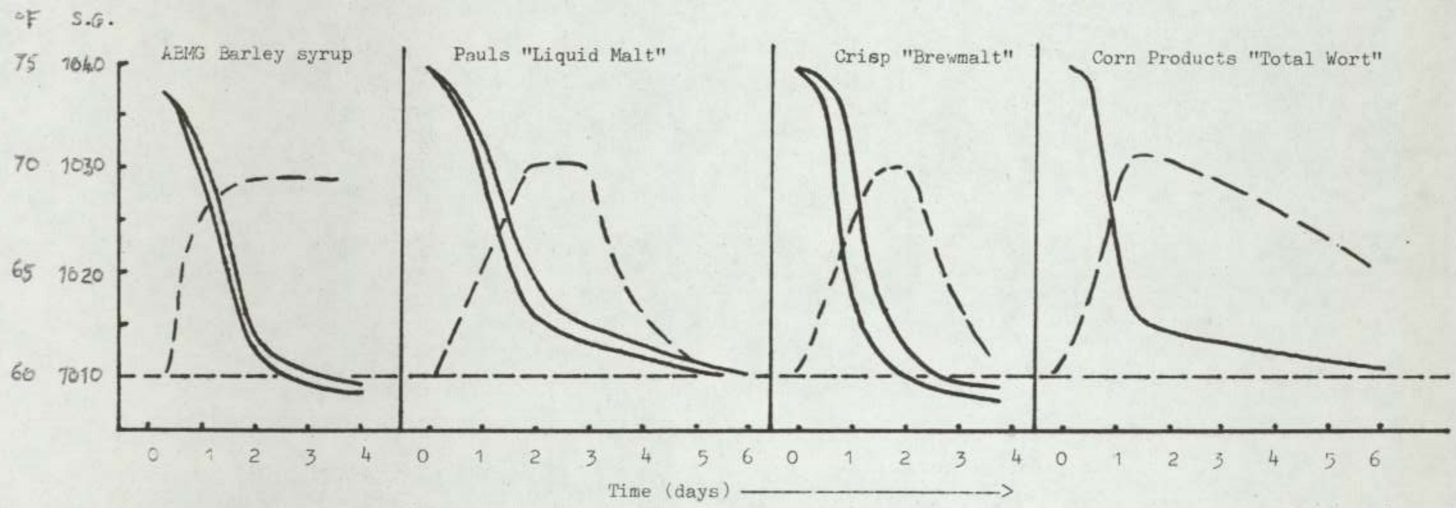



Fig. 30 Fermentation of 100% barley-syrup brews

Table 1

WHEAT-FLOUR ANALYSES

| | | Summit | | Silver Crest | Brumore | | |
|---|---|---|---|---|---|---|---|
| | | L | M | N | O | P | Q |
| Moisture % | A | 10.6 | 10.9 | 12.2 | 12.8 | 12.7 | 12.3 |
| % Nitrogen - on sample | B | 1.31 | 1.30 | 1.22 | 0.98 | 1.39 | 1.04 |
| - on solids | C | 1.47 | 1.46 | 1.38 | 1.12 | 1.59 | 1.19 |
| *Protein - on sample % | D | 7.5 | 7.4 | 6.9 | 5.6 | 7.9 | 5.9 |
| - on solids % | E | 8.4 | 8.3 | 7.9 | 6.4 | 9.1 | 6.8 |
| †Total starch - on sample % | F | 77.4 | 77.2 | 76.4 | 77.1 | 74.9 | 77.3 |
| - on solids % | G | 86.7 | 86.7 | 87.1 | 88.5 | 85.9 | 88.1 |
| ** % as glucose, on sample | H | 86.0 | 85.8 | 84.9 | 85.7 | 83.2 | 85.9 |
| % as glucose, on solids | I | 96.3 | 96.3 | 96.8 | 98.3 | 95.5 | 97.9 |
| Extract yield - on sample (brewers lb/qr) | J | 106.5 | 108.5 | 106.7 | 108.0 | 103.3 | 109.4 |
| ††Extract yield on starch (lb/qr) = J/F x 100 | K | 138 | 141 | 140 | 140 | 138 | 141 |

* Protein = Nitrogen x 5.7

† Assumed starch content of a flour at 14.5% moisture and 12% protein is 69%.(102) Hence total starch for any flour except wheat meal and whole meal

<u>Table 1 footnotes cont.</u>

may be calculated:

Total Starch%= 81.0 + (14.5 - flour moisture %) - flour protein

** Since wheat starch is highly polymerised, assume

$(C_6 H_{10} O_5)_n$ Unit M.W. = 162

Now glucose M.W. = 180

Hence total starch content $\equiv$ Starch as glucose x 162/180

= Starch as glucose x 0.9

†† Dr A.M. Maiden (52) has calculated a value of 138.2 brewers lb/qr for starch solids.

Table 2

# MALT ANALYSES

| Brew no. | 10 W1 | 10 W2 | 17 W1 | 17 W2 | 25 W1 | 15 W1 | 15 W2 |
|---|---|---|---|---|---|---|---|
| Type | Pale Malt | Pale Malt | Pale Malt | Pale Malt | Pale Malt | Pale Malt | Pale Malt |
| Extract lb/qr | 100 | 97.6 | 101.6 | 100.4 | 100.4 | 98.4 | 99.6 |
| Moisture % | 2.0 | 3.1 | 2.1 | 2.3 | 2.1 | 2.2 | 2.8 |
| CWE % | 17.4 | 18.5 | 18.8 | 18.7 | 18.2 | 20.7 | 19.2 |
| Diastatic power ° | 46 | 42 | 40 | 56 | 40 | 56 | 52 |
| Colour | 9.0 | 5.3 | 5.6 | 4.6 | 5.6 | 6.0 | 4.6 |

| Brew no. | 15 W3 | 15 W4 | 10 P | | | |
|---|---|---|---|---|---|---|
| Type | Pale Malt | Pale Malt | Pale Malt | Crystal Malt | Flaked Maize | Flaked Maize |
| Extract lb/qr | 98.0 | 98.6 | 98.3 | 86 | 106.5 | 107.8 |
| Moisture % | 2.2 | 2.2 | 2.7 | | 8.8 | 9.8 |
| CWE % | 18.7 | 18.2 | 16.1 | | - | - |
| Diastatic power° | 48 | 48 | 42 | | Nil | Nil |
| Colour | 5.0 | 4.6 | 4.6 | | - | - |

→

Table 3

EFFECT OF MILL ROLL-SETTINGS ON MALT SIEVE ANALYSIS

| Roll settings | | Sieve Analysis (%) | | |
|---|---|---|---|---|
| Top Rolls | Bottom rolls | > 1.5 mm | 0.15 - 1.5 mm | < 0.15 mm |
| 9.5 | 9.5 | 47.9 | 42.7 | 9.4 |
| | 9.0 | 39.2 | 49.8 | 11.0 |
| | 8.5 | 42.2 | 50.0 | 7.8 |
| | Average | 43.0 | 47.6 | 9.4 |
| 9.0 | 9.5 | 38.2 | 50.4 | 11.4 |
| | 9.0 | 37.2 | 52.4 | 10.4 |
| | 8.5 | 33.4 | 52.8 | 13.8 |
| | Average | 36.2 | 51.9 | 11.9 |
| 8.75 | 9.5 | 31.2 | 54.3 | 14.5 |
| | 9.0 | 30.6 | 53.6 | 15.8 |
| | 8.5 | 33.0 | 54.4 | 12.6 |
| | Average | 31.3 | 54.1 | 14.2 |

Table 4

SIEVE ANALYSIS OF GROUND MALT

| Run number | Sieve Analysis (%) | | |
| --- | --- | --- | --- |
| | > 1.5 mm | 0.15 - 1.5 mm | < 0.15 mm |
| Production brewery | 45.4 | 46.9 | 7.7 |
| Control brew 3 | 46.4 | 46.0 | 7.6 |
| Control brew 7 | 63.1 | 32.6 | 4.3 |
| 10 W1 | 50.9 | 41.1 | 8.0 |
| 17 W1 | 58.4 | 36.4 | 5.2 |
| 17 W2 | 59.1 | 36.4 | 4.5 |
| 15 W1 | 55.2 | 37.7 | 7.1 |
| 15 W3 | 58.6 | 36.2 | 5.2 |
| 10 P | 60.0 | 33.3 | 6.7 |

Table 5

PRODUCTION, CONTROL AND WHEAT-FLOUR GRISTS

| Raw material | Production and Control grists | Wheat-flour grists 10% | 15% | 17% | 25% |
|---|---|---|---|---|---|
| Pale Malt ) % | 88.8 | 78.8 | 80.9 | 78.8 | 70.9 |
| Crystal Malt ) Weight | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 |
| Flaked maize ) Basis | 7.1 | 7.1 | - | - | - |
| Wheat flour ) | - | 10.0 | 15.0 | 17.1 | 25.0 |
| | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Malt grist as % of total extract | 87.5 | 87.5 | 87.5 | 87.5 | 87.5 |
| Liquid sucrose as % of total extract | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 |
| | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

Table 6

ANALYSES OF BREWS WITH ZERO MASH STAND-TIME

| | Brew 1 | Brew 2 | Average |
|---|---|---|---|
| Pilot brewery extract (lb/qr) | 95.8 | 95.4 | 95.6 |
| Spent grains loss (lb/qr) | 3.7 | 3.9 | 3.8 |
| Grist utilisation % | 95.6 | 95.5 | 95.5 |
| Wort alpha-amino nitrogen (g/l) | 0.14 | 0.15 | 0.14 |
| Wort total nitrogen (g/l) | 0.66 | 0.66 | 0.66 |
| Alpha amino N/total N (%) | 21% | 22% | 21% |
| Beer total nitrogen (g/l) | 0.40 | 0.41 | 0.40 |
| Wort carbohydrates: | | | |
| Non-carbohydrate % total solids | 4.8 | 4.9 | 4.8 |
| Non-fermentable carbohydrate % total solids | 23.0 | 24.8 | 23.9 |
| Fermentable carbohydrate by AL (%) | 68.8 | 68.9 | 68.8 |
| Present gravity (PG) at AL | 1.0068 | 1.0069 | 1.0068 |
| Sieve test of ground malt | | | |
| Weight % > 1.5 mm | | 51.8 | |
| Weight % 0.15 - 1.5 mm | | 39.6 | |
| Weight % < 0.15 mm | | 8.6 | |

Note: Wort and beer analyses expressed in terms of 1.040° SG.

Table 7a, b

ANALYSES OF 10%, 17% AND 25% WHEAT-FLOUR BREWS

a) Utilisation of grists (brewers lb/qr except where % age)

| Brew | A<br>Pilot-Brewery Extract | B<br>Spent Grain Loss | C<br>A + B | D<br>Lab. ext. of Pale Malt | E<br>Predicted Lab. ext. of grist | F<br>$\frac{C + E}{2}$ | G<br>Utilisation $\frac{A}{F} \times 100$ % |
|---|---|---|---|---|---|---|---|
| CB2 | 97.6 | 3.6 | 101.2 | 97.6 | 97.6 | 99.4 | 98.2 |
| CB4 | 97.8 | 3.8 | 101.6 | 100.4 | 100.4 | 101.0 | 96.8 |
| CB7 | 97.6 | 3.4 | 101.0 | 101.0 | 101.0 | 101.0 | 96.7 |
| | | | | | | Av. | 97.2% |
| 10 W1 | 98.2 | 2.5 | 100.7 | 100.0 | 100.7 | 100.7 | 97.5 |
| 10 W2 | 96.7 | 3.4 | 100.1 | 97.6 | 98.3 | 99.2 | 97.5 |
| | | | | | | Av. | 97.5% |
| 17 W1 | 96.5 | 3.3 | 99.8 | 101.6 | 102.3 | 101.0 | 95.6 |
| 17 W2 | 96.5 | 4.5 | 102.0 | 100.4 | 101.1 | 101.5 | 96.1 |
| | | | | | | Av. | 95.8% |

b) Spent-grain analyses (brewers lb/qr)

10% wheat-flour brews

| 10 WF 1 | top of bed ⟶ | | | | | | | bottom | Av. |
|---|---|---|---|---|---|---|---|---|---|
| Total loss | 2.8 | 2.4 | 2.4 | 2.7 | 2.7 | 2.0 | 2.5 | 2.7 | 2.5 |
| Unconverted | 0.5 | 0.7 | 0.3 | 0.3 | 0.7 | 0.7 | 0.7 | 0.7 | 0.5 |
| Unsparged | 2.3 | 1.7 | 2.1 | 2.2 | 2.0 | 1.3 | 1.8 | 2.2 | 2.0 |

| 10 WF 2 | top | bottom | Av. | Overall 10% WF Av. |
|---|---|---|---|---|
| Total loss | 2.9 | 4.0 | 3.4 | 2.9 |
| Unconverted | 0.8 | 1.9 | 1.3 | 0.9 |
| Unsparged | 2.1 | 2.1 | 2.1 | 2.0 |

Table 7b cont.

17% wheat-flour brews (brewers lb/qr)

| 17 WF 1 | top ——> | | | bottom | Av. |
|---|---|---|---|---|---|
| Total loss | 2.9 | 2.5 | 3.6 | 4.0 | 3.2 |
| Unconverted | 1.6 | 1.0 | 2.3 | 1.9 | 1.7 |
| Unsparged | 1.3 | 1.5 | 1.3 | 2.1 | 1.6 |

| 17 WF 2 | top | | bottom | Av. |
|---|---|---|---|---|
| Total loss | 3.2 | 5.9 | 4.4 | 4.5 |
| Unconverted | 1.9 | 3.1 | 1.9 | 2.3 |
| Unsparged | 1.3 | 2.8 | 2.5 | 2.2 |

| Overall 17% Av. | |
|---|---|
| Total loss | 3.8 |
| Unconverted | 2.0 |
| Unsparged | 1.8 |

Control brews

| | CB1 | | | | CB2 | | |
|---|---|---|---|---|---|---|---|
| | top | | bottom | Av. | top | bottom | Av. |
| Total loss | 2.9 | 3.2 | 3.2 | 3.1 | 2.8 | 3.7 | 3.2 |
| Unconverted | 2.0 | 1.6 | 1.6 | 1.7 | 0.8 | 2.2 | 1.5 |
| Unsparged | 0.9 | 1.6 | 1.6 | 1.4 | 1.0 | 1.5 | 1.7 |

| | CB4 | | | | CB7 | | | |
|---|---|---|---|---|---|---|---|---|
| | top | | bottom | Av. | top | | bottom | Av. |
| Total loss | 3.4 | 4.4 | 3.7 | 3.8 | 3.1 | 3.3 | 3.7 | 3.4 |
| Unconverted | 2.7 | 2.9 | 1.7 | 2.4 | 1.7 | 1.8 | 0.6 | 1.4 |
| Unsparged | 0.7 | 1.5 | 2.0 | 1.4 | 1.4 | 1.5 | 3.1 | 2.0 |

Overall Control Av.

| | |
|---|---|
| Total loss | 3.4 |
| Unconverted | 1.8 |
| Unsparged | 1.6 |

Table 7c

c) Nitrogen analyses (expressed in terms of 1040° SG wort)

Wheat-flour brews

| Hopped wort | 10 W1 | 10 W2 | 17 W1 | 17 W2 | 25 W1 | 25 W2 |
|---|---|---|---|---|---|---|
| $\alpha$-$NH_2$ -N (g/l) | 0.10 | 0.10 | 0.11 | 0.11 | 0.13 | 0.11 |
| Total N (g/l) | 0.62 | - | 0.62 | 0.67 | 0.64 | 0.40 |
| $\alpha$ $NH_2$/TN (%) | 16% | - | 18% | 16% | 20% | 27% |
| Conditioning tank | | | | | | |
| $\alpha$-$NH_2$ -N (g/l) | 0.025 | 0.030 | 0.028 | 0.025 | 0.028 | 0.040 |
| Total N (g/l) | 0.34 | 0.34 | 0.44 | 0.36 | 0.34 | 0.53 |
| $\alpha NH_2$/TN (%) | 7% | 9% | 6% | 7% | 8% | 8% |

Control brews

| Hopped wort | CB1 | CB2 | CB3 | CB4 | CB5 | CB6 | CB7 |
|---|---|---|---|---|---|---|---|
| $\alpha$-$NH_2$-N (g/l) | 0.13 | 0.13 | 0.17 | - | 0.15 | 0.15 | 0.11 |
| Total-N (g/l) | 0.66 | 0.66 | 0.68 | 0.62 | 0.71 | 0.70 | 0.54 |
| $\alpha$-$NH_2$/TN (%) | 20% | 20% | 25% | - | 21% | 21% | 20% |
| Conditioning tank | | | | | | | |
| $\alpha$-$NH_2$-N (g/l) | 0.036 | 0.04 | 0.04 | 0.013 | 0.03 | 0.04 | 0.03 |
| Total N (g/l) | 0.39 | 0.40 | 0.39 | 0.37 | 0.34 | 0.42 | 0.41 |
| $\alpha$-$NH_2$/TN (%) | 9% | 10% | 10% | 4% | 9% | 10% | 7% |

→

Table 7d

d) Taste Panel Results

Control brews

| | CB1 | CB2 | CB3 | CB4 | CB5 | CB6 | CB7 |
|---|---|---|---|---|---|---|---|
| Sweetness | 3.4 | 4.4 | 4.9 | 4.9 | 4.2 | 4.1 | 3.6 |
| Bitterness | 4.3 | 5.1 | 4.5 | 3.9 | 5.1 | 5.0 | 4.9 |
| Hop Aroma | 2.8 | 4.0 | 3.4 | 3.2 | 3.0 | 2.5 | 3.6 |
| Fullness | 4.7 | 5.3 | 5.1 | 5.1 | 4.8 | 4.3 | 4.2 |
| Harshness | - | - | - | - | + | + | +? |
| Off flavour | - | -- | - | - | +? | + | +? |
| Assessment | 5.9 | 6.6 | 6.0 | 5.2 | 5.0 | 4.7 | 5.1 |

Wheat flour brews

| | 10 W1 | 17 W1 | 25 W1 | 25 W2 | 10 W2 | 17 W2 |
|---|---|---|---|---|---|---|
| Sweetness | 3.9 | 3.5 | 4.2 | 4.2 | 3.5 | 3.2 |
| Bitterness | 4.3 | 5.1 | 5.5 | 4.5 | 5.6 | 5.0 |
| Hop Aroma | 3.0 | 2.8 | 3.2 | 2.8 | 2.9 | 3.4 |
| Fullness | 5.1 | 4.1 | 4.6 | 4.9 | 4.3 | 4.4 |
| Harshness | - | - | - | - | ++ | - |
| Off flavour | - | - | + | + | - | - |
| Assessment | 6.1 | 5.6 | 4.9 | 4.0 | 4.1 | 5.2 |

Table 8a, b

ANALYSES OF 15% WHEAT-FLOUR BREWS

a) Utilisation of grists (brewers lb/qr except where %age)

| Brew | A<br>Pilot Brewery Extract | B<br>Spent Grain Loss | C<br>A + B | D<br>Lab. ext. of Pale Malt | E<br>Predicted Lab. ext. of grist | F<br>$\frac{C + E}{2}$ | G<br>Utilisation $\frac{A}{F}$ x 100 % |
|---|---|---|---|---|---|---|---|
| 15 W1 | 97.2 | 2.7 | 99.9 | 98.4 | 98.6 | 99.3 | 98.0 |
| 15 W2 | 97.2 | 3.0 | 100.2 | 99.6 | 99.8 | 100.0 | 97.2 |
| 15 W3 | 96.1 | 3.0 | 99.1 | 98.0 | 98.2 | 98.7 | 97.4 |
| 15 W4 | 96.5 | 3.1 | 99.6 | 98.6 | 98.8 | 98.7 | 97.8 |
| | | | | | | Av. | 97.6% |

b) Spent grain extract loss (brewers lb/qr)

| | Brew number | | | |
|---|---|---|---|---|
| | 15 W1 | 15 W2 | 15 W3 | 15 W4 |
| Top of bed | | | | |
| Total loss | 2.0 | 2.3 | 3.1 | 2.5 |
| Unconverted | 1.1 | 1.1 | 2.7 | 1.0 |
| Unsparged | 0.9 | 1.2 | 0.4 | 1.5 |
| Middle of bed | | | | |
| Total loss | 3.5 | 2.7 | 1.9 | 3.3 |
| Unconverted | 1.8 | 1.1 | 1.1 | 1.2 |
| Unsparged | 1.7 | 1.6 | 0.8 | 2.1 |
| Bottom of bed | | | | |
| Total loss | 2.7 | 4.0 | 3.9 | 3.6 |
| Unconverted | 0.7 | 1.6 | 2.3 | 1.2 |
| Unsparged | 2.0 | 2.4 | 1.6 | 2.4 |

b) cont.

Table 8b cont., c, d

Average total spent grain loss

| | |
|---|---|
| Top of bed | 2.5 |
| Middle | 2.9 |
| Bottom | 3.6 |

Overall av. loss = 3.0 brewers lb/qr

c) Sugar analysis of hopped worts (% of total carbohydrate)

| | Wheat-flour Brews | | | | | Control Brews | | |
|---|---|---|---|---|---|---|---|---|
| | 15 W1 | 15 W2 | 15 W3 | 15 W4 | Av. | CB1 | CB2 | Av. |
| Fructose | 4.6 | 2.3 | 2.7 | 2.6 | 3 | 3.6 | 2.8 | 3 |
| Glucose | 8.2 | 5.8 | 7.4 | 6.4 | 7 | 7.3 | 7.9 | 8 |
| Sucrose | 12.4 | 12.2 | 13.9 | 13.8 | 13 | 13.0 | 14.4 | 14 |
| Maltose | 44.8 | 44.9 | 45.3 | 45.2 | 45 | 42.5 | 42.1 | 42 |
| Maltotriose | 9.0 | 13.8 | 9.7 | 11.0 | 11 | 12.6 | 11.8 | 12 |
| Dextrins | 21.0 | 21.0 | 21.0 | 21.0 | 21 | 21.0 | 21.0 | 21 |

d) Nitrogen analyses (expressed in terms of 1040° SG wort)

| Hopped wort | 15 W1 | 15 W2 | 15 W3 | 15 W4 | Av. |
|---|---|---|---|---|---|
| $\alpha$-$NH_2$-N (g/l) | 0.13 | 0.13 | 0.14 | 0.12 | 0.13 |
| TN (g/l) | 0.66 | 0.65 | 0.69 | 0.68 | 0.67 |
| $\alpha$-$NH_2$/TN % | 19.7 % | 19.8 % | 19.7 % | 17.7 % | 19.4 % |

e) Taste panel evaluation

Wheat-flour brews

| | 15 W1 | 15 W2 | 15 W3 | 15 W4 | Av. |
|---|---|---|---|---|---|
| Sweetness | 4.9 | 4.6 | 4.6 | 4.1 | 4.5 |
| Bitterness | 4.7 | 5.0 | 4.9 | 5.3 | 5.0 |
| Hop Aroma | 2.4 | 3.1 | 2.5 | 2.8 | 2.7 |
| Fullness | 5.0 | 5.5 | 5.4 | 5.2 | 5.2 |
| Overall assessment | | | | | |

Control brews

| | CB1 | CB2 | CB3 | CB4 | Av. |
|---|---|---|---|---|---|
| Sweetness | 4.3 | 4.0 | 4.1 | 3.3 | 3.9 |
| Bitterness | 4.4 | 5.7 | 5.4 | 6.0 | 5.4 |
| Hop Aroma | 2.7 | 3.1 | 2.1 | 2.7 | 2.7 |
| Fullness | 4.9 | 4.8 | 4.5 | 5.3 | 4.9 |
| Overall assessment | 5.0 | 5.1 | 5.0 | 4.9 | 5.0 |

TABLE .9.

BARLEY ADJUNCT ANALYSES

| | Barley flour SF 85 | | | | Flaked Barley | Barley Meal BM/R | "Pearly Brights" |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | | | |
| Moisture % | 10.3 | 13.5 | 12.9 | 12.8 | 10.4 | 13.6 | 10.0 |
| % Nitrogen - dry basis | 1.55 | 1.55 | 1.55 | 1.55 | 1.41 | 1.9 | 1.56 |
| Extract - on sample (brewers lb/qr) | 97.8 | 98.0 | 98.6 | 98.8 | 89.0 | 90.9 | 101 - 104 |

## TABLE 10

PARTICLE-SIZE ANALYSIS OF BARLEY FLOUR AND BARLEY MEAL

| | Barley flour SF 85 | Barley meal BM / R |
|---|---|---|
| Over 170 µ | 6.5 | 76.9 |
| " 155 µ | 17.2 | 3.7 |
| " 106 µ | 19.5 | 1.6 |
| " 90 µ | 11.1 | 1.0 |
| " 79 µ | 10.7 | 1.8 |
| Under 79 µ | 35.0 | 15.0 |
| | 100 % | 100 % |

## TABLE 11

ANALYSES OF 10%, 17% AND 25% BARLEY-FLOUR BREWS

a) Utilisation of grists (brewers lb/qr except where %age)

| Brew | Pilot Brewery Extract | Spent Grain Loss | A + B | Lab. ext. of Pale Malt | Predicted Lab. ext. of grist | $\frac{C + E}{2}$ | Utilisation $\frac{A}{F}$ x 100 % |
|---|---|---|---|---|---|---|---|
| 10 B1 | 96.2 | 2.3 | 98.5 | 99.6 | 99.6 | 99.0 | 97.2 |
| 10 B2 | 95.4 | 4.7 | 100.1 | 101.6 | 101.6 | 100.3 | 95.2 |
| | | | | | | Av. | 96.2 |
| 15 B1 | 94.2 | 3.0 | 97.2 | 99.0 | 97.1 | 97.2 | 97.1 |
| 17 B1 | 91.0 | 8.1 | 99.1 | 100.4 | 100.4 | 99.8 | 91.2 |
| 17 B2 | 85.5 | 8.0 | 93.5 | 98.4 | 96.6 | 95.0 | 90.0 |
| | | | | | | Av. | 90.6 |
| 25 B1 | Set mash | V.high | - | 100.5 | 100.5 | - | Very low |

Table 11b

b) Spent-grain analyses (brewers lb/qr)

10% barley-flour brews

| | 10 B1 | | | | | 10 B2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | top ——> bottom | | | | Av. | top ——> bottom | | | | Av. |
| Total loss | 2.0 | 1.4 | 2.4 | 2.9 | 2.3 | 4.5 | 4.9 | 4.9 | 4.4 | 4.7 |
| Unconverted | 1.5 | 0.9 | 2.2 | 2.4 | 1.8 | 2.1 | 1.6 | 1.9 | 1.7 | 1.8 |
| Unsparged | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2.4 | 3.3 | 3.0 | 2.7 | 2.9 |

15% barley flour brews

| | 15 B 1 | | | |
|---|---|---|---|---|
| | top ——> bottom | | | Av. |
| Total loss | 2.5 | 2.8 | 3.7 | 3.0 |
| Unconverted | 2.4 | 2.1 | 3.5 | 2.7 |
| Unsparged | 0.1 | 0.7 | 0.2 | 0.3 |

17% barley flour brews

| | 17 B1 | | | | 17 B2 | | | |
|---|---|---|---|---|---|---|---|---|
| | top —> bottom | | | Av. | top —>bottom | | | Av. |
| Total loss | 5.5 | 10.5 | 8.3 | 8.1 | 2.7 | 8.2 | 13.1 | 8.0 |
| Unconverted | 2.2 | 2.2 | 2.2 | 2.2 | 2.1 | 3.6 | ·2.7 | 2.8 |
| Unsparged | 3.3 | 8.3 | 6.1 | 5.9 | 0.6 | 4.6 | 10.4 | 5.2 |

Table 12

## SUGAR ANALYSIS OF HOPPED WORTS

a) % of total carbohydrate

| | 10 B1 | 10 B2 | 17 B1 | 25 B1 |
|---|---|---|---|---|
| Fructose | 2.4 | 4.7 | 2.7 | 3.3 |
| Glucose | 9.2 | 7.3 | 10.5 | 6.5 |
| Sucrose | 16.3 | 12.6 | 14.2 | 16.0 |
| Maltose | 43.1 | 29.0 | 31.7 | 35.8 |
| Maltotriose | 12.3 | 5.9 | 14.7 | 9.3 |
| Dextrins | 16.7 | 40.5 | 26.3 | 29.3 |

b) % of total carbohydrate assuming 21% dextrins

| | 10 B1 | 10 B2 | 17 B1 | 25 B1 |
|---|---|---|---|---|
| Fructose | 2.3 | 6.3 | 2.8 | 3.7 |
| Glucose | 8.7 | 9.7 | 11.2 | 7.2 |
| Sucrose | 15.4 | 16.7 | 15.2 | 17.8 |
| Maltose | 40.9 | 38.5 | 34.0 | 40.0 |
| Maltotriose | 11.7 | 7.8 | 15.8 | 10.3 |
| Dextrins | 21 | 21 | 21 | 21 |

# TABLE 13

## NITROGEN ANALYSIS

(expressed in terms of 1040° SG wort)

| Hopped wort | 10 B1 | 10 B2 | 15 B1 | 17 B1 | 17 B2 | 25 B1 |
|---|---|---|---|---|---|---|
| $\alpha$-$NH_2$-N | 0.097 | 0.14 | 0.13 | 0.11 | 0.14 | 0.093 |
| Total-N | 0.063 | 0.64 | 0.67 | 0.75 | 0.70 | 0.63 |
| $\alpha$-$NH_2$/TN | 15 % | 22 % | 19 % | 14 % | 20 % | 15 % |
| **Conditioning tank** | **10 B1** | **10 B2** | **15 B1** | **17 B1** | **17 B2** | **25 B1** |
| $\alpha$-$NH_2$-N | 0.012 | 0.03 | 0.03 | 0.038 | 0.03 | 0.02 |
| Total-N | 0.035 | 0.35 | 0.40 | 0.36 | 0.43 | 0.29 |
| $\alpha$-$NH_2$/TN | 4 % | 9 % | 7.5% | 11 % | 7 % | 7 % |

# TABLE 14

## TASTE PANEL RESULTS

| | 10 B1 | 10 B2 | 15 B1 | 17 B1 | 17 B2 | 25 B1 |
|---|---|---|---|---|---|---|
| Sweetness | 3.7 | 2.5 | 4.5 | 3.6 | 4.0 | 3.6 |
| Bitterness | 5.7 | 5.0 | 5.0 | 4.1 | 5.4 | 5.4 |
| Hop Aroma | 3.6 | 3.0 | 2.5 | 2.6 | 3.0 | 3.0 |
| Fullness | 3.6 | 3.9 | 4.7 | 4.3 | 3.6 | 5.0 |
| Harshness | – | – | – | ++ | – | + |
| Off flavour | – | – | – | + | – | – |
| Assessment | 6.9 | 4.5 | 5.9 | 4.1 | 5.1 | 5.1 |

Table 15a, b

ANALYSES OF 10% AND 17% FLAKED BARLEY BREWS

a) Spent grain analyses (brewers lb/qr)

| | 10% flaked barley | | | | 17% flaked barley | | | |
|---|---|---|---|---|---|---|---|---|
| | top | bottom | | Av. | top | bottom | | Av. |
| Total loss | 2.9 | 3.6 | 5.6 | 4.0 | 5.6 | 3.6 | 4.3 | 4.3 |
| Unconverted | 1.6 | 1.9 | 4.4 | 2.6 | 2.4 | 1.6 | 2.3 | 2.1 |
| Unsparged | 1.3 | 1.7 | 1.2 | 1.4 | 3.2 | 2.0 | 2.0 | 2.4 |

b) Utilisation of grists (brewers lb/qr except where %age)

| Brew | A<br>Pilot Brewery Extract | B<br>Spent Grain Loss | C<br>A + B | D<br>Lab. ext. of Pale Malt | E<br>Predicted Lab. ext. of grist | F<br>(C + E)/2 | G<br>Utilisation<br>A/F x 100 % |
|---|---|---|---|---|---|---|---|
| 10% FB | 97.1 | 4.0 | 101.1 | 101 | 99.3 | 100.2 | 96.9 |
| 17% FB | 92.3 | 4.3 | 96.6 | 101 | 98.4 | 97.5 | 94.8 |

Table 15c, d

c) Analyses of wort and beers (wort analyses adjusted to 1040° SG)

| | 10% flaked barley | | 17% flaked barley | |
|---|---|---|---|---|
| Wort $\alpha$-$NH_2$ nitrogen | 0.12 | | 0.13 | |
| S G at attenuation limit | 1007.0 | | 1006.3 | |
| Conditioning | start | end | start | end |
| S G | 11.3 | 11.2 | 10.4 | 8.3 |
| pH | 3.90 | 3.86 | 3.84 | 3.84 |
| Yeast (lb/brl) | 0.56 | - | 1.12 | - |
| Bitterness E.B.U. | 25 | 23 | 29 | 26 |
| Total nitrogen | 0.36 | - | 0.38 | - |
| $\alpha$-$NH_2$ nitrogen | 0.02 | - | 0.02 | - |

d) Taste profile results

| | 10% flaked barley | 17% flaked barley |
|---|---|---|
| Sweetness | 4.7 | 3.7 |
| Bitterness | 4.2 | 4.7 |
| Hop Aroma | 2.7 | 2.6 |
| Fullness | 4.2 | 4.0 |
| Off flavours | None | sl. harsh |
| Overall assessment | 5.0 | 4.7 |

Table 16

NITROGEN ANALYSES IN WORTS

(micro-grams nitrogen per ml at SG.1100)

| Amino-acids (α-amino nitrogen) | Wheat-flour slurry + amylase | | Malt-grist wort |
|---|---|---|---|
| | No protease | + protease | |
| Aspartic acid | 2.4 | 1.8 | 8.7 |
| Threonine | 0.6 | 0.4 | 14.6 |
| Serine | 0.2 | 0.2 | 15.9 |
| Glutamic acid | 1.5 | 2.8 | 11.0 |
| Proline | 0.8 * | 0.5 * | 69.6 * |
| Glycine | 1.0 | 0.9 | 8.5 |
| Alanine | 1.7 | 1.8 | 24.2 |
| Valine | 0.5 | 0.3 | 2.0 |
| Cystine | 0.2 | 0.1 | - |
| Methionine | trace | - | 4.8 |
| Iso-leucine | 0.1 | - | 10.4 |
| Leucine | 0.4 | 0.6 | 25.4 |
| Tyrosine | 0.3 | 0.2 | 11.6 |
| Phenyl-alanine | 0.4 | 0.3 | 16.5 |
| Ammonia | (6.8) ** | (10.1) ** | (30.3) ** |
| Lysine | 0.1 | - | 10.3 |
| Histidine | 0.1 | trace | 5.5 |
| Arginine | 0.5 | 0.4 | 14.9 |
| Tryptophan | 0.6 | 0.6 | 4.7 |

cont'd

Table 16 cont'd

| Amino-acids (α-amino nitrogen) | Wheat-flour slurry + amylase | | Malt-grist wort |
|---|---|---|---|
| | No protease | + protease | |
| Σ alpha-amino N | 11.8 | 9.9 | 189 |
| Σ alpha-amino N + proline | 12.6 | 10.4 | 259 |
| Σ N in amino-acids | 14.8 | 12.8 | 330 |
| Σ N (amino-acids + ammonia) | 21.7 | 22.9 | 360 |
| Total nitrogen (Kjeldahl) | 750 | 840 | 1.350 |
| alpha-amino nitrogen (Satake) | trace | 40 approx | 230 |

* imino N

** non-amino N

Note: The position of tryptophan on the charts was checked by running a standard solution which gave a peak corresponding exactly in both shape and and position with the peak ascribed to tryptophan in these analyses, also Table 18.

→

Table 17

## NITROGEN OF MALT-GRIST WORT AND WHEAT- AND BARLEY-FLOUR ENZYME-WORTS

Nitrogen figures as grams nitrogen per litre of wort, except where stated otherwise.

| Calculation | Symbol | Malt | Wheat flour | Barley flour |
|---|---|---|---|---|
| Extract (lb/qr as is) | m | 100.6 | 106.5 | 90.6 |
| Total Nitrogen (% as is) | n | 1.37 | 1.31 | 1.70 |
| " " (% on dry) | p | 1.41 | 1.47 | 1.91 |
| Wt cereal used per litre wort (g) | a | 119 | 200 | 250 |
| Qrs. cereal used (a/454 x 336) | b | - | 0.00131 | 0.00164 |
| Gals of wort (1 litre) | c | 0.2199 | 0.2199 | 0.2199 |
| Specific gravity of wort | d | 1044.2 | 1044.5 | 1067.1 |
| Brewers lb (0.36 cd/36) | e | - | 0.0978 | 0.1475 |
| Brewers lb/qr (e/b) | f | 97 | 74.7 | 90.0 |
| Utilisation (f/m x 100%) | g | 96.5 | 70.1 | 99.3 |
| Total cereal N (an) | h | 1.63 | 2.62 | 4.25 |
| Total cereal N x utilisation, (hg) | i | 1.57 | 1.85 | 4.22 |
| Total wort Nitrogen (Kjeldahl) | j | 0.60 | 0.36 | 1.60 |
| Alpha-$NH_2$·N (Satake) | k | 0.10 | ~ 0.02 | 0.2 |
| amino-acid analysis | | | | |
| Σ α-$NH_2$·N | l | 0.084 | 0.0048 | 0.116 |
| Σ α-$NH_2$·N + proline | r | 0.114 | 0.0051 | 0.122 |
| Σ N in amino-acids | s | 0.146 | 0.0061 | 0.165 |
| Σ N in amino-acids + $NH_3$ | t | 0.159 | 0.0099 | 0.192 |

cont'd

Table 17 cont'd

| Calculation | | Symbol | Malt | Wheat flour | Barley flour |
|---|---|---|---|---|---|
| % of total cereal N | | | | | |
| Total cereal N x utilisation | (i/h) | x | 96.5% | 70.1% | 99.3% |
| Total wort/syrup N | (j/h) | y | 36.8% | 14 % | 37.7% |
| $\Sigma$ $\alpha$-$NH_2$·N | (l/h) | z | 5.2% | 0.2% | 2.7% |

## TABLE 18

### NITROGEN ANALYSIS OF WORTS

(micro-grams nitrogen per ml at SG.1100)

| Amino-acids ($\alpha$-amino nitrogen) | Barley-enzyme wort | Malt-grist wort |
|---|---|---|
| Aspartic acid | 8.4 | 8.7 |
| Threonine | 12.6 | 14.6 |
| Serine | 9.4 | 15.9 |
| Glutamic acid | 8.8 | 11.0 |
| Proline | 9.1 * | 69.6 * |
| Glycine | 8.9 | 8.5 |
| Alanine | 22.4 | 24.2 |
| Valine | 13.6 | 2.0 |
| Cystine | - | - |
| Methionine | 6.1 | 4.8 |
| Iso-leucine | 6.8 | 10.4 |
| Leucine | 22.7 | 25.4 |
| Tyrosine | 7.5 | 11.6 |
| Phenyl alanine | 9.6 | 16.5 |
| Ammonia | (41.4) ** | (30.3) ** |

Table 18 cont'd

| Amino-acids ($\alpha$-amino nitrogen) | Barley-enzyme wort | Malt-grist wort |
|---|---|---|
| Lysine | 14.2 | 10.3 |
| Histidine | 3.3 | 5.5 |
| Arginine | 12.6 | 14.9 |
| Tryptophan | 5.0 | 4.7 |
| $\Sigma$ alpha-amino N | 172 | 189 |
| $\Sigma$ alpha-amino N + proline | 181 | 259 |
| $\Sigma$ N in amino-acids | 245 | 330 |
| $\Sigma$ N (amino-acids + ammonia) | 286 | 360 |
| Total nitrogen (Kjeldahl) | 2,400 | 1,350 |
| alpha-amino nitrogen (Satake) | 300 | 230 |

* imino N

** non-amino N

Table 19

SUGAR ANALYSIS OF BARLEY-ENZYME WORTS

| | Barley-enzyme worts (% of total carbohydrates) | |
|---|---|---|
| | Bacterial amylase +Fungal amylase | Bacterial amylase + Malt |
| Fructose | 1.55 | 1.92 |
| Glucose | 7.27 | 8.68 |
| Sucrose | 0.00 | 0.00 |
| Maltose | 54.0 | 58.5 |
| Maltotriose | 12.52 | 15.27 |
| Total fermentable | 75.3 | 84.4 |
| Dextrins | 24.7 | 15.6 |

# TABLE 20

## SUGAR ANALYSES OF SYRUPS (% OF TOTAL CARBOHYDRATE)

| | Green malt syrup | Barley Syrups | | | | | Wort syrups | | |
|---|---|---|---|---|---|---|---|---|---|
| | Pauls liquid Malt | ABMG First Sample | Barley Syrups Second sample Producers Analysis | Barley Syrups Second sample Our Analysis | Corn products Total wort | Crisp Brewmalt | ABMG WS 1 Producers Analysis | WS 1 Our Analysis | WS 2 Producers Analysis |
| | A | B | C | D | E | F | G | H | I |
| Glucose | 4.0 | 22.4 | 7 | 5.0 | 15.4 | 23.1 | 40 | 39.1 | 57 |
| Maltose | 54.2 | 47.9 | 48 | 50.6 | 56.2 | 49.2 | 20 | 17.2 | 18 |
| Maltotriose | 17.8 | 5.7 | 17.5 | 20.4 | 4.4 | 3.7 | 13 | 14.6 | 12 |
| Dextrins | 24.0 | 24.0 | 27.4 | 24 | 24 | 24 | 27 | 29.1 | 13 |

Note: For green malt and barley syrups a dextrin content of 24% of total carbohydrate has been assumed (except for producers analysis).

TABLE 21. SUGAR ANALYSIS OF WORTS (% of total carbohydrate)
(adjusted to composition before addition of sucrose syrup)

| | Control brew worts | Laboratory dual enzyme barley wort | Average wheat flour worts | Average barley flour worts |
|---|---|---|---|---|
| Fructose | 3.6 | 1.5 | 3.5 | 4.3 |
| Glucose | 8.7 | 7.3 | 8.0 | 10.5 |
| Sucrose | 1.4 | 0 | 0.5 | 4.4 |
| Maltose | 48.3 | 54.0 | 51.5 | 43.8 |
| Maltotriose | 14.0 | 12.5 | 12.5 | 13.0 |
| Dextrins | 24.0 | 24.7 | 24.0 | 24.0 |

| TABLE 22 NITROGEN ANALYSES OF SYRUPS | Total Nitrogen (%TS) | α-amino nitrogen (%TS) | Lundin Fractions % A | B | C |
|---|---|---|---|---|---|
| Pauls "Liquid malt" | 1.03 | 0.15 | | | |
| ABMG "barley syrup" First Sample | 0.92 | 0.19 | | | |
| Second Sample Producers analysis | 0.85 | 0.20 | 24.5 | 16.0 | 59.5 |
| Second Sample Our analysis | 0.96 | 0.17 | | | |
| Corn Products "Total Wort" | 0.96 | 0.14 | | | |
| Crisp Malt Products "Brewmalt" | 0.90 | 0.15 | | | |
| ABMG WS 1 Producers specification | 0.26 (max) | - | 16.5 | 17.5 | 66.0 |
| ABMG WS 1 Our analysis | 0.23 | 0.02 | | | |
| ABMG WS 2 Producers specification | 0.26 (max) | - | 5 (max) | 5 (max) | 80 (min) |

Table 23

FERMENTABILITY OF WORT SYRUPS WS1, WS2

| | | Sugar composition (% of total carbohydrate) | | | | | |
|---|---|---|---|---|---|---|---|
| | | WS1 | | WS2 | | Malt grist wort | |
| RFS | ( Fructose | 0 ) | 58 | 0 ) | 75 | 3.6 ) | 61.5 |
| | ( Glucose | 40 ) | | 57 ) | | 8.7 ) | |
| | ( Sucrose | 0 ) | | 0 ) | | 1.4 ) | |
| | ( Maltose | 18 ) | | 18 ) | | 48.3 ) | |
| SFS | Maltotriose | | 14 | | 12 | | 14.0 |
| NFS | Dextrins | | 28 | | 13 | | 24 |
| RFS + SFS | Fermentability | | 72% | | 87% | | 76% |

Note: RFS = readily fermentable sugars

SFS = slowly fermentable sugars

NFS = non-fermentable sugars

## TABLE 24

### WORT SYRUP AND CONTROL MALT GRISTS

| Grist | Material | % Malt grist (weight basis) | % total extract (extract basis) |
|---|---|---|---|
| (33 WS) | Pale malt | 88.8 | ) |
| | Crystal malt | 4.1 | ) 67 |
| | Flaked maize | 7.1 | ) |
| | ABMG WS1 | | 33 |
| (33 WS + S) | Pale malt | 88.8 | ) |
| | Crystal malt | 4.1 | ) 55 |
| | Flaked maize | 7.1 | ) |
| | ABMG WS1 | | 33 |
| | ABMG LP1 | | 12 |
| Control | Pale malt | 88.8 | ) |
| | Crystal malt | 4.1 | ) 87.5 |
| | Flaked maize | 7.1 | ) |
| | ABMG LP1 | | 12.5 |

## TABLE 25

### THEORETICAL FERMENTABILITIES OF GRIST CARBOHYDRATES

| | % total extract A | Carbohydrate fermentability B | AB |
|---|---|---|---|
| Control grist | | | |
| Malt grist | 87.5 | 76% | 0.665 |
| Liquid sucrose | 12.5 | 100% | 0.125 |
| Fermentability | | | 79.0 % |
| (33 WS + S) grist | | | |
| Malt grist | 55 | 76% | 0.418 |
| WS 1 | 33 | 72% | 0.237 |
| Sucrose | 12 | 100% | 0.120 |
| Fermentability | | | 77.5 % |
| (33 WS) grist | | | |
| Malt grist | 67 | 76% | 0.509 |
| WS 1 | 33 | 72% | 0.237 |
| Fermentability | | | 74.6 % |

TABLE 26 NITROGEN LIMITATIONS OF WS1 WORT ATTENUATION

| | Available N mg/100 ml | | |
|---|---|---|---|
| WS1 nitrogen | $NH_4Cl$-N | Total-N | Final S G |
| 6.7 | - | 6.7 | 1013 |
| " | 0.9 | 7.6 | 1011 |
| " | 3.3 | 10.0 | 1008 |
| " | 6.4 | 13.1 | 1008 |
| " | 9.3 | 16.0 | 1008 |

TABLE 27 SUGAR ANALYSIS OF CONTROL WORTS

| | Control Brews, CB, (% of total carbohydrates) | | | | |
|---|---|---|---|---|---|
| | CB1 | CB2 | CB3 | CB4 | Average |
| Fructose | 4.8 | 3.7 | 4.0 | 2.9 | 3.8 |
| Glucose | 8.4 | 8.4 | 6.3 | 7.6 | 7.7 |
| Sucrose | 13.2 | 12.1 | 14.2 | 14.3 | 13.5 |
| Maltose | 33.5 | 40.9 | 36.4 | 40.9 | 37.9 |
| Maltotriose | 19.1 | 13.9 | 18.1 | 13.3 | 16.1 |
| Dextrins (assumed) | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 |

TABLE 28 SUGAR ANALYSIS OF WORT-SYRUPS WORTS

| | (33 WS) grists | | | (33 WS + S) grists | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | Average | (1) | (2) | Average |
| Fructose | 1.5 | 0 | 0.7 | 2.9 | 5.4 | 4.1 |
| Glucose | 16.5 | 20.4 | 18.5 | 18.4 | 18.1 | 18.3 |
| Sucrose | trace | 0 | 0 | 14.0 | 11.6 | 12.8 |
| Maltose | 42.6 | 39.4 | 41.0 | 28.2 | 27.0 | 27.6 |
| Maltotriose | 14.0 | 14.8 | 14.4 | 14.0 | 15.4 | 14.7 |
| Dextrins (assumed) | 25.4 | 25.4 | 25.4 | 22.5 | 22.5 | 22.5 |

TABLE 29

WORT-NITROGEN ANALYSIS OF CONTROL BREWS

(expressed in terms of 1040° SG wort, g/l of nitrogen)

| | CB1 | CB2 | CB3 | CB4 | CB5 | CB6 | Average |
|---|---|---|---|---|---|---|---|
| $\alpha$-$NH_2$ N | 0.132 | 0.127 | 0.169 | 0.150 | 0.150 | 0.113 | 0.140 |
| Total N | 0.66 | 0.66 | 0.69 | 0.71 | 0.71 | 0.54 | 0.66 |
| $\alpha$-$NH_2N$/TN | 20% | 19% | 24% | 21% | 21% | 21% | 21% |

TABLE 30

WORT-NITROGEN ANALYSIS OF WORT SYRUP BREWS

(expressed in terms of 1040° SG wort, g/l of nitrogen)

| | (33 WS) worts | | | | (33 WS + S) worts | | | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | Average | (1) | (2) | (3) | Average |
| $\alpha$-$NH_2$ N | 0.092 | 0.113 | 0.118 | 0.108 | 0.107 | 0.093 | (0.060) | 0.100 |
| Total N | 0.55 | 0.58 | 0.56 | 0.56 | 0.49 | 0.49 | 0.50 | 0.49 |
| $\alpha$-$NH_2N$/TN | 17% | 21% | 20% | 19% | 22% | 19% | (12%) | 20% |

TABLE 31 WORT NITROGEN

(Summary)

| | Control brews | (33 WS) worts | | (33 WS + S) worts | |
|---|---|---|---|---|---|
| | | | % of control | | % of control |
| $\alpha$-$NH_2$ N | 0.140 | 0.108 | 77 | 0.100 | 74 |
| Total N | 0.66 | 0.56 | 85 | 0.49 | 71 |
| $\alpha$-$NH_2$ N/TN | 21% | 19% | | 20% | |

TABLE 32

PREDICTED AND ACTUAL WORT-NITROGEN LEVELS FOR WORT SYRUP AND CONTROL GRISTS

| Grist (% on extract basis) A | Nitrogen factor B | Predicted Nitrogen in wort (% of control) AB | Actual Nitrogen in wort (% of control) |
|---|---|---|---|
| Control grist | | | |
| 87.5 malt grist | 1.14 | 100 | 100 |
| 12.5 sucrose | 0.00 | | |
| | | 100 | 100 |
| (33 WS) Grist | | | |
| 67 malt grist | 1.14 | 76.4 | |
| 33 WS1 | 0.38 | 12.5 | |
| | | 88.9 | 85 |
| (33 WS) + S Grist | | | |
| 55 malt grist | 1.14 | 62.5 | |
| 33 WS1 | 0.38 | 12.5 | |
| 12 sucrose | 0.00 | 75.0 | 74 |

TABLE 33 TASTE PROFILES OF (33 WS) BEERS

| Brew No | 1 | 2 | 3 | Average |
|---|---|---|---|---|
| Sweetness | 4.5 | 3.2 | 3.9 | 3.9 |
| Bitterness | 3.9 | 4.6 | 5.7 | 4.7 |
| Hop Aroma | 2.5 | 3.1 | 3.0 | 2.9 |
| Fullness | 5.1 | 4.2 | 4.2 | 4.5 |
| Harshness | + | – | ++ | + |
| Off flavour | + | + | + | + |
| Assessment | 5.8 | 3.8 | 4.4 | 4.7 |

TABLE 34 TASTE PROFILES OF (33 WS + S) BEERS

| Brew No. | 1 | 2 | 3 | Average |
|---|---|---|---|---|
| Sweetness | 4.5 | 4.3 | 5.0 | 4.6 |
| Bitterness | 5.2 | 3.9 | 5.3 | 4.8 |
| Hop aroma | 2.4 | 2.9 | 3.1 | 2.8 |
| Fullness | 4.7 | 4.5 | 5.3 | 4.8 |
| Harshness | – | – | – | – |
| Off flavour | +? | – | – | – |
| Assessment | 5.2 | 6.0 | 5.9 | 5.7 |

TABLE 35 TASTE PROFILES OF CONTROL BEERS

| Brew No. | CB1 | CB2 | CB3 | CB4 | CB5 | CB6 | CB7 | Average |
|---|---|---|---|---|---|---|---|---|
| Sweetness | 3.4 | 4.4 | 4.9 | 4.9 | 4.2 | 4.1 | 3.6 | 4.2 |
| Bitterness | 4.3 | 5.1 | 4.5 | 3.9 | 5.1 | 5.0 | 4.9 | 4.7 |
| Hop aroma | 2.8 | 4.0 | 3.4 | 3.2 | 3.0 | 2.5 | 3.6 | 3.2 |
| Fullness | 4.7 | 5.3 | 5.1 | 5.1 | 4.8 | 4.3 | 4.2 | 4.8 |
| Harshness | – | – | – | – | + | + | +? | – |
| Off flavour | – | – | – | – | +? | + | +? | – |
| Assessment | 5.9 | 6.6 | 6.0 | 5.2 | 5.0 | 4.7 | 5.1 | 5.5 |

TABLE 36

EXPERIMENTAL BARLEY-SYRUP GRIST

| | % of malt grist | % of total extract |
|---|---|---|
| White malt | 88.8 ) | 33 |
| Crystal malt | 4.1 ) | |
| Flaked maize | 7.1 ) | |
| ABMG Barley Syrup | | 67 |
| | | 100 |

TABLE 37

WORT NITROGEN AND BEER NITROGEN

Nitrogen expressed as g/l of 1040° SG wort

| Brew number | | Av. Control | Barley syrup brews (1) | (2) | Av. | % of control |
|---|---|---|---|---|---|---|
| Wort S G | SYRUP | - | 44.1 | 44.4 | - | - |
| Total-N on sample | SYRUP | - | 0.56 | 0.69 | - | - |
| Alpha-amino N. | SYRUP | - | 0.13 | 0.12 | - | - |
| Total-N (SG 1040) | WORT | 0.66 | 0.51 | 0.62 | 0.57 | 86 |
| Alpha-amino N | WORT | 0.14 | 0.12 | 0.11 | 0.12 | 86 |
| Amino N/TN ratio | WORT | 21% | 23% | 17% | 20% | - |
| Beer total-N | BEER | 0.39 | 0.40 | 0.36 | 0.38 | 98 |
| Beer alpha-amino N | BEER | 0.036 | 0.04 | 0.04 | 0.04 | 111 |
| Amino N/TN ratio in fermented beer | BEER | 9% | 10% | 11% | 10% | - |

TABLE 38

ANALYSIS OF BARLEY-SYRUP BEERS DURING CONDITIONING

| | Paul's "Liquid Malt" | | ABMG Barley-Syrup | | Corn Products Total Wort | | Crisp Brewmalt | |
|---|---|---|---|---|---|---|---|---|
| | Receipt | Rack | Receipt | Rack | Receipt | Rack | Receipt | Rack |
| AG | 9.9° | 8.5° | 7.7° | 7.1° | 10.7° | 10.4° | 8.6° | 8.2° |
| pH | 3.95 | 3.96 | 4.30 | 4.20 | 4.14 | 4.10 | 4.34 | 4.14 |
| Yeast (lb/brl) | 1.7 | - | 2.0 | - | 7.8 | - | 2.8 | - |
| EBU | - | 23.5 | - | 28 | 26 | 25 | - | 26 |
| Total Nitrogen (g/l) | 0.41 | - | 0.48 | - | 0.43 | - | 0.44 | - |
| $\alpha$-$NH_2$ N (g/l) | 0.03 | - | 0.04 | - | 0.04 | - | 0.03 | - |

TABLE 39

TASTE PROFILE RESULTS

| | Paul's "Liquid Malt | ABMG Barley-Syrup | Corn Products Total Wort | Crisp Brewmalt |
|---|---|---|---|---|
| Sweetness | 4.4 | 4.3 | 3.7 | 4.1 |
| Bitterness | 4.7 | 5.0 | 4.7 | 4.4 |
| Hop Aroma | 1.6 | 1.7 | 2.0 | 1.8 |
| Fullness | 4.0 | 4.0 | 4.4 | 4.2 |
| Off flavours | - | Slightly harsh | - | - |
| Overall assessment | 4.6 | 3.7 | 4.6 | 4.3 |

# PART 2. MASS-BALANCE AND ECONOMICS

## PREFACE TO PART 2

In Part 1 the use of cereal flours and flaked barley in the malt grist and the use of brewing syrups were considered. Grist utilisation was described in terms of realisation of available extract and on this basis a cost-evaluation of the various grists will be made.

In Part 2 the composition of a single production brewery grist is considered in more detail. The fate of the components derived from the grist-carbohydrate raw-materials is traced into the finished beer and into 'losses' and by products such as spent grain and yeast. Excise Duty is levied on wort at the point of transition from wort preparation to wort fermentation thus providing a division in both processing and economic considerations. The brewing process is thus broadly divided into grist extraction and wort fermentation, and the economic argument into cost-evaluation of different grists and utilisation of duty-paid wort solids. Part 2 is therefore in two sections, related to wort preparation and wort fermentation; each section carries a) the mass balance, and b) the economic argument, of the respective process stage.

In Section 1 a) a mass balance of wort preparation from a single established production grist is derived, and in the light of this there follows, in Section 1 b), a discussion of the raw-material cost of wort preparation from the various experimental grists described in Part 1. Consideration is then given, in Section 2 a), to the fate of the carbohydrates, nitrogen and other compounds during fermentation, leading to the development of a mass balance of fermentation. The ways in which the mass-balance of duty-paid wort components may be modified to the economic advantage of the brewer are related in Section 2 b).

In both wort-preparation and fermentation mass-balances the wort produced or utilised is identical; thus they can be used to construct an overall mass balance from raw materials to the finished product.

Sections 1 and 2 also provide a basis for the discovery of the relative importance of raw-material and Duty costs which enables the cost savings inherent in different grists to be seen in perspective with the Excise Duty levied on the wort solids derived from them. The overall mass-balance and summary of cost evaluation are found in Section 3.

## SECTION 1 a) - WORT-PREPARATION MASS - BALANCE

A single commercial grist, designated RBK, is considered. The laboratory analyses and production data of the RBK-grist materials, spent grain, and wort, are used in the construction of a mass-balance.

Grist

In a typical RBK grist the brewers' aim was to provide 'extract' from the grist components in the following proportions: 80% pale malt, 5% crystal malt, 5% flaked maize, 10% wort syrup. In deciding the weight percentages of each component, the laboratory-extract analyses give an indication of the relative potential extracts of unit weights of the components and since the chosen proportions need not be met precisely, the indicated weight percentages are rounded up or down to convenient levels. The laboratory analyses of such a grist and chosen weight percentages are shown in Table 40. The wort syrup is added directly to the wort in the copper and the brewer, in assessing the extract obtained from the malt grist, assumes that the laboratory extract of the wort syrup is indeed achieved (Table 1, column E). On this basis the extract achieved from the malt grist was 90.7 brewers lb/qr, or 96.9 % of the potential malt grist extract indicated by laboratory analysis. The brewery extract therefore showed a short-fall of 2.9 brewers lb/qr.

TABLE 40

| Malt Grist | A<br>Weight % of malt grist | B<br>Laboratory extract lb/qr | C<br>Moisture % | D<br>Nitrogen % of solids | E<br>Contribution to total realised extract % |
|---|---|---|---|---|---|
| Pale malt | 89.7 | 94 | 3.6 | 1.63 | 80.7 |
| Crystal malt | 5.5 | 82 | 3.0 | 1.55 | 4.4 |
| Flaked maize | 4.8 | 100 | 12.0 | 1.4 | 4.5 |
| Malt grist | 100 | 93.61 | 3.97 | 1.59 (≡ 10.0% protein*) | 89.6 |
| Wort syrup | - | 70 lb/2 cwt | 19.1 | 0.16 (≡ 1.0% protein*) | 10.4 |

* % nitrogen x 6.25 = % "protein"

| Basis - 1 qr (330 lb) malt grist + 27.26[a] lb wort syrup solids | lb Solids |
|---|---|
| Malt grist solids | |
| Malt grist moisture content = 3.97% | |
| Thus solids content of 1 qr malt grist = 330 x 0.9603 | 316.9 |
| Wort syrup solids | |
| Malt grist brewery extract = 90.7 brewers lb/qr | |
| = 89.6% of total extract[b] | |
| But wort syrup extract = 10.4% of total extract[b] | |
| = 10.53 brewers lb | |
| And 2 cwt of 19.1% moisture syrup yields 70 brewers lb | |
| Hence 10.53 brewers lb are yielded by 27.26 lb solids | 27.3 |
| Total grist solids | 344.2 |
| Wort solids | |
| Declared gravity in FV of 1037.8° ≡ 13.61 brewers lb/brl | |
| and 101.26 brewers lb yield 7.44 brl wort | |
| But solids content of 1.0378° wort = 95 g/l[c] | |
| and 1 brl = 163.65 l | |
| Hence total wort solids = 7.44 x 163.65 x 95 = 115.6 kg | 254.6 |

Hydrolysis gain

Now only ~ 80% of extract is a result of starch hydrolysis showing a hydrolysis gain of 4% in the wort solids[d].

Thus hydrolysis gain of wort solids due to starch = 3.2%

But proteolysis etc. also involve hydrolyses, hence overall hydrolysis gain is probably ~ 3.4%

<u>Grist solids utilised</u>

| | lb Solids |
|---|---|
| Thus grist solids corresponding to the declared wort solids = 254.6 x 0.966[e] | 245.9 |

<u>Grist solids 'lost'</u>

| | |
|---|---|
| Hence grist solids lost in preparation of the wort = 344.16 - 245.9 = | 98.2 |

<u>Protein precipitation loss</u>

Loss of protein during wort boiling ~ 6% (40)

'Protein' content of wort solids ~ 5%

| | |
|---|---|
| Hence protein loss in boiling = 0.05 x 0.06 x 245.9 = | 0.74 |

<u>Transfer and wetting losses</u>

| | |
|---|---|
| Allow loss of 0.1% of wort solids during transfers = | 0.26 |

<u>Spent grain loss</u>

| | |
|---|---|
| Spent grain loss = total loss - protein loss - transfer etc. loss = | 97.2 |

a. Calculated under 'Wort syrup solids', previous page.

b. see Table 40.

c. Solution factor 3.982 (100 ml/g) (79)

d. Reference (80)

e. Allowing for hydrolysis gain.

Mass-balance summary

Thus 344.16 lb (malt grist + wort syrup solids) yielded:-

254.6 lb realised extract in FV (245.9 lb before hydrolysis gain)

+ 98.2 lb 'lost' solids

The mass-balance is summarised below in terms of both lb weight and brewers lb per qr of malt grist + wort syrup; the balance is also expressed in terms of g/100 ml wort so that the wort preparation mass-balance may later be related to the fermentation mass-balance.

Summary of wort preparation mass-balance

| | lb solids per quarter of malt grist + 27.26 lb wort syrup solids | Brewers lb per quarter of malt grist + 27.26 lb wort syrup solids | g solids per 100 ml of 1.0378° SG wort in FV |
|---|---|---|---|
| Malt grist solids | 316.9 | 93.6 | 11.82 |
| Wort syrup solids | 27.26 | 10.5 | 1.02 |
| Total grist solids | 344.16 | 104.1 | 12.84 |
| Solids dissolved to FV | 245.9 | - | 9.18 |
| Hydrolysis gain | 8.7 | - | 0.32 |
| Total solids in FV | 254.6 | 101.2 | 9.50 |
| Spent grain loss | 97.2 | 2.7 | 3.63 |
| Protein loss in boiling | 0.74 | 0.2 | 0.02 |
| Transfer losses | 0.26 | 0.1 | 0.01 |
| Total losses | 98.2 | 3.0 | 3.66 |

Discussion

A discussion of the mass-balance of carbohydrate utilisation is appropriately prefaced by a brief consideration of the efficiency with which carbohydrates are synthesised by plants and of the losses incurred in malting and in adjunct preparation. Carbohydrates are synthesised in the leaves of cereals from carbon dioxide and water by the process of photosynthesis, driven by the quantum energy of light:

$$6CO_2 + 6H_2O + \text{light energy} \longrightarrow C_6H_{12}O_6 + 6O_2$$

Since carbon dioxide and water are ubiquitous, the efficiency of this process is described in terms of quantum yield by plant biochemists. The theoretical quantum requirement (i.e. highest quantum yield) for the photochemical reduction of $CO_2$ to $(CH_2O)$ appears to be four, but even in the most efficient experimental systems the actual quantum requirement is never less than 8-12, indicating that chlorophyll is utilising light energy with something less than 40% efficiency (81). In cereal leaves the efficiency is much less. The farmer talks in terms of crop yield per acre and much successful effort has been made to improve these agricultural yields. Perhaps the most practical term is that of starch yield per acre: 'naked' varieties of barley have been developed giving a 7% lower crop yield but a net higher yield of starch per acre (82).

The raw barley passes from the farmer to the maltster who incurs serious losses of solids, despite his best efforts, in the malting process. Current malting losses range from 6-12% of solids ( 83), 6-8% in the more efficient modern methods (84), (85). This loss of solids is largely due to metabolic activity, respiration accounting for ~ 4% and rootlet growth ~ 3%. The respiration loss is perhaps more important since starch is the principal substrate. The loss of hexose during the germination stage is ~ 4% of solids or

6-7% of carbohydrate, since starch comprises 55-60% of the barley corn (86). Current attempts to reduce losses are therefore aimed at restriction of embryo growth, by use of sulphur dioxide, for example (84). Kilning further reduces extract yield, especially if the drying temperature is high (87). The high loss of carbohydrate during malting largely explains the economic attractiveness of the use of unmalted adjuncts or barley/enzyme brewing in which losses due to embryo activity are avoided. It should not be ignored that there are also significant losses in the preparation of unmalted adjuncts. Hicks (88) states that in maize-starch refining a typical yield would be 609 kg starch from 650 kg in the raw grain, for example.

The malt and adjuncts now pass from the maltster or starch-refiner to the brewer, whose efficiency in extracting soluble material from a malt grist as revealed in the mass balance outlined above was 96.9 %. In terms of total solids, however, extraction efficiency is much lower: 98 lb of solids being lost from 317 lb malt grist solids i.e. extraction efficiency of total solids ~ 71%. The 'lost' solids include cellulose, hemicellulose and other carbohydrates as insoluble polymers of glucose or related compounds each derived from the simple sugars formed during photosynthesis. The commercial development of enzymes to release these bound sugars would be of great economic significance, but at present they are left to the rumen bacteria of the cattle that we feed on spent grain.

The mass-balance was described in terms of total solids, or total extractable solids, with little reference to composition. Brewing raw materials are variable in composition, largely as a result of climatic conditions, varietal differences and agricultural practices. Therefore a detailed mass-balance of components can only be applied to a single batch of materials. Nevertheless there is a remarkable degree of constancy in wort composition (23) and even in barley and malt the ranges are limited, the analyses of Hopkins & Krause (89 ), Hall, Harris and MacWilliam (90) and Harris (91) being amongst those most frequently quoted (61) (91 - 94). On the basis of these analyses, and those of suppliers and brewery laboratories, it is therefore possible to construct a more detailed mass balance revealing the probable approximate composition of malt grist and spent grain, thus also showing the origins of wort components. This has been attempted for the RBK grist and the result is shown in Table 41, on the next page.

TABLE 41

COMPOSITION AND FATE OF GRIST COMPONENTS

| Pale malt + crystal malt (contributing 85.1% of total extract) | | A Composition % solids (91) (Harris) | B Composition of grist % solids | C Grist Extract to copper (% solids) | D % Grist Solids to spent grain |
|---|---|---|---|---|---|
| Starch | | 58 - 60 | 55.7 | 53.8 | 1.9 |
| Sugars | a | 8 - 11 | 6.5 | 6.5 | 0.0 |
| Soluble gums | b d | 2 - 4 | 2.0 | 2.0 | 0.0 |
| Hemicellulose | b d e | 6 - 8 | 8.0 | 0.2 | 7.8 |
| Protein | | 8 - 11 | 10.0 | 4.0 | 6.0 |
| Cellulose | b c | 5 | 5.8 | 0 | 5.8 |
| Ash | f | 2.2 | 2.0 | 1.6 | 0.4 |
| Lipid | | 2 - 3 | 3.0 | 0 | 3.0 |
| Other materials | | 6 - 7 | 7.0 | 0.6 | 6.4 |
| | | | 100.0 | 68.7 | 31.3 |
| Flaked maize (4.5% of total extract) | | | | | |
| | Starch | | 81 | 78.9 | 2.1 |
| | Protein | | 8.5 | 3.4 | 5.1 |
| | Lipid etc. | | 10.5 | 0 | 10.5 |
| | | | 100 | 82.3 | 17.7 |
| Wort syrup (10.4% of total extract) | | | | | |
| | Glucose | | 52.2 | 52.2 | 0 |
| | Maltose | | 11.9 | 11.9 | 0 |
| | Maltotriose | | 12.9 | 12.9 | 0 |
| | Dextrins | | 19.8 | 19.8 | 0 |
| | Proteins | | 1.0 | 1.0 | 0 |
| | Ash etc. | | 2.2 | 2.2 | 0 |
| | | | 100 | 100 | 0 |

footnotes — see over ⟶

a. Sugars are formed during malting by degradation of starch, soluble polysaccharides, and gums (95).

b. The extent to which hemicelluloses or cellulose contribute to extract is not clear, but less than 1-2% of extract is indicated (92) (96) (97 ).

c. Preece also found cellulose forms 5% solids of the grain (98).

d. Preece found 1/4 of barley hemicellulose shows solubility changes during malting (98).

e. Enzymes releasing pentoses from hemicellulose are largely inactivated by the high temperature of the infusion mash (99).

f. Approx 40% of ash is phosphate (100).

Malt grist

The malted barley was the major component of the grist and since the proportion of crystal malt was small, and since crystal and pale malts are grossly similar in composition, the two have been grouped together. (Allowance has been made for the lower laboratory extract of the crystal malt.) The data of Harris (91), Table 41 column A, are used in assessing the probable composition of the malt in the RBK grist. The laboratory extract of the malt was low, indicating low starch and sugar content; 'protein' content is calculated as 6.25 x malt nitrogen. The flaked-maize composition is calculated on the basis that the extract of starch solids is 138.2 brewers lb/qr. ( 1 ), and protein content = 6.25 x nitrogen content. The wort syrup composition is based on the manufacturer's specification.

Spent grain

The proportion of the malt-grist solids appearing in the spent grain is dependent on the amount of insoluble material present in the malt grist and the efficiency with which the potentially soluble material is extracted. In the recommended Institute of Brewing method (101), it is assumed that 24 g dried grain obtain from 100 g malt, but published figures vary from 24% to 30% (43) (80) (101) (102). In this RBK grist the proportion of insoluble material was relatively high (low laboratory extract) and it has been calculated that the spent-grain solids-content was ~ 30.7% of original malt grist solids. The spent-grain solids-content includes insoluble lipid and cellulose, and most of the malt hemicellulose, only a small proportion of which is dissolved during mashing (91) (96) (98) (99) (103 - 105). The mass balance of nitrogen compounds shows that 60% of these remain undissolved and are thus lost in the spent grain. Insoluble 'ash' includes a high proportion of the silicates which are abundant in husk. MacFarlane (102) showed that a spent grain solids content of 5% carbohydrate as dextrose (thus 4.5% as starch) was equivalent to an extract loss of 2 brewers lb/qr. For an extract loss in the spent grain of 2.7 brewers lb/qr therefore, the equivalent starch content is 6.1% of spent-grain solids. The composition of flaked-maize spent-grain was estimated in a similar manner, and is also shown in column D, Table 41. Overall spent-grain composition and origins are shown in Table 42, on the next page.

Other losses

The major loss of malt-grist solids was in the spent grain; other losses however, included 0.3% as protein precipitated during wort boiling.

Wort

The relative proportions of dissolved materials, Table 41, column C, are assessed by difference (grist solids - spent grain solids) and remain unchanged, except for protein precipitation during boiling, up to entry into the FV. It is therefore possible to assess wort composition in FV knowing the relative contributions of grist components to overall extract (Table 43 on the next page), this indicates 92.1% carbohydrates, 5.0% nitrogen compounds, 2.2% ash and 0.7% other materials. This compares closely with 91.9%, 4.9%, 2.1% and 0.7% respectively, shown in the fermentation mass balance, (0.4% was unaccounted for).

TABLE 42

SPENT-GRAIN ORIGIN AND COMPOSITION

The relative contributions of flaked maize and malt to the spent grain are calculated from the data in Tables 40, 41.

| Contribution to spent grain from:- | g/100 g malt-grist solids | % spent-grain solids |
|---|---|---|
| Malt | 29.9 | 97.3 |
| Flaked maize | 0.8 | 2.7 |
| | 30.7 | 100.0 |

The detailed spent-grain composition may now be deduced from the data of Table 41:

| | Contribution to spent grain (% solids) from:- | | Total (= spent grain composition, % solids) |
|---|---|---|---|
| | Malt | Flaked maize | |
| Starch + sugars | 5.9 | 0.3 | 6.2 |
| Hemicellulose | 24.2 | - | 24.2 |
| Cellulose | 18.1 | - | 18.1 |
| Protein | 18.7 | 0.8 | 19.5 |
| Ash | 1.2 | - | 1.2 |
| Lipid + other matter | 29.2 | 1.6 | 30.8 |
| | 97.3 | 2.7 | 100.0 |

TABLE 43

WORT COMPOSITION AND ORIGIN

| Origin | Wort composition[a] | | | | |
|---|---|---|---|---|---|
| | Dissolved starch + hemicellulose, soluble gums + sugars | | Dissolved "crude" protein | Ash | Other materials |
| Pale + crystal Malt | Starch | 66.7 | 5.0 | 2.0 | 0.7 |
| | Sugars | 8.0 | | | |
| | Soluble gums | 2.5 | | | |
| | Hemi-cellulose | 0.2 | | | |
| % contribution to total realised extract = 85.10 | | 77.4 | 5.0 | 2.0 | 0.7 |
| Flaked maize | Starch | 4.31 | 0.19 | | |
| % contribution to total realised extract = 4.50 | | 4.31 | 0.19 | | |
| Wort Syrup | Glucose | 5.43 | 0.10 | 0.20 | 0.03 |
| | Maltose | 1.24 | | | |
| | Malto-triose | 1.34 | | | |
| | Dextrins | 2.06 | | | |
| % contribution to total realised extract = 10.40 | | 10.07 | 0.10 | 0.20 | 0.03 |
| % total realised extract = 100 | | 91.78 | 5.29 | 2.20 | 0.73 |
| (adjusted for protein loss during wort boiling)[b] | | 92.06 | 4.99 | 2.21 | 0.74 |

a. Calculated as Table 41 column C values x %-contribution to total realised extract.

b. Taking into account a loss of 6% of the "crude" protein = 0.3% of wort solids content during copper boiling and assuming hydrolysis gain is similar in each category.

At the beginning of this discussion it was said that carbohydrates are derived from carbon dioxide. It is also true that all the carbon found in brewing raw materials is derived from carbon dioxide and thus a carbon balance of wort preparation would reveal the utilisation of the carbon bound by photosynthesis. Such a balance has been constructed, see Appendix p. 158 , for a simple grist comprising malt and wort syrup. Its validity, however, is questionable since production data were inconsistent, and as in the mass-balance the proportion of malt solids lost in spent grains cannot be measured. The main advantage of the carbon-balance lies in its simplicity referring as it does to the basal unit of all carbohydrate metabolism. The mass-balance, or available-extract balance, are of more practical use however, and these are the balances used in cost evaluation of grist utilisation as shown in Section 1 b).

Conclusions

The main conclusions to be drawn are:-

1) Losses of carbohydrate, or potential carbohydrate, begin on the farm and in the maltings but can be minimised by improved agricultural practices, and by restricting embryo growth during malting or by-passing the malting stage as in barley/enzyme brewing.

2) The efficiency of grist extraction in the brewery at 97% in terms of available extract is high, but low at 71% of total solids for the RBK grist considered here; the difference being largely due to the lock-up of sugars in insoluble polymers.

3) For each of the balances considered (mass, available extract, carbon) the yield of spent grain from malt must be assumed.

4) The origins of wort components can be traced in a more detailed mass-balance of a brewery grist.

APPENDIX TO SECTION 1a

## CARBON BALANCE OF WORT PREPARATION

Grist

| Malt grist | Moisture % | Solids (kg) | Carbon (% solids) | Carbon (kg) |
|---|---|---|---|---|
| Pale malt<br>108 qr<br>(330 lb/qr) | 3.41 | 15,615 | 44.59 | 6,963 |
| Crystal malt<br>5.5 qr<br>(330 lb/qr) | 4.02 | 790 | 45.70 | 361 |
| Total malt grist solids and carbon | | 16,205 | | 7,324 |
| Wort syrup<br>74 cwt<br>(3,759 kg) | | | 33.84% on syrup | 1,272 |
| Total carbon | | | | 8,596 |

Collected wort

912 brls of 1038.8° wort were collected

But sample = 1039.7° @ 4.55% carbon

Hence wort carbon

$$= \frac{38.8}{39.7} \times 912 \times 163.655 \times 1.0397 \times 0.0455 \text{ kg} = \underline{\underline{6{,}898 \text{ kg carbon}}}$$

'Lost carbon' 8,596 - 6,898 = 1,698 kg carbon

Spent grain carbon

Carbon content of spent grain = 47.23% of solids

Assuming most of 'lost' carbon is to be found in the spent grain (see mass balance), say 1,683 kg carbon

Then spent grain solids = $\frac{1,683}{0.4723}$ = 3563 kg

Thus % of malt grist solids to spent grain = $\frac{3563}{16205}$ x 100 = 22.0%

Wetting losses etc.

Wetting loss (by difference) = 15 kg

Summary

| | Total carbon (kg) | % of total carbon |
|---|---|---|
| Grist carbon | 8,596 | 100 |
| Wort carbon | 6,898 | 80.24 |
| 'Lost' carbon | 1,698 | 19.76 |

Notes.

1. This grist contained no flaked maize, comprising pale + crystal malt alone. The laboratory extract of the pale malt was low, at 89 brewers lb/qr., and the loss of potentially soluble material in spent grain was equivalent to 3.6 brewers lb/qr of the malt grist. These factors lead to the expectation of at least as high a loss of grist solids to spent grain as the 31% indicated in the grist mass-balance. (Table 40) The results of the carbon balance however, are consistent with either the loss of only 22% of grist solids to spent grain, or with the use of more malt than the 113.5 qr indicated in the Brewing Book. Support for the latter explanation is given by the fact that a 100% utilisation of extract was indicated in the production records despite the loss of 3.6 brewers lb/qr (4.1% of available extract) in the spent grains.

2. % carbon in $(C_6H_{10}O_5)_n$ = 44.5%

SECTION 1b) - CARBOHYDRATE RAW MATERIAL ECONOMICS

One of the main objectives in the use of carbohydrate adjuncts is to reduce the bill for raw materials in brewing. For this reason some of the lower-priced adjuncts were evaluated in the experimental brewing work described in the first Part. Raw wheat and raw barley, two of the cheapest sources of extract, were not considered initially since modification of the malt mill or use of a hammer mill would have been necessary in preparing the grist; supplies are more variable in quality and are thus more difficult to assess than other adjuncts; also there were worries on account of flavours imparted by the husk or bran. At the time of the experimental work (1968-9) little was known of the availability of such materials as unpurified wheat starch and potato starch and so these materials were not considered at the time, although they would merit a place in any future work. Wheat and barley flours and flaked barley are little more expensive than the above-mentioned materials in terms of available extract; they are used in considerable quantities in the brewing and baking industries and thus less subject to variation, due to increased quality control; also their use in brewing does not require the installation or major modification of equipment so that successful work can be rapidly translated into brewing practice.

Wort syrups were more expensive than the adjuncts designed for use in the mash tun, but in by-passing the mash tun, losses are reduced so that in terms of realised extract considerable savings are possible. Further advantages lie in the reduced processing costs, increased brewhouse capacity where the mash-tun is the bottle-neck in production, and in the preparation of worts of high specific gravity, low nitrogen content, or controlled fermentability. Although barley syrups showed no appreciable raw-material cost-saving, the possibility of building future breweries with no mash-tun or associated equipment arises, as these materials are designed as complete wort-replacements. Thus both wort and barley syrups were included in the experimental-brewing programme.

The results obtained in experimental brews using both mash-tun adjuncts and syrups at different percentages of the total carbohydrate-grist have already been described. These results indicated the maximum level of usage for mash-tun adjuncts, beyond which decreased utilisation was overwhelming, Table 44 below:-

TABLE 44

UTILISATION OF EXTRACT IN EXPERIMENTAL MALT GRISTS

| Malt grists | Adjunct level | Utilisation of available extract (%) | Utilisation of available extract (% of control) |
|---|---|---|---|
| Control grist | 0% | 97.2 | 100.0 |
| Barley flour | 10 % | 96.2 | 99.0 |
| | 17 % | 90.6 | 93.2 |
| | 25 % | v. low | v. low |
| Wheat flour | 10 % | 97.5 | 100.3 |
| | 15 % | 97.6 | 100.4 |
| | 17 % | 95.8 | 98.6 |
| | 25 % | v. low | v. low |
| Flaked barley | 10 % | 96.9 | 99.7 |
| | 17 % | 94.8 | 97.5 |

This table shows that for barley flour and to a lesser extent for flaked barley, utilisation fell sharply when the percentage of the adjunct in the malt grist was increased from 10% to 17%. Maximum utilisation was obtained at 15% for wheat-flour grists, an improvement on control-grist utilisation being made at this level and at 10% wheat flour. There was a reduction in utilisation at a level of 17% wheat-flour usage but this was not as marked as for barley flour. For both wheat and barley-flours the extreme processing difficulties encountered at 25% resulted in very poor utilisation of available extract.

Cost evaluation must therefore take account of both the price of the constituents and the overall utilisation of the malt grist in order to show the extent of any savings. Such evaluation reveals whether low raw-material prices outweigh decreased utilisation and where the break-even point lies. For the 10% and 15% wheat-flour grists the evaluation shows how the increased utilisation enhances the cost-reducing effect of the low price of the adjunct. In evaluating the effective costs of the grists including sucrose, wort or barley syrups, a 100% utilisation of the adjunct is assumed since the adjunct is already soluble and is added directly to the copper (or could be added directly to the FV) and is thus not subject to the extraction losses that malt grists suffer. The wort-preparation mass-balance showed that the only substantial loss of available extract was in the spent grain. Raw-material prices vary from year to year, as will be discussed later, and in the interval between the time of experimental-brewing work (1968-9) and the time of writing (1971) there has been an abnormally large change in price structure, as shown in Table 45:-

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TABLE 45

PRICES OF CARBOHYDRATE RAW-MATERIALS IN 1968 AND 1971

| Raw Material | Return on spent grain (p/qr) | Price (p)/brewers lb of available extract, including allowance for return on spent grain | |
|---|---|---|---|
| | | Year 1969 | Year 1971 |
| Crystal malt | 0.5 | 9.4 | 11.9 |
| Pale malt | 0.5 | 7.7 | 10.1 |
| Barley syrups | 0 | 7.8 | 10.0 |
| Flaked maize | 0.25 | 6.3 | 8.2 |
| Wort syrups | 0 | 6.7 | 8.1 |
| Sucrose | 0 | 7.8 | 8.05 |
| Flaked barley | 0.5 | 5.4 | 6.8 |
| Barley flour | 0 | 5.4 | 5.9 |
| Wheat flour | 0 | 5.4 | 5.9 |
| Wheat starch | 0 | - | 5.7 |
| Raw barley | 0.5 | 4.9 | 5.4 |
| Potato starch | 0 | - | 5.4 |
| Raw wheat | 0.25 | 4.2 | 4.8 |

It is shown in this table that some prices have risen more steeply (e.g. malt) than others (e.g. sucrose) and thus the relative costs of different materials have changed. For the purpose of cost evaluation of the experimental grists the more recent prices have been used, but it is, of course, always possible to up-date the evaluation by substituting revised prices and recalculating. The cost evaluations of the experimental grists are shown in the Appendix, p. 170. In each case the most important statistic is the net carbohydrate raw-material cost of unit extract <u>realised</u>; the extent to which this differs from the cost of <u>available</u> extract is a measure of the scope of cost savings by improvement of the efficiency of malt grist extraction. A summary of

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these evaluations is shown in Table 46:-

TABLE 46

RAW-MATERIAL COST OF EXTRACT (SUMMARY OF APPENDIX)

| GRIST | | Net raw-material cost of unit extract | | | |
|---|---|---|---|---|---|
| | | Available in grist | | Realised in FV | |
| | | (p/brewers lb) | (% of control) | (p/brewers lb) | (% of control) |
| Control | | 9.77 | 100.0 | 10.025 | 100.0 |
| Barley-flour | 10% | 9.41 | 96.2 | 9.74 | 97.1 |
| | 17% | 9.27 | 94.8 | 10.12 | 101.0 |
| | 25% | 8.97 | 91.8 | v. high | v. high |
| Wheat-flour | 10% | 9.38 | 96.0 | 9.60 | 95.7 |
| | 15% | 9.32 | 95.4 | 9.53 | 95.0 |
| | 17% | 9.23 | 94.4 | 9.59 | 95.7 |
| | 25% | 8.93 | 91.4 | v. high | v. high |
| Flaked barley | 10% | 9.63 | 98.5 | 9.91 | 98.8 |
| | 17% | 9.44 | 96.6 | 9.90 | 98.8 |
| Wort syrup | + sucrose | 9.15 | 93.6 | 9.31 | 92.8 |
| (33%) | - sucrose | 9.39 | 96.0 | 9.58 | 95.5 |
| Barley syrup | 67% | 10.01 | 102.4 | 10.10 | 100.8 |
| | 100% | 10.00 | 102.3 | 10.00 | 99.8 |

These results show that in terms of realised extract the least expensive experimental grist consisted of 33% wort syrup, 12% sucrose and 55% control malt-grist. This was followed by the wheat-flour grists showing an optimum replacement-level of 15% at which the overall grist-cost was reduced to 95% of control. The use of barley flour at 10% also resulted in fairly substantial savings, but the decreased utilisation at 17% resulted in this grist being more expensive than the control. Flaked-barley grists showed only marginal savings, whereas the cost of realised extract from barley-syrup grists was similar to that of the control, but processing cost savings must also be considered.

In terms of available extract, grists containing high proportions of wheat and barley flour showed most promise. At 25% flour the cost of available extract was only 91-92% that of control. In order to achieve this saving, a procedure such as the slurrying process proposed earlier would be necessary. Hence the costs of slurrying and enzyme addition must be considered. Enzyme costs have fallen remarkably since 1969: the cost of adding the equivalent α-amylase activity of 0.3% on flour weight of a 620 SKB units/g enzyme would now increase the cost of 1 brewers lb of extract from flour by only 0.07 p or < 0.02 p on the cost of 1 brewers lb from the grist.

TABLE 47

COST OF α-AMYLASE IN THE FLOUR-SLURRYING PROCESS, 1971

| Enzyme Name and Supplier | Enzyme Activity (SKB/g) | Enzyme Price (p/lb) | Enzyme Price ($p/10^6$ SKB) | Cost of enzyme equivalent to 0.3% on flour weight of 620 SKB/g enzyme, p/brewers lb: Barley | Wheat |
|---|---|---|---|---|---|
| Bacterase (ABM) | 620 | 70 (1969) | 249 | 0.72 | 0.68 |
| BAN 120 (Novo) | 2,280 | 25 (1971) | 24 | 0.070 | 0.065 |
| SP 100 (Wallerstein) | 5,600 | 75 | 30 | 0.120 | 0.082 |
| Nervanase (ABM) | 1,200 | 13.6 | 25 | 0.073 | 0.10 |

Provided that the slurrying process proved as efficient as control-grist extraction in the mash tun, the total carbohydrate raw-material bill of 25% flour-grist brews would be only 92% of control.

The possibilities of adding a saccharification stage to the slurrying process have been discussed (Part 1, Section 3b , p. 57). The additional enzymes required to prepare a wort-replacement or barley syrup in such a way would add only 0.5 p/brewers lb. The total raw-material cost of such a syrup would therefore amount to only ~ 7p/ brewers lb realised-extract. Using raw barley, as preferred in commercial barley-syrup procedures, by methods similar to those described earlier (Part 1, Section 4 , p. 64), the cost would be reduced to ~ 6.5 p/brewers lb. Raw-material costs are therefore reduced to only 65-70% of traditional malt-grist costs in such dual-enzyme processes, but processing costs are higher. The use of starch slurries was investigated on laboratory-scale only, however, and thus a detailed economic evaluation of brewing with raw barley, or brewery starch-syrup production is inappropriate, but the low raw-material costs suggest that the development of such processes would carry high rewards for brewers who would not incur the high evaporation, purification and transport costs borne by commercial barley-syrup producers.

Reasons for the relatively high cost of commercial barley syrups have already been suggested. The experimental-brewery trials showed that barley syrups were not generally acceptable, on account of flavour defects, abnormal pH and poor trub separation. These brews were made in 1969 however, and in the two years following they have become acceptable in most breweries, but only at levels of ~ 25% (106) in which proportion they are useful at times of peak production if milling or mash-tun capacity is a bottleneck. The work described in Part 1, Section 4, p. 68 has shown that the cheaper wort syrups are at least equally suitable for such an application, and no real advantage is gained by using a more expensive syrup. Barley syrups would show substantial economic advantages only in breweries in which milling and mashing equipment is scrapped, or in the building of new 'liquid' breweries through reduced capital expenditure on malt-grist extraction-plant. At present therefore the use of wort syrups is extremely attractive on the following counts [(33% WS + S) grist] :-

1. Raw-material cost-saving (92.8% of control)
2. Mash-tun capacity is effectively increased (160% of control) at times of peak production.
3. Reduction of wort nitrogen-content (71% of control)
4. Adjustment of wort fermentability
5. Overcoming the technical difficulties and increased losses attendant on the production of high specific gravity worts from malt grist

The carbohydrate raw-materials have now been evaluated in terms of <u>extract</u> cost with little reference to extract <u>composition</u>. Different raw materials contribute differing quantities of the various wort components, as shown in the mass balance of wort preparation Table 43, p. 156. Sucrose contributes virtually nothing other than fermentable carbohydrate to the wort whereas malt contributes soluble gums, other unfermentable carbohydrates, nitrogen compounds, mineral salts, tannins and other materials. The values of materials other than fermentable carbohydrates lie in yeast nutrition and beer flavour and the absolute amounts required by yeast during fermentation, and the amounts residual in the beer after fermentation which can best be determined in a mass-balance of fermentation, as described in Section 2a, p. 177.

It has been shown that raw-material prices can vary dramatically in a relatively short period. In formulating a buying policy for carbohydrate raw-materials the brewer must therefore take account of the various factors affecting market prices, including short term supply/demand situations, agricultural policies and legislation. In

1970 for instance, the shortage and poor quality of the barley crop coupled with the partial failure of the American maize crop resulted in sharp price increases for maize and barley (55). Shortage of barley and maize put pressure on the demand for wheat so that the price of this commodity also rose whereas the U.K. price of sugar rose only slightly as a result of government control. Malt prices therefore rose by up to 40%, also the price of adjuncts such as flaked, pearled and torrefied barley, barley flour and barley syrups. The prices of flaked maize and maize syrups rose by 15-20%, as did those of wheat flour and wheat syrups. The price of sugar, as previously mentioned, rose by only 2-3%. Price differentials between the various brewing carbohydrates were thus altered considerably. Whereas for example, barley syrups were more expensive than malt in tems of extract cost, they are now at similar prices. Sucrose was considerably more expensive than maize syrups, but the gap is narrowing. The attention of the brewer is drawn to carbohydrate costs when these are rising more rapidly than the price of beer, and to the possibilities of using adjuncts when the gap between the price of these and malt widens. In 1970 there was cause for renewed and selective interest in adjuncts on both these considerations. The present Government policy of reducing deficiency payments and raising internal prices is likely to maintain current high price levels even if subsequent crops are improved. The minimum price level for imported cereals will ensure that there will be no reduction of internal price as a result of pressure from any world surplus. Furthermore, if Britain is to join the EEC, the economy will have to be adjusted to higher farm prices. An important question that remains to be answered in relation to joining the EEC is the extent to which the use of adjuncts in brewing would be allowed. The "Purity Laws" that operate in West Germany allow the use of little other than malt and hops in brewing: much will therefore depend on their influence in the Council of Ministers. It has recently been pointed out that the Council is currently considering a proposal that would allow certain adjuncts to be used at a level of up to 30% of the grist.

The experimental-brewery work has shown that a number of different grists can be used to produce beer of equal quality and similar flavour. Thus the brewer can be flexible in his buying policy and can take advantage of the availability of a low priced carbohydrate-source. The materials cost of brewing, however, is small in comparison with the total manufacturing cost of beer. By the time that the cost of production, distribution and Excise Duty have been added, the brewer has at his command a mixture of sugars that is 13-14 times as expensive as the grist from which it was produced. It is therefore not surprising that he should devote much of his energy to the achievement of maximum utilisation of wort sugars and other materials. A mass-balance of fermentation is therefore presented in the next section followed by a discussion of the utilisation that is made during fermentation of the components of wort extract derived from the carbohydrate raw-materials.

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Appendix to Section 1b - Grist Costs

Control grist — Utilisation of malt grist = 97.2%

| % malt grist (weight basis) | % malt grist (extract basis) | Cost per available brewers lb (p) | Extract cost in:- 1.0 brewers lb available (p) | 0.875 brewers lb available (p) | 0.875 brewers lb realised (p) | Material |
|---|---|---|---|---|---|---|
| 88.8 | 88.8 | 10.1 | 8.969 | 7.848 | 8.074 | Pale Malt |
| 4.1 | 3.55 | 11.9 | 0.422 | 0.370 | 0.380 | Crystal Malt |
| 7.1 | 7.65 | 8.2 | 0.627 | 0.549 | 0.565 | Flaked maize |
| | | | | | | |
| Extract cost from malt grist | | | 10.018 | 8.767 | 9.019 | |
| Sucrose cost per 0.125 brewers lb | | | | 1.006 | 1.006 | Sucrose |
| Cost of 1 brewers lb – available | | | | 9.773 p | | |
| Cost of 1 brewers lb – realised | | | | | 10.025 p | |

10% barley flour — Utilisation of malt grist = 96.2%

| % malt grist (weight basis) | % malt grist (extract basis) | Cost per available brewers lb (p) | Extra cost in:- 1.0 brewers lb available (p) | 0.875 brewers lb available (p) | 0.875 brewers lb realised (p) | Material |
|---|---|---|---|---|---|---|
| 78.8 | 78.8 | 10.1 | 7.959 | 6.964 | 7.239 | Pale Malt |
| 4.1 | 3.55 | 11.9 | 0.422 | 0.370 | 0.384 | Crystal Malt |
| 10.0 | 10.0 | 5.9 | 0.590 | 0.516 | 0.537 | Barley flour |
| 7.1 | 7.65 | 8.2 | 0.627 | 0.549 | 0.571 | Flaked maize |
| Extract cost from malt grist | | | 9.600 | 8.399 | 8.731 | |
| Sucrose cost per 0.125 brewers lb | | | | 1.006 | 1.006 | Sucrose |
| Cost of 1 brewers lb – available | | | | 9.405 p | | |
| Cost of 1 brewers lb – realised | | | | | 9.737 p | |

17% barley flour      Utilisation of malt grist = 90.6%

| % malt grist (weight basis) | % malt grist (extract basis) | Cost per available brewers lb (p) | Extract cost in:- 1.0 brewers lb available (p) | 0.875 brewers lb available (p) | 0.875 brewers lb realised (p) | Material |
|---|---|---|---|---|---|---|
| 78.8 | 79.24 | 10.1 | 8.003 | 7.003 | 7.729 | Pale Malt |
| 4.1 | 3.56 | 11.9 | 0.424 | 0.371 | 0.409 | Crystal Malt |
| 17.1 | 17.20 | 5.9 | 1.015 | 0.888 | 0.980 | Barley flour |
| | | | | | | |
| Extract cost from malt grist | | | 9.442 | 8.261 | 9.118 | |
| Sucrose cost per 0.125 brewers lb | | | | 1.006 | 1.006 | Sucrose |
| Cost of 1 brewers lb – available | | | | 9.267p | | |
| Cost of 1 brewers lb – realised | | | | | 10.124p | |

25% barley flour      Utilisation of malt grist = v. low

| % malt grist (weight basis) | % malt grist (extract basis) | Cost per available brewers lb (p) | Extra cost in:- 1.0 brewers lb available (p) | 0.875 brewers lb available (p) | 0.875 brewers lb realised | Material |
|---|---|---|---|---|---|---|
| 70.9 | 71.2 | 10.1 | 7.191 | 6.292 | - | Pale Malt |
| 4.1 | 3.6 | 11.9 | 0.428 | 0.375 | - | Crystal Malt |
| 25.0 | 25.2 | 5.9 | 1.487 | 1.301 | - | Barley flour |
| | | | | | | |
| Extract cost from malt grist | | | 9.106 | 7.968 | - | |
| Sucrose cost per 0.125 brewers lb | | | | 1.006 | 1.006 | Sucrose |
| Cost of 1 brewers lb – available | | | | 8.974 p | | |
| Cost of 1 brewers lb – realised | | | | | - | |

10% flaked barley — Utilisation of malt grist = 96.9%

| % malt grist (weight basis) | % malt grist (extract basis) | Cost per available brewers lb (p) | Extract cost in:- 1.0 brewers lb available (p) | 0.875 brewers lb available (p) | 0.875 brewers lb realised (p) | Material |
|---|---|---|---|---|---|---|
| 85.9 | 87.1 | 10.1 | 8.797 | 7.697 | 7.943 | Pale Malt |
| 4.1 | 3.6 | 11.9 | 0.428 | 0.375 | 0.387 | Crystal Malt |
| 10.0 | 9.3 | 6.8 | 0.632 | 0.553 | 0.571 | Flaked barley |
| | | | | | | |
| Extract cost from malt grist | | | 9.857 | 8.625 | 8.901 | |
| Sucrose cost per 0.125 brewers lb | | | | 1.006 | 1.006 | Sucrose |
| Cost of 1 brewers lb – available | | | | 9.631 p | | |
| Cost of 1 brewers lb – realised | | | | | 9.907 p | |

17% flaked barley — Utilisation of malt grist = 94.8%

| % malt grist (weight basis) | % malt grist (extract basis) | Cost per available brewers lb (p) | Extra cost in:- 1.0 brewers lb available (p) | 0.875 brewers lb available (p) | 0.875 brewers lb realised (p) | Material |
|---|---|---|---|---|---|---|
| 78.8 | 80.5 | 10.1 | 8.131 | 7.114 | 7.504 | Pale Malt |
| 4.1 | 3.6 | 11.9 | 0.428 | 0.375 | 0.395 | Crystal Malt |
| 17.1 | 15.9 | 6.8 | 1.081 | 0.946 | 0.998 | Flaked barley |
| | | | | | | |
| Extract cost from malt grist | | | 9.640 | | | |
| Sucrose cost per 0.125 brewers lb | | | | 1.006 | 1.006 | Sucrose |
| Cost of 1 brewers lb – available | | | | 9.441 p | | |
| Cost of 1 brewers lb – realised | | | | | 9.903 p | |

<u>10% Wheat flour</u> Utilisation of malt grist = 97.5%

| % malt grist (weight basis) | % malt grist (extract basis) | Cost per available brewers lb (p) | Extract cost in:- 1.0 brewers lb available (p) | 0.875 brewers lb available (p) | 0.875 brewers lb realised (p) | Material |
|---|---|---|---|---|---|---|
| 78.8 | 78.3 | 10.1 | 7.908 | 6.920 | 7.097 | Pale Malt |
| 4.1 | 3.5 | 11.9 | 0.416 | 0.364 | 0.374 | Crystal Malt |
| 10.0 | 10.6 | 5.9 | 0.625 | 0.547 | 0.561 | Wheat flour |
| 7.1 | 7.6 | 8.2 | 0.623 | 0.545 | 0.559 | Flaked maize |
| Extract cost from malt grist | | | 9.572 | | | |
| Sucrose cost per 0.125 brewers lb | | | | 1.006 | 1.006 | Sucrose |
| Cost of 1 brewers lb – available | | | | 9.382 p | | |
| Cost of 1 brewers lb – realised | | | | | 9.597 p | |

<u>15% Wheat flour</u> Utilisation of malt grist = 97.6 %

| % malt grist (weight basis) | % malt grist (extract basis) | Cost per available brewers lb (p) | Extra cost in:- 1.0 brewers lb available (p) | 0.875 brewers lb available (p) | 0.875 brewers lb realised (p) | Material |
|---|---|---|---|---|---|---|
| 80.9 | 80.7 | 10.1 | 8.151 | 7.132 | 7.307 | Pale Malt |
| 4.1 | 3.6 | 11.9 | 0.428 | 0.375 | 0.384 | Crystal Malt |
| 15.0 | 15.7 | 5.9 | 0.926 | 0.811 | 0.830 | Wheat flour |
| | | | | | | |
| Extract cost from malt grist | | | 9.505 | 8.318 | 8.521 | |
| Sucrose cost per 0.125 brewers lb | | | | 1.006 | 1.006 | Sucrose |
| Cost of 1 brewers lb – available | | | | 9.324 p | | |
| Cost of 1 brewers lb – realised | | | | | 9.527 p | |

17% Wheat flour    Utilisation of malt grist = 95.8%

| % malt grist (weight basis) | % malt grist (extract basis) | Cost per available brewers lb (p) | Extract cost in:- 1.0 brewers lb available (p) | 0.875 brewers lb available (p) | 0.875 brewers lb realised (p) | Material |
|---|---|---|---|---|---|---|
| 78.8 | 78.3 | 10.1 | 7.908 | 6.920 | 7.223 | Pale Malt |
| 4.1 | 3.5 | 11.9 | 0.416 | 0.364 | 0.380 | Crystal Malt |
| 17.1 | 18.2 | 5.9 | 1.074 | 0.940 | 0.981 | Wheat flour |
| | | | | | | |
| Extract cost from malt grist | | | 9.398 | 8.224 | 8.584 | |
| Sucrose cost per 0.125 brewers lb | | | | 1.006 | 1.006 | Sucrose |
| Cost of 1 brewers lb – available | | | | 9.230 p | | |
| Cost of 1 brewers lb – realised | | | | | 9.590 p | |

25% Wheat flour    Utilisation of malt grist = v. low

| % malt grist (weight basis) | % malt grist (extract basis) | Cost per available brewers lb (p) | Extra cost in:- 1.0 brewers lb available (p) | 0.875 brewers lb available (p) | 0.875 brewers lb realised | Material |
|---|---|---|---|---|---|---|
| 70.9 | 70.1 | 10.1 | 7.080 | 6.195 | - | Pale Malt |
| 4.1 | 3.5 | 11.9 | 0.416 | 0.364 | - | Crystal Malt |
| 25.0 | 26.4 | 5.9 | 1.558 | 1.363 | - | Wheat flour |
| | | | | | | |
| Extract cost from malt grist | | | 9.054 | 7.922 | - | |
| Sucrose cost per 0.125 brewers lb | | | | 1.006 | 1.006 | Sucrose |
| Cost of 1 brewers lb – available | | | | 8.928 p | | |
| Cost of 1 brewers lb – realised | | | | | - | |

33% wort syrup + sucrose. Utilisation of malt grist = 97.2%

| | Extract cost in:- 1.0 brewers lb available (p) | 0.55 brewers lb available (p) | 0.55 brewers lb realised (p) | Material |
|---|---|---|---|---|
| | 10.018 | 5.510 | 5.669 | Control malt grist |
| Cost of 0.33 brewers lb | | 2.673 | 2.673 | Wort syrup |
| Cost of 0.12 brewers lb | | 0.996 | 0.996 | Sucrose |
| Cost of 1 brewers lb – available | | 9.149 p | | |
| Cost of 1 brewers lb – realised | | | 9.308 p | |

33% wort syrup. Utilisation of malt grist = 97.2%

| | Extract cost in:- 1.0 brewers lb available (p) | 0.67 brewers lb available (p) | 0.67 brewers lb realised (p) | Material |
|---|---|---|---|---|
| | 10.018 | 6.712 | 6.905 | Control malt grist |
| Cost of 0.33 brewers lb | | 2.673 | 2.673 | Wort syrup |
| Cost of 1 brewers lb – available | | 9.385 p | | |
| Cost of 1 brewers lb – realised | | | 9.578 p | |

<u>67% Barley syrup</u> Utilisation of malt grist = 97.2%

| | Extract cost in:- | | | Material |
|---|---|---|---|---|
| | 1.0 brewers lb available (p) | 0.33 brewers lb available (p) | 0.33 brewers lb realised (p) | |
| | 10.018 | 3.306 | 3.401 | Control malt grist |
| Cost of 0.67 brewers lb | | 6.700 | 6.700 | Barley syrup |
| Cost of 1 brewers lb – available | | 10.01 p | | |
| Cost of 1 brewers lb – realised | | | 10.10p | |

100% Barley syrup

Cost of 1 brewers lb available/realised = 10.0 p

## Section 2 a) WORT-FERMENTATION MASS-BALANCE

Fermentation of the wort derived from the RBK grist-formulation, considered in Section 1 was studied on production scale in batch and continuous systems. Conico-cylindrical vessel (CCV) fermentations were more easily studied than traditional batch due to ease of yeast-growth measurement and sampling. The continuous fermentation system (CF) studied was a two-stage open system. In addition, some laboratory studies were made on the effects of aeration, pitching rate and yeast strain. It was originally intended to prepare separate mass balances for CF and CCV fermentations, but the differences between the two proved to be so slight that they were masked by other factors, such as the difficulties in obtaining corresponding wort and beer samples in CF where the residence time is > 30 hr during which the batch of wort supply is changed. Thus a general mass-balance is presented and the effects on this of such differences as do exist between CF and CCV are discussed separately. A notable difference in the amounts of yeast growth in CF and CCV systems was found, however, as described below.

### Yeast growth in CF

The production-scale CF system has been described by Bishop (107). It is intermediate between a single perfectly mixed vessel, and a continuous plug-flow tubular reactor, and can therefore be described as partially homogeneous. Under normal operating conditions it is an open system, but can be partially closed by recycling a proportion of the separated yeast to one of the two fermenters (CFV1 and CFV2).

The wort is oxygenated to 9-10 p.p.m. of dissolved oxygen immediately prior to entry to CFV1. There is a pick-up of approx. 4-5 p.p.m. dissolved oxygen during wort storage and this is supplemented by the injection of oxygen into the cooled sterilised wort immediately prior to entry into

CFV1 (see Fig 31 and Table 48, pps 197, 200). This reduces the likelihood of oxygen-limitation of yeast-cell growth. In CFV1 growth is probably limited by availability of assimilable nitrogen, and in CFV2 growth is additionally carbohydrate-limited and the increased alcohol concentration has a further inhibitory effect (Table 49 on p. 201).

If the AG in CFV1 is maintained at approx. 1.022° then the yeast exhibits no appreciable flocculence (the same yeast strain begins to flocculate at AG 1.022 in batch fermentation (Fig 32 p. 198). The contents of CFV1 are therefore homogeneous, aided by mechanical agitation and the stirring effect of rising carbon-dioxide bubbles. Samples withdrawn from CFV1 are thus representative, and the amount of growth in this vessel can be calculated from the concentration of yeast determined in the sample. In CFV2, however, the yeast is flocculent and heterogeneously distributed so that yeast concentration in samples taken is variable. Furthermore the sampling point is in the lower part of the vessel thus giving false and generally high results (Table 50, p. 200).

In one production line, D, the amount of yeast pressed in a period of several weeks was measured, and since the volume of wort fermented during this time was known, a measure of total yeast-growth was obtained indicating 4.65 lb pressed-yeast/brl. To this figure should be added the amount of yeast which is carried with the beer from the yeast-separating vessel, YSV, 0.1-0.2 lb/brl, indicating a total yeast production of 4.75-4.85 lb/brl, and additional growth in CFV2 of 0.5 lb/brl. The range of yeast-production rates in the CF line studied is therefore 4.75-5.15 lb/brl, averaging 4.95 lb/brl.

→

Yeast growth in CCV fermentations

In order to determine the amount of yeast grown in a batch fermentation it is necessary to measure the amount of yeast pitched into the fermenting vessel (FV), the amount pressed from the cone of the vessel, and the amount remaining in suspension in the beer at rack. In two brewery fermentations the yeast pitched and the yeast collected were weighed. The amount of yeast remaining in the beer was calculated from the yeast concentration determined by haemocytometer count. The results were:-

| | Brew 1<br>G 262 NB | | Brew 2<br>G 270 WRB | |
|---|---|---|---|---|
| Declared gravity | 1033.5° | | 1037.8° | |
| Brls brewed | 266.1 | | 250 | |
| | lb/FV | lb/brl | lb/FV | lb/brl |
| Pressed weight of yeast crop | 1,100 | 4.86 | 1,150 | 4.60 |
| Yeast remaining in the beer | 20 | 0.09 | 40 | 0.16 |
| Total yeast | 1,120 | 4.95 | 1,190 | 4.76 |
| Pitching yeast | - 200 | - 0.88 | - 200 | - 0.8 |
| Net yeast production | 920 | 4.07 | 990 | 3.96 |

These results indicated a net yeast growth of 4.0 lb pressed yeast (25-27% solids) per barrel of wort. In measuring the weight of pressed yeast from the cone of the FV after fermentation the pressing main, yeast receiving vessel and press were first cleared of any yeast from previous racks. The Saunders valve at the base of the FV was opened gradually and the sedimented yeast slurry pumped into the receiving vessel from which it was pressed. When the beer at the sight glass at the FV base was clear, a further period was allowed for the sedimentation of any residual yeast from the cone and this yeast was also pressed. The beer was then pumped into 3 x 90 brl-conditioning tanks when measurement of the residual yeast concentration indicated the amount of yeast not pressed. The emptied FV was examined and found to contain little residual yeast and the experimentally determined value of 4.0 lb/brl-yeast production was thus close to the actual yeast production, but probably a slight underestimate due to pressing losses.

An independent confirmation of this rate of yeast production was made by following the increase of yeast concentration during fermentation by haemocytometer count (Fig 32, p 198). This showed a normal growth curve until an AG of 1.022° was reached, when the yeast flocculated. After flocculation the suspension became heterogeneous due to yeast sedimentation. Extrapolation of the growth curve beyond this point indicated a final yeast concentration of 5.0 lb/brl representing a net yeast production of 4.2 lb/brl., since 0.8 lb/brl. was the pitching rate.

Since the value obtained by weighing, 4.0 lb/brl was considered to be a slight underestimate of yeast production due to pressing losses, and an independent value of 4.2 lb/brl was indicated from consideration of the growth curve, the true rate of yeast production probably lies within the range 4.15 $\pm$ 0.10 lb pressed yeast/brl.

Specific Gravity determinations of beer and wort

Random samples of beer in container for CF and batch RBK-brews during August-October 1970 at one brewery were analysed (see below). The brewing gravity aimed for was 1.0378° and within close limits this value was achived. The original gravity (OG) of the beer in container varies more widely due to the variable amounts of dilution of the beer by rinse liquor and liquor used to 'chase' beer out of mains and filters during processing. Variation in brewing gravity and beer dilution also contribute to the variation of the apparent gravity (AG) of the beer in container, but the major factor is the degree of fermentation which is more difficult to control as this in turn depends upon wort fermentability, yeast physiology etc. Attenuation limit (AL) is also related to wort fermentability and yeast physiology and shows slightly more variance than AG due to the additional experimental variance. The AG-AL value, which is used as a measure of beer sweetness, sums the variances of AG and AL:-

SPECIFIC GRAVITY DETERMINATIONS OF WORT AND BEER

(17 random samples)

| | Gravity * | Standard deviation | % deviation |
|---|---|---|---|
| Wort | | | |
| Original Gravity (OG) | 37.80 | ± 0.10 | 0.3 |
| Beer (in container) | | | |
| Original Gravity (OG) | 37.35 | ± 0.54 | 1.4 |
| Apparent Gravity (AG) | 9.33 | ± 0.72 | 7.7 |
| Attenuation Limit (AL) | 5.47 | ± 0.63 | 11.6 |
| AG-AL | 3.87 | ± 0.77 | 19.9 |

* Gravity = (Specific Gravity - 1) x 1000

Mass balance of RBK wort fermentation

Basis : RBK beer OG 1037.35°

AG 1009.33°

Residual Gravity (RG) and alcohol

Apparent fermentation = 37.35 - 9.33 = 28.02°

A Spirit Indication (SI) = 5.21°

But apparent ° fermented = actual ° fermented + SI

28.02 = 22.81° + 5.21°

Therefore actual fermented = 22.81°

RG = OG - actual ° fermented = 37.35 - 22.81

= 14.50°

Alcohol content equivalent to SI 5.21 = 2.85 % w/w

Wort solids

B Solution factor for 1037.35 wort = 3.982 (100 ml/g)

Thus wort solids = 37.35/3.982 = 9.38 g/100 ml wort

Fermented sugars

C The average degree of polymerisation of sugars fermented

= 2.0 hexose units/molecule

D The stoichiometric equation for disaccharide fermentation

shows 53.6 g ethanol ≡ 100 g disaccharide

Now the beer alcohol content was 2.85 % w/w

≡ 2.83 % w/v

D Disaccharide required to produce 2.83 g alcohol

| | | g/100 ml of wort | % of wort solids |
|---|---|---|---|
| $= 2.83 \times 100/53.6$ | = | 5.28 | 56.26 |

Unfermented carbohydrates

| | | | g/100 ml of wort | % of wort solids |
|---|---|---|---|---|
| E | Carbohydrate content of wort solids | = | 8.62 | 91.90 |
| | But fermented sugars, as disaccharide | = | 5.28 | 56.26 |
| | Hence unfermented carbohydrates | = | 3.34 | 35.64 |

a ... carbohydrates assimilated by yeast

F Yeast production ~ 4.65 lb/brl (pressed) 1.29

G Yeast solids = 27% of pressed wt = 0.27 x 1.29 = 0.35

H 'Polyhexose' content of yeast = 48% of solids

Av. MW of 'polyhexose' hexose unit ($C_6H_{10}O_5$) = 162

MW of disaccharide hexose unit ($C_6H_{11}O_{5.5}$) = 171

Hence wort disaccharide assimilated in

0.35 g yeast solids = 171/162 x 0.48 x 0.35 = 0.176 1.88

b ... residual carbohydrates

| | | | g/100 ml of wort | % of wort solids |
|---|---|---|---|---|
| I | Carbohydrates unfermented at AL, 'dextrins' | = | 2.413 | 25.72 |
| | Residual carbohydrates at AG 9.33° = unfermented carbohydrates - assimilated carbohydrate | = | 3.17 | 33.76 |
| I | Thus residual fermentable sugars (= residual carbohydrates - 'dextrins') | = | 0.754 | 8.04 |

J Non-carbohydrate wort constituents 0.760 8.10

(N-compounds + ash + other materials)

K Nitrogenous wort constituents 0.46 4.9

(assimilated + dissolved + precipitated) a ... N-compounds assimilated by yeast

| | | g/100 ml of wort | % of wort solids |
|---|---|---|---|
| L | N-compounds represent 43% of yeast solids | | |
| | But 0.35 g yeast solids produced/100 ml | | |
| | Hence assimilation of N-compounds | | |
| | = 0.43 x 0.35 g = | 0.15 | 1.6 |

b ... N-compounds remaining in beer

| | | | |
|---|---|---|---|
| M | Nitrogen content of beer = 0.036 g/100 ml | | |
| | 1 g nitrogen ≡ 6.25 g nitrogen compound | | |
| | Thus peptides etc. remaining in beer | | |
| | = 0.036 x 6.25 = | 0.225 | 2.4 |
| | c ... N-compounds precipitated as 'break' (total - assimilated - dissolved) | 0.08 | 0.9 |
| N | 'Ash' content of wort solids | 0.20 | 2.1 |
| | a ... 'ash' assimilated by yeast | | |
| O | 'Ash' content of yeast solids = 9% | | |
| | But 0.35 g yeast solids produced/100 ml | | |
| | Hence uptake by yeast of 'ash' | | |
| | + 0.09 x 0.35 = | 0.03 | 0.3 |
| P | b ... 'ash' residual in beer | 0.17 | 1.8 |
| Q | Other materials | 0.07 | 0.8 |
| | Balance unaccounted for | 0.03 | 0.3 |

| SUMMARY | g/100 ml wort | | % wort solids | |
|---|---|---|---|---|
| Fermented sugars (as disaccharide) | | 5.28 | | 56.26 |
| Unfermented carbohydrates | | 3.34 | | 35.64 |
| a ... assimilated | 0.176 | | 1.88 | |
| b ... residual | 3.17 | | 33.76 | |
| b1. - 'dextrins'= 25.72% | | | | |
| b2. - fermentable = 8.04% | | | | |
| Nitrogenous wort constituents | | 0.46 | | 4.9 |
| a ... assimilated | 0.15 | | 1.6 | |
| b ... residual | 0.225 | | 2.4 | |
| c ... precipitated | 0.08 | | 0.9 | |
| 'Ash' content of wort solids | | 0.20 | | 2.1 |
| a ... assimilated | 0.03 | | 0.3 | |
| b ... residual | 0.17 | | 1.8 | |
| Other materials | | 0.07 | | 0.8 |
| Balance unaccounted for | | 0.03 | | 0.3 |
| | | 9.38 | | 100.0 |

Appendix to wort fermentation mass-balance

(A) Spirit Indication of beer = 1000 x SG of distillate made up to original volume, deducted from SG of water i.e.

$1000\ (1.000 - 0.99479) = 5.21$ (48)

(B) Where K = solution factor (100 ml/g)

$K_o$ = solution factor at solvent SG = 4.00

$S_1$ = factor = - 0.488 for malt wort

g = SG solution

$g_o$ = SG solvent

$$K = K_o + S_1\ (g - g_o)$$

$$K = 4.00 - 0.488\ (1.038 - 1.000)$$ (79)

(C) There is a mixture of sugars present in brewers wort:-

| Reference (55) | % total carbohydrates | glucose units/molecule |
|---|---|---|
| Monosaccharides | 11.3 | 1 |
| Disaccharides | 50.2 | 2 |
| Trisaccharides | 13.6 | 3 |
| Dextrins | 24.9 | non-fermentable |

This table shows that the average degree of polymerisation in the carbohydrates fermented is 2.0 (hexose units per molecule). Therefore the formula for a disaccharide must be used in the stoichiometric equation to describe the fermentation of brewers wort.

(D) Thus: $C_{12}H_{22}O_{11} + H_2O \xrightarrow{\text{hydrolysis}} 2\,C_6H_{12}O_6$

$$2\,C_6H_{12}O_6 \xrightarrow{\text{fermentation}} 4\,CO_2 + 4\,C_2H_5OH \quad (108)$$

Net: $C_{12}H_{22}O_{11} + H_2O \longrightarrow 4\,CO_2 + 4\,C_2H_5OH$

$$100\text{ g} + 4.71\text{ g} \longrightarrow 51.2\text{ g} + 53.6\text{ g}$$

(E) Wort preparation mass-balance indicated that the carbohydrate content of wort solids was 92%. Hall et al (90) showed that for malt wort, carbohydrate % of wort solids as found = 91.8%. For worts including 10% of low-nitrogen wort syrup it is to be expected that this figure would be slightly higher. Cook (96) and MacWilliam (23) also report carbohydrate contents in the range 90-92% of wort solids for malt worts.

(F) It has been shown that:

Yeast growth in CF = 4.95 lb/brl

Yeast growth in CCV = 4.15 lb/brl

Both these figures are considered to be slight underestimates and an abitary intermediate figure of 4.65 lb/brl has been selected for the purposes of the general mass-balance.

(G) Yeast dry weight determined after drying 18 hrs at 105°C.

(H) For a yeast containing 45% of solids as carbon, Harrison (109) found a polyhexose content of 46% and lipids + sterols 2%. The yeasts studied here had carbon contents of 44-46% of solids.

(I) A measure of the relative proportions of fermentable and unfermentable carbohydrates is obtained by consideration of the AL. At the AL there remain only unfermentable carbohydrates such as isomaltose, maltotetraose, and higher oligosaccharides. A

→

carbohydrate balance of an attenuation limit fermentation therefore reveals the amount of unfermentable carbohydrate, and the additional carbohydrate remaining at the end of the brewery fermentation is residual fermentable carbohydrate.

Attenuation-limit fermentation

Basis

| | | |
|---|---|---|
| RBK bitter OG 1037.35 AG = AL | = | 5.47 |
| Apparent ° fermented 37.35 - 5.47 | = | 31.88 |
| 31.88 ° ≡ 25.973 fermented + 5.907 SI | | |
| Actual ° fermented | = | 25.97 ° |
| RG = 1037.35 - 25.97 | = | 11.38 |
| Alcohol content (SI 5.907) | + | 3.25 % w/w |

Fermented sugars

| | g/100 ml | % wort solids |
|---|---|---|
| Alcohol content of beer = 3.25% w/w at SG 5.47 or 1000/1005.47 x 3.25 = 3.23 % w/v | | |
| Disaccharide required to produce 3.23 g alcohol = 3.23/53.6 x 100 | 6.03 | 64.30 |
| Unfermented carbohydrates 8.62 - 6.03 | 2.59 | 27.60 |
| Carbohydrates assimilated by yeast | 0.176 | 1.88 |
| Residual = unfermentable carbohydrate | = 2.413 | 25.72 |

Residual carbohydrates in AG 9.33 ° fermentation

| | | |
|---|---|---|
| Residual carbohydrates in AG 9.33 ° fermentation | 3.1 | 33.76 |
| Residual carbohydrates in AG=AL=5.47 ° fermentation (= dextrins + isomaltose etc.) | 2.413 | 25.72 |
| Hence fermentable sugars remaining in beer after AG 9.33 ° fermentation | 0.754 | 8.04 |

(J) Carbohydrates were given as 91.9% of solids, hence non-carbohydrate = 100 - 91.9 = 8.1 % of solids.

(K) Wort preparation mass-balance indicated that the nitrogen-compound content of wort solids was 5.0 %.

Wort analyses have shown an average protein content (N x 6.25) of 0.462 g/100 ml = 4.86% of solids in 1.0378° SG wort.

It is generally found (110) that the nitrogen spectrum does not vary among all-malt worts, and MacWilliam (23) revealed this to be, for British pale ale worts:-

17% protein of MW > 4,000

30 - 40% dipeptides to polypeptides

30% amino acids + some peptides

10% purines etc.

The absolute amount of nitrogenous material increases with higher malt nitrogen content, however, (110). MacWilliam (23) showed a range of 4-5% of solids as nitrogenous material; Harris (96) found 5-6%.

(L) Analysis of the yeast produced in the continuous fermentation of RBK wort gave nitrogen content 6.9% of yeast solids. Thus nitrogen-compound content = 6.25 x 6.9% = 43%.

(M) The control grists described in Part 1 were similar to the RBK grist in composition and the average nitrogen content of beers produced from them was 0.036 g/100 ml of 1.0378 ° OG beer. Nitrogen content of beer produced in CF from RBK grist was similar ( Table 49, p. 201)

(N) Wort-preparation mass-balance indicated that the inorganic content of wort solids was 2.2 %. MacWilliam (23) found that ash contents were most frequently quoted in the range 1.5 - 2.0 % of wort solids. Our analyses have shown that the ash content of 1.0378 ° SG wort is 2.1%.

(O) Yeast ash content was determined after twice washing the yeast in water, drying at 105°C and ashing at 600°C for 2 hr. Ash content = 9% ± 1, of dry weight. Harrison (109) also quotes 9% ash content; Nordstrom (111) 8%.

(P) Beer ash content was also determined after evaporating the beer, drying at 105°C and ashing at 600°C. Ash content = 0.174 g/100 ml, 1.83% of wort solids.

(Q) The wort preparation mass-balance indicated that 'other' materials accounted for 0.7% of wort solids. Our analyses of RBK wort showed a tannin content of 0.38% of wort solids (on average) but other materials were not determined.

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## Discussion

The fate of wort carbohydrates in normal brewery fermentation was shown in the mass-balance. In terms of total carbohydrate this was as follows:-

| | |
|---|---|
| Fermented sugars (as disaccharide) | 61.3% |
| Sugars assimilated by yeast | 2.1% |
| Residual fermentable sugars | 8.7% |
| Residual unfermentable carbohydrate | 28.1% |

The effects of differences in yeast production on carbohydrate utilisation are therefore relatively modest: yeast production in CCV and CF fermentations account for only ~ 1.9% and ~ 2.3% of total carbohydrate respectively, a difference of ~ 0.4% of total carbohydrate. Since assimilable sugars are also fermentable by S. cerevisiae (112 ) the proportion of fermented carbohydrate is increased from 61.1% in CF to 61.5% in CCV fermentation on consideration of yeast growth. Loss of alcohol through stripping by the carbon dioxide evolved was not considered in the mass-balance since it is small and variable. Gas chromatography measurements and calculations based on an ideal system, Appendix 1 p. 202 showed that the loss of alcohol was equivalent to ≯ 0.1% of carbohydrate, ≯ 0.2% of fermented sugars. Since sucrose, fructose and glucose disappear early in fermentation, residual fermentable sugars are largely maltotriose and a little maltose (113 - 115). Other than the sugars fermented, residual unfermentable carbohydrate represents by far the largest category and is thus of greatest economic importance as will be discussed in Section 2b). This 'dextrin' fraction includes a small proportion (< 5 mg/100 ml beer) of unfermentable sugars such as xylose and arabinose derived from gums, and isomaltose nigerose and maltulose, but is mostly composed of branched and linear glucose polymers together with some pentosan polymers ( 23) ( 99) (116).

It has been assumed in the mass balance that alcoholic fermentation alone accounts for the fermented wort carbohydrates. Carbohydrate is, however, diverted along other metabolic pathways leading to production of carbon dioxide, glycerol, organic acids and esters. It has been suggested (117) that ester formation in continuous fermentation is higher, due to the presence of ethanol throughout fermentation. Acetaldehyde may be expected to accumulate due to its slower rate of reduction to ethanol in CF (117) (118). Our results, however, show levels of fusel alcohols, esters, organic acids and other components no higher than in batch fermentation:-

MINOR COMPONENTS IN CONTINUOUSLY FERMENTED BEER - TYPICAL RESULTS
(expressed as p.p.m. in beer)

| Component | ML1 | ML2 | ML1 | ML2 | L 1 | L 2 | Normal |
|---|---|---|---|---|---|---|---|
| Dimethyl Sulphide | <0.001 | <<0.001 | 0.002 | <<0.001 | 0.001 | <0.001 | <0.003 |
| iso-Amyl Acetate | 0.5 | 1.5 | 0.75 | 2 | 0.5 | 0.75 | 0.75-1.5 |
| Ethyl Acetate | 5 | 14 | 8 | 15 | 8 | 8 | 8 -15 |
| Diacetyl | <<0.1 | 0.1 | 0.1 | 0.1 | 0.1 | TRACE | <0.3 |
| Acetaldehyde | trace | 1 | 1 | 1 | <1 | <1 | <3 |

The alternative pathways that operate include the tricarboxylic acid (TCA) cycle and the hexose monophosphate (HMP) pathway. If carbohydrate is metabolised extensively in such ways then the mass-balance described would need revision.

In CF the supply of oxygen dissolved in the inflowing wort to CFV1 was no more than 10 p.p.m. which is also the upper limit for CCV fermentation. This is equivalent to 0.0312 m.moles $O_2$/100 ml wort. Now the net equation for aerobic respiration is:-

$$C_6H_{12}O_6 \quad + \quad 6O_2 \longrightarrow 6\,CO_2 = 6H_2O$$

0.0052 m.moles    0.312 m.moles

Thus aerobic respiration could account for no more than 0.94 mg hexose/ 100 ml wort, or 0.01% of total carbohydrate. The TCA cycle could rely on alternatives such as glycerol formation for the supply of hydrogen acceptors, however, and 0.2 g of glycerol per 100 ml beer is usually found (119 - 121), but this might partly be due to yeast growth which is also oxidative, oxidations being counterbalanced by the formation of glycerol (111). Also, in yeast the TCA cycle is found to be several times more active than the HMP pathway (122). In brewery fermentation systems therefore, only small quantities of carbohydrate could be diverted to carbon dioxide production via TCA and HMP pathways. The role of oxygen as a terminal electron acceptor is therefore small; oxygen appears to act as a growth factor perhaps due to enzyme inductions caused by the molecular oxygen (123). This is confirmed by the finding that in batch fermentation increases in initial oxygen concentration above 9 ppm, the level to which CCV wort was oxygenated, have little effect on yeast yield (124). Yeast production is reduced if the initial wort oxygen concentration is much less than this.

Yeast production can be controlled by variation of the initial wort oxygen-concentration. In the Tower system of continuous fermentation, for example, Ault found that a wort oxygen-level of 6 ppm was necessary to promote normal growth of 3.9 lb/brl (115). Ricketts and Hough (125) found that yeast grew slowly and rate of beer production was slow when a two-vessel CF system was operated under virtually anaerobic conditions, but at low rates of wort aeration yeast crops and alcohol production were similar to batch fermentation. In continuous fermentation systems therefore, normal rates of beer production and reduced production of yeast can be coupled only through 're-using' the yeast by partial closure of the system. This can be achieved by recycling the yeast from the effluent beer of an otherwise open system, or by restricting the escape of the yeast from the fermenter.

The effect of extremely high levels of oxygenation is shown in a carbon-balance of fermentation, Appendix 2 p 208, to increase the proportion of carbohydrate-carbon assimilated by yeast from 7% to 14% at the expense of alcohol production. Larger increases can be achieved, as in bakers yeast production, by incremental feeding of the carbohydrate source.

Factors other than wort oxygen-concentration influence the amount of yeast production. Hough (126) found that increased yeast concentration led to a decrease in yeast production and thus less carbohydrate was diverted to cell growth. In laboratory fermentations using Watney 118 yeast in RBK wort this was confirmed (Fig 33 p. 199) at high pitching rates but not at the rates of 2.2-2.8 g/100 ml used in production-scale CCV fermentations.

The optimum temperature for growth of Saccharomyces cerevisiae is ~ 28°C (127), but the maximum fermentation coefficient is at a higher temperature (128). Thus at higher temperatures there is relatively less cell production. Lie (123) suggested that this effect is probably due to temperature increased instability of energy-rich compounds leading to higher wastage of energy during cell production or maintenance. In the CF system described here, the normal temperature range of fermentation is 21-24°C whereas in batch fermentation the maximum temperature is 21°C. The higher level of yeast production in CF is contrary to this temperature effect, although the level of wort oxygenation is no higher in batch fermentation. A more likely explanation therefore is that in unstirred batch fermentations growth is diffusion limited.

Gilliland (129) found considerable strain variation in yeast yield. The yield varied from 9.2-17.5 g/l. A single yeast strain was used in the CF and CCV fermentations described here, although a chain-forming yeast is used in some traditional batch fermentations. Laboratory studies of the two yeasts showed no strain variation in yeast yield for shake-flask fermentations of oxygenated wort incubated in an atmosphere of carbon dioxide. There are many pitfalls to avoid when measuring yeast production. Thorpe and Brown (130) relied on a haemocytometer cell count in their work which was used in the revision of the Original Gravity Tables ( 49) in current use. This method can be criticised not only on grounds of the high level of variance inherent in the method (131) but also on account of the variation of cell size during fermentation (123) (132). Dry-weight determination following removal of trub from the sample is a more accurate method (133), but more time-consuming. Capillary centrifugation, following trub removal, is a satisfactory rapid method but should be calibrated against dry-weight determinations for each yeast strain since there are differences in voidage depending on flocculence and cell size. Furthermore there may be differences in the chemical composition of yeast solids. The cell nitrogen content rises whereas the level of cell carbohydrates falls during the later stages of fermentation (123) largely due to glycogen catabolism. Thus dry-weight determinations should be supplemented by chemical determinations of carbon, nitrogen etc.

Conclusions

1. In the mass-balance of RBK wort fermentation the fate of the major wort constituents is traced into the beer.

2. Only 61.3% of carbohydrates were fermented, but the evidence is that only a small amount of these follow biochemical pathways other than alcoholic fermentation.

3. The 'dextrin' fraction was as large as 28.1% of total carbohydrate, its contribution to beer quality therefore deserves critical assessment,

as does the use of residual fermentable sugars (8.7% of total carbohydrate) to provide sweetness in beer.

4. Loss of alcohol by 'evaporation' was equivalent to only ~ 0.1% of total carbohydrate.

5. Only small differences in terms of fermentation mass-balance exist between CF and CCV systems of fermentation, the greatest resulting from the increased amount of yeast production in the open CF system. Partial closure, as operated in the Tower fermentation system, could be achieved in the CF system e.g. by use of yeast recycle, thus enabling a reduction of yeast growth. Yeast growth is also influenced by oxygen supply, temperature, and pitching rate.

6. A laboratory method for the gravimetric determination of the carbon-dioxide produced during fermentation, under aerobic or anaerobic conditions, is described.

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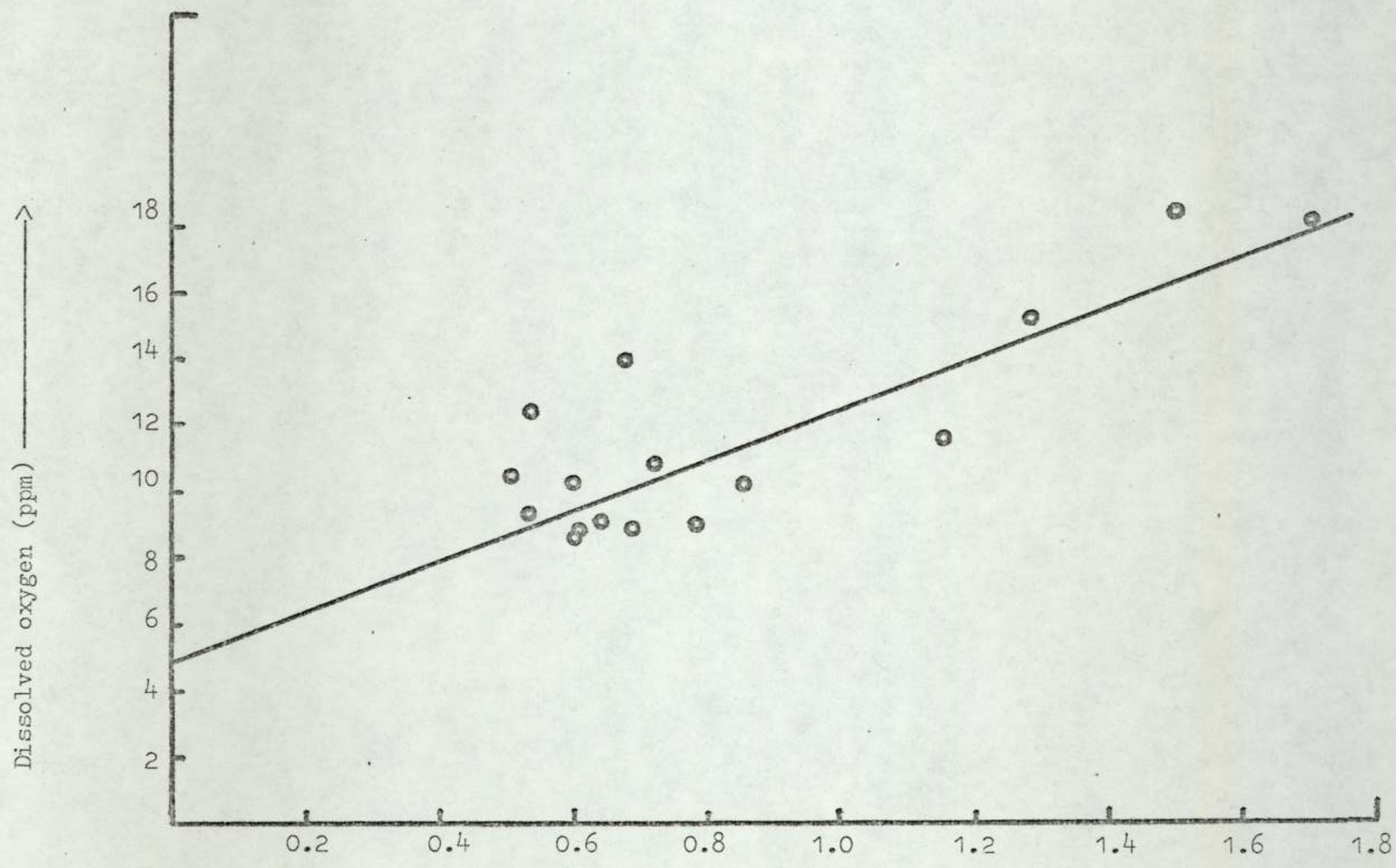



Fig. 31 Dissolved oxygen in CF wort

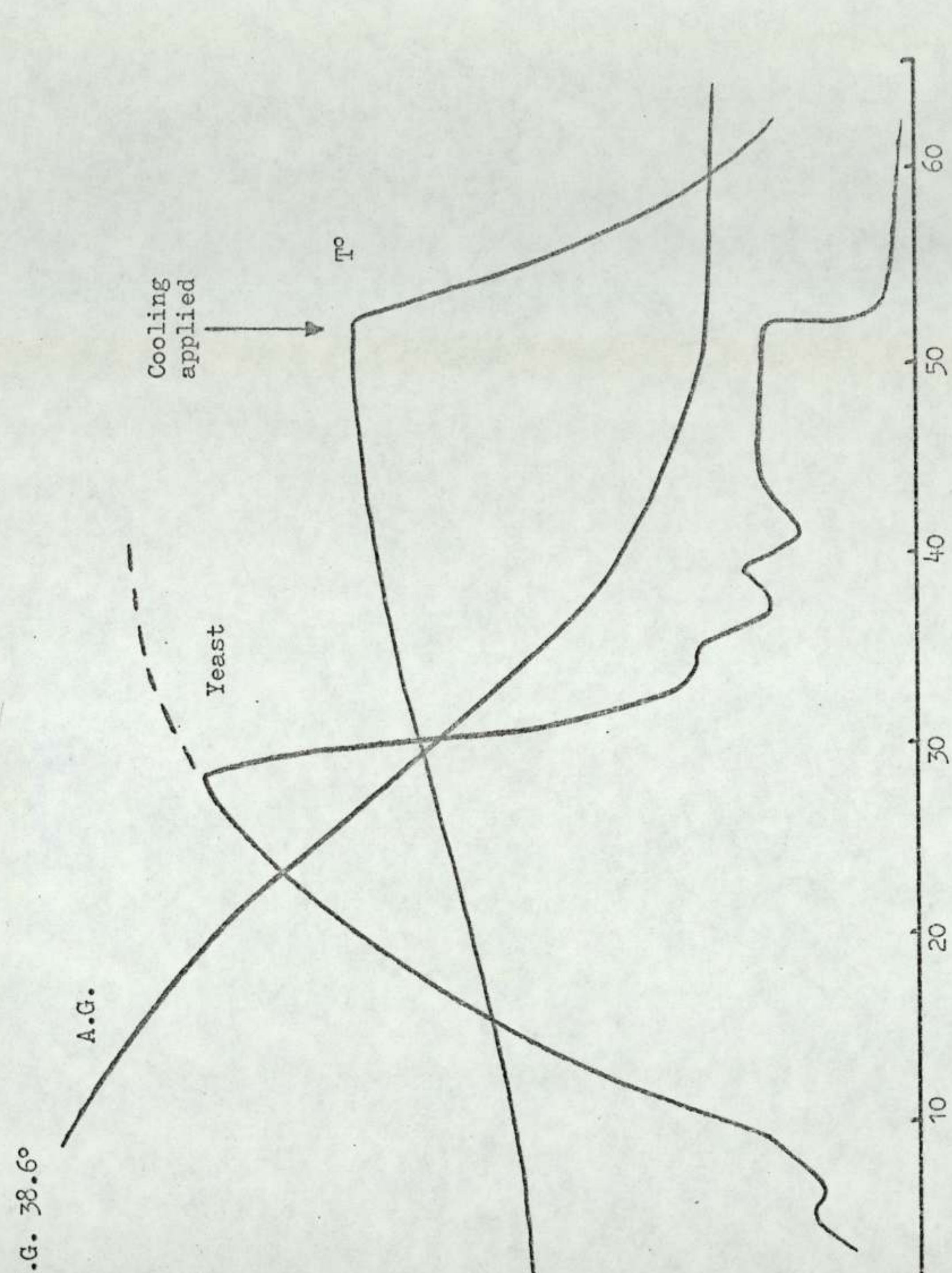



Fig. 32 Yeast growth in batch fermentation

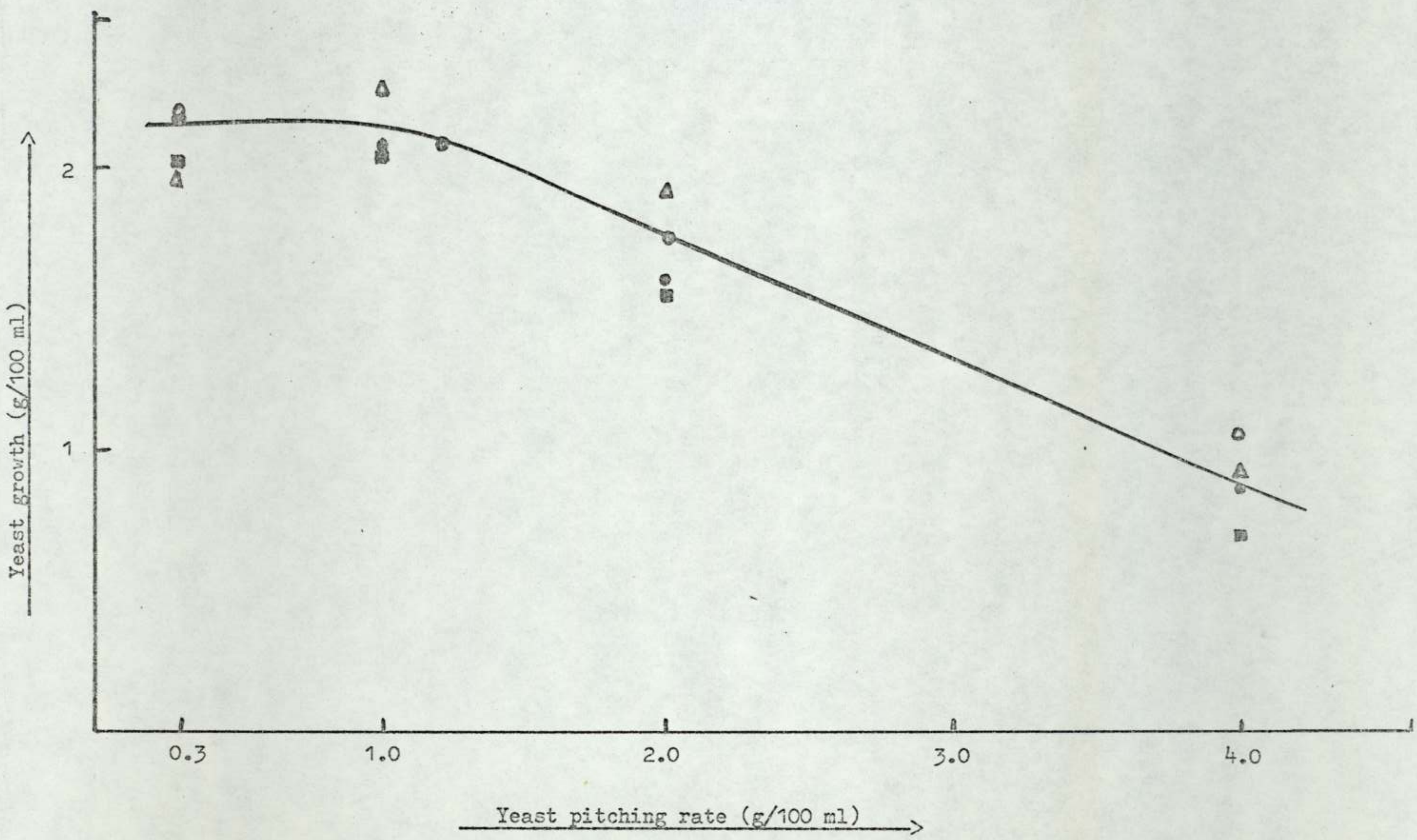



Fig. 33 Effect of pitching rate on yeast production during fermentation

## TABLE 48

### OXYGEN DISSOLVED IN WORT SUPPLYING CFV1

| | |
|---|---|
| Oxygen injection rate (ml/min) | 128 |
| Wort flow rate (brl/hr) | 12 |
| Hence oxygen supply rate (l/brl) | 0.64 |
| (ppm) | 5.2 |
| Dissolved oxygen concentration (ppm) | 10.0 |
| Hence oxygen pick-up during wort storage (ppm) | 4.8 |

## TABLE 49

(see over, p. 201)

## TABLE 50

### YEAST CONCENTRATIONS IN CFV1 AND CFV2 SAMPLES

| | C F V 1 | | | C F V 2 | | |
|---|---|---|---|---|---|---|
| Production Line | Yeast lb pressed weight/brl* | Standard Deviation | % Deviation | Yeast lb pressed weight/brl* | Standard Deviation | % Deviation |
| ML1 | 4.52 | 0.50 | 11 | 5.18 | 0.93 | 18 |
| ML2 | 4.65 | 0.50 | 11 | 4.85 | 0.75 | 15 |
| D1 | 4.32 | 0.45 | 10 | 6.59 | 0.67 | 10 |

* Determined by capillary centrifugation. Dry weight determinations following vacuum filtration of samples and drying 20hrs/105°C showed that the solids content of the pressed yeast was 27%.

TABLE 49

ANALYSES OF WORT AND BEER IN PRODUCTION-SCALE CF

| | Wort | CFV 1 | CFV 2 | YSV |
|---|---|---|---|---|
| Apparent Gravity (AG) | 37.8° | 22.0° | 9.3° | 9.3° |
| Residual Gravity (RG) | 37.8° | 24.3° | 14.6° | 14.6° |
| Alcohol (% w/w) | 0.0 | 1.6 | 2.9 | 2.9 |
| Total-N (mg/100 ml) * | 70 | 50 | 40 | 40 |
| $\alpha$-$NH_2$-N (mg/100 ml) * | 15 | 3.7 | 2.5 | 2.5 |
| Fermentable sugars (g/100 ml) | 6.05 | ~ 3.0 ** | 0.75 ** | 0.75 ** |
| Oxygen concn. (ppm) | 9.5 | 0.0 | 0.0 | 0.0 |
| Temperature (°C) | 7 | 21 | 24 | 5-7 |
| pH | 5.0 | 4.0 | 3.9 | 3.9 |
| Yeast concn. (lb/brl) | 0 | 4.5 | 5.0 | 0.2 (effluent) |
| Vessel capacity (brl) | - | 160 | 160 | 87 |

* Estimated from the data of Bishop (107).

** Mostly maltose + maltotriose in CFV 1,

maltotriose in CFV 2 (115)

Appendix 1 - to Section 2a

## ALCOHOL AND WATER-VAPOUR LOSSES IN FERMENTATION

### 1. Theoretical loss calculated for an ideal system

Basis  100 g wort solids of a 1037.8° OG wort fermented to 1008.5° AG. Previous calculations showed that in such a fermentation 58.3 g sugar (disaccharide) are fermented:-

$$58.3 \text{ g disaccharide} \longrightarrow 29.85 \text{ g } CO_2 + 31.25 \text{ g alcohol}$$

### Batch fermentation

During batch fermentation there is an initial lag period followed by yeast growth and fermentation of sugars. When the fermenting wort becomes saturated with carbon dioxide (approx 1 volume) subsequent $CO_2$ produced is liberated in bubbles which rise from the base of the FV carrying some alcohol and water vapour.

$CO_2$ remaining in beer ($\sim$ 1 vol.) = 1.92 g

Hence $CO_2$ evolved = 29.85 - 1.92 = 27.93 = 0.635 g moles

The carbon dioxide evolved strips water and alcohol from the fermenting beer depending on their vapour pressures.

31.25 g alcohol ≡ 0.679 g moles

950 g water ≡ 52.78 g moles

But the alcohol is produced throughout fermentation and the mean concentration during stripping is approx 2/3 the final alcohol concentration.

Average stripping alcohol content = 2/3 x 0.679 = 0.453 g moles.

The temperature range of batch fermentation is 17-22°C, but since most of the $CO_2$ stripping occurs in the higher range of temperature, 21°C may be taken as the mean stripping temperature.

Vapour pressure of pure ethanol at 21°C = 45 mm Hg

" " " " water at 21°C = 19 mm Hg

But the V.P. exerted is directly related to the molar concentrations of the dissolved gases.

| | | |
|---|---|---|
| Alcohol | 0.68 g moles | 0.013 molefractions |
| Water | 52.78 g moles | 0.987 molefractions |
| Total | 53.46 g moles | 1.000 molefractions |

Now V.P. exerted = molefractions x V.P. pure

Alcohol = 0.013 x 45 = 0.57 mm Hg

Water = 0.987 x 19 = 18.8 mm Hg

The amount of alcohol/water stripped is related to the partial pressure exerted by the alcohol/water, and the amount of $CO_2$ evolved:

Moles alcohol/water stripped = moles $CO_2$ x partial pressure of alcohol/water

<u>Water</u>

Partial pressure = 18.8/760 = 2.47% of total pressure

0.635 x 2.47%= 0.0157 g mole water

<u>0.282 g water</u>

<u>Alcohol</u>

Partial pressure = 0.57/760 = 0.075% of total pressure

0.635 x 0.075% = 0.000477 g mole alcohol

= <u>0.0219 g alcohol</u>

Continuous fermentation

Observation of normal running conditions shows that approximately ½ of the alcohol is produced in the first fermentation vessel (CFV1) at 21°C, and ½ in CFV2 at 23.5°C.

a) CFV1

| | | |
|---|---|---|
| Carbon dioxide produced = 29.85/2 | = | 14.92 g |
| $CO_2$ remaining in beer (~ 1 vol) | = | 1.92 g |
| Hence $CO_2$ evolved | = | 13.00 g |
| | = | 0.296 g moles |
| Alcohol present 31.25/2 = 15.625g | = | 0.340 g moles |
| Water | = | 52.78 g moles |
| | | 53.12 |

Alcohol mole fractions 0.0064

Water mole fractions 0.9936

V.P. due to alcohol 45 x mole fractions = 0.288 mm

V.P. due to water 19 x mole fractions = 18.88 mm

Water

Partial pressure = 18.88/760 = 2.48%

0.296 x 2.48% = 0.00734 g mole water

= 0.132 g water

Alcohol

Partial pressure = 0.288/760 = 0.000379 %

0.2955 x 0.000379% = 0.000112 g mole alcohol

= 0.00515 g alcohol

b) CFV2

Beer in and out is saturated with $CO_2$, hence no allowance for $CO_2$ remaining in beer.

Hence $CO_2$ evolved = 14.925 g = 0.339 g moles

| | | |
|---|---|---|
| Alcohol present | 0.679 g moles | = 0.0127 m. fractions |
| Water | 52.78 g moles | = 0.987 m. fractions |

V.P. pure alcohol at 23.5°C = 53 mm

V.P. pure water at 23.5°C = 22 mm

V.P. due to alcohol = 53 x 0.0127 = 0.673 mm Hg

water = 22 x 0.9873 = 21.72 mm Hg

Water

Partial pressure 21.72/760 = 2.86

2.86% x 0.339 = 0.00969 g moles

= 0.1745 g water

Alcohol

Partial pressure 0.673/760 = 0.0886%

0.0886% x 0.339 = 0.000300 g moles

= 0.0138 g alcohol

2. Determination of alcohol loss in CF by gas chromatography

Sample collection. Samples of the effluent gas from CF were collected in a 500-ml glass container fitted with a silicone-rubber septum.

Gas chromatography. 3 µl of n-propyl alcohol (internal standard) were injected into the sample container which was then held for 10 min. at 28°C. Then 5 ml of the gas mixture was withdrawn through the septum into a warm syringe and injected into the gas chromatograph.

Separation: An F&M Model 400 chromatograph fitted with an FID detector was used. The glass column (1m x 1/4 in O.D.) was packed with 10% Carbowax 1540 on 60/80 mesh Chromosorb W. The column was held at 50°C with an $N_2$-carrier flow-rate of 40 ml/min.

Quantitation: The amount of ethanol present in the sample was calculated from the ratio of the ethanol-peak height to that of the internal standard. The calibration graph was prepared by injecting known volumes of ethanol into the sample container filled with carbon dioxide. Since the approximate total volume of gas produced per unit weight of alcohol formed was known (see calculation for ideal system) it was thus possible to calculate the percentage loss of alcohol. The results are shown in the summary below.

## 3. Summary

The alcohol and water-vapour losses in batch (enclosed) and continuous fermentation are summarised below.

| | Water loss | | Alcohol loss | | |
|---|---|---|---|---|---|
| | g/100 g wort solids | % of total water | g/100g wort solids | % of total alcohol | g.disaccharide equivalent |
| 1. Batch fermentation (if ideal system) | 0.282 | 0.028 | 0.0219 | 0.070 | 0.041 |
| Continuous fermentation (if ideal system) | | | | | |
| CFV1 | 0.132 | | 0.0052 | | |
| CFV2 | 0.175 | | 0.0138 | | |
| 1. Total | 0.307 | 0.031 | 0.0190 | 0.061 | 0.035 |
| 2. Total (determined by GC) | | Run 1 | 0.050 | 0.16 | 0.092 |
| | CF | Run 2 | 0.068 | 0.22 | 0.126 |
| | | Run 3 | 0.056 | 0.18 | 0.103 |
| | Av. total loss = | | 0.059 | 0.19 | 0.109 |

Vapour loss of alcohol during fermentation is therefore ~ 3-times greater than the amount calculated for an ideal system, but nevertheless accounts for only ~ 0.2% of the total alcohol produced during fermentation.

Appendix 2 - to Section 2a

## CARBON-BALANCE OF FERMENTATION

It is predictable from consideration of the stoichiometric equation for wort fermentation (p. 187 note D) that the amount of carbon lost in carbon dioxide would be half that taken up into alcohol. A laboratory method was devised to test this prediction and to examine the effect of excessive aeration or oxygenation on the carbon-balance.

The apparatus used is shown in Fig. 34. 150-ml aerated wort, OG 1.040° is pitched with 0.3 g pressed Watney 118 yeast and fermented in a stirred culture vessel at 20-22°C with 0.1% MS antifoam. Nitrogen, air, or oxygen is continuously bubbled through the fermenting liquid, a condenser restricting loss of alcohol or water vapour from the culture vessel. The effluent gas is dried through sulphuric acid and phosphorus pentoxide, the carbon dioxide being absorbed by Carbosorb (6-12 mesh, BDH) in two absorption tubes; these were first equilibrated using water in the culture vessel. The culture vessel was sterilised chemically before use.

Yeast produced was dried and carbon-content analysed. Carbon dioxide was determined by the gravimetric method described. Wort carbohydrate-content was assessed as in the fermentation mass-balance, and carbohydrate-carbon content assessed from the formula $(C_6H_{10}O_5)n$. Residual carbohydrate-carbon in the beer was assessed in a similar way. Acidity was measured, and if greater than 0.15%, the experiment was abandoned.

The results are shown below:-

| Gas stream | % of carbohydrate-carbon utilised | % of utilised carbon | | |
|---|---|---|---|---|
| | | Alcohol | $CO_2$ | Yeast |
| N2 | 65 | 64 | 32 | 7 |
| Air | 74 | 55 | 34 | 11 |
| Air | 71 | 52 | 34 | 12 |
| $O_2$ | 61 | 55 | 30 | 14 |

Thus, under anaerobic conditions the amount of carbon-dioxide-carbon was half the amount of alcohol-carbon. Under aerobic conditions extra yeast growth accounted for the reduction in the amount of alcohol-carbon.

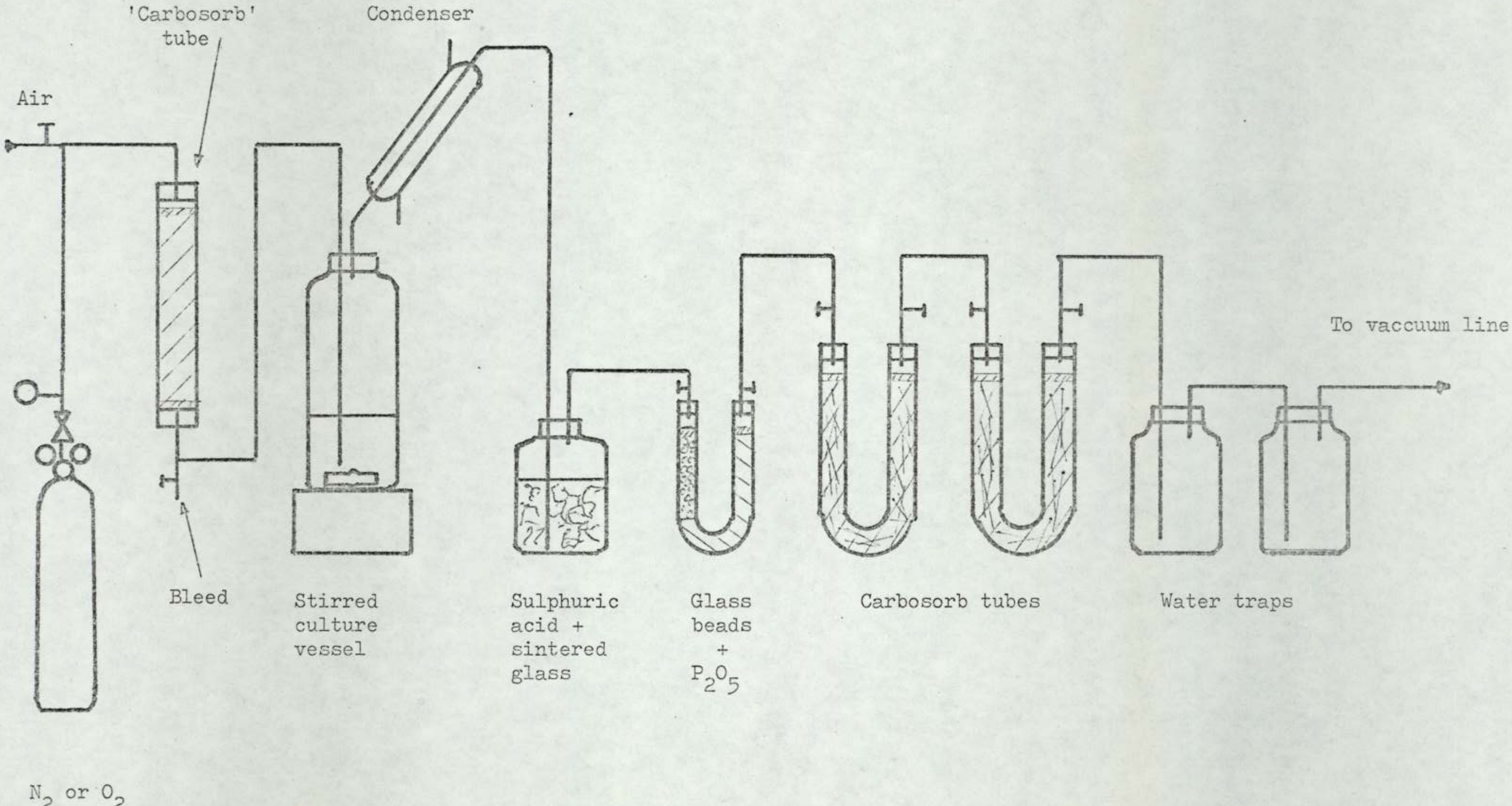



Figure 34 Apparatus for gravimetric determination of $CO_2$ produced during fermentation

## Section 2b) Economics of fermentation

### Excise Duty

As was mentioned in the Preface to Part 2, Excise Duty is levied on the wort collected in the FV. An allowance of 6% is made in respect of subsequent processing losses. This may seem to be a surprising high level of loss, but has recently been confirmed by Søltoft (134) for a modern lager brewery. The percentage loss, in terms of alcohol, in various process stages between the beer in the fermenting vessel and beer in bottle have been calculated from Søltoft's figures and are reproduced below. The net loss of 6.75% indicates that the Excise allowance of 6% would be insufficient to cover the true processing losses of a similar brewery sited in the U.K.

BEER PROCESSING LOSSES

| | % of alcohol produced in fermentation | | |
|---|---|---|---|
| | gain | loss | net |
| Fermentation | 100.00 | | 100.00 |
| Evaporation | | 0.08 | 99.92 |
| Pitching yeast | 0.43 | | |
| Starting tank sludge | | 0.04 | |
| Yeast crop | | 1.30 | |
| Storage tank bottoms | | 0.43 | |
| Stabilising tank bottoms | | 0.70 | |
| Sludge going to waste | | 0.12 | |
| Beer loss at transfers in cellars | | 1.38 | |
| Beer going into filter | | | 96.38 |
| Beer loss at filtration | | 1.38 | |
| Spent kieselguhr | | 0.25 | |
| Beer loss at filling | | 0.10 | |

| | % of alcohol produced in fermentation | | |
|---|---|---|---|
| | gain | loss | net |
| Beer loss at fobbing up | | 0.29 | |
| Beer loss at pasteurisation | | 0.93 | |
| Beer loss at rinsing of plant | | 0.18 | |
| Bottled beer | | | 93.26 |
| Net loss | | 6.75 | |

after Søltoft (134)

For RBK beer the losses are smaller since most of the beer is racked into keg and is thus not subject to the tunnel-pasteurisation losses which are so high for bottled beer. Beer losses are notoriously difficult to measure. In the fermentation mass-balance it was noted that the OG of finished beer was lower than the OG of the wort, due to ~ 1% dilution during processing. Furthermore there is some variation in the volume of beer racked into each keg. For the purposes of this cost evaluation therefore, the Excise allowance of 6% has been accepted as representing the true loss of RBK wort during processing. Thus 1.064 brls of SG 1.0378 wort in FV are required to produce 1.000 brl of OG 1.0378 RBK beer in keg.

The Excise Duty payable is calculated by reference to Clark's Duty Tables (135):

Basis: 1.064 brl of SG 1.0378 wort in FV

less 6% allowance = 1.000 chargeable bulk brls.

Standard brls. = 1.000 x 37/55 = 0.673 standard brls.

| | | |
|---|---|---|
| Basic charge on 0.6727 standard brls | = | £ 16.280 |
| Rebate on bulk barrelage | = | £ 2.825 |
| Hence Net Duty payable | = | £ 13.455 |

Carbohydrate raw material cost

The raw material cost of the RBK grist described in Section 1a) may be calculated in the same way as that of the experimental grists, Section 1b) Appendix p 170. It is shown below that the cost of 1 brewers pound of RBK extract realised in the FV is 10.15 p:-

RBK grist Utilisation of malt grist = 96.92 %

| % malt grist (weight basis) | % malt grist (extract basis) | Cost per available brewers lb (p) | Extract cost in:- 1.0 brewers lb available (p) | 0.896 brewers lb available (p) | 0.896 brewers lb realised (p) | Material |
|---|---|---|---|---|---|---|
| 89.68 | 90.0 | 10.1 | 9.09 | 8.15 | 8.41 | Pale Malt |
| 5.56 | 4.9 | 11.9 | 0.55 | 0.49 | 0.51 | Crystal Malt |
| 4.76 | 5.1 | 8.2 | 0.42 | 0.38 | 0.39 | Flaked maize |
| | | | | | | |
| Extract cost from malt grist | | | 10.06 p | | | |
| Wort syrup cost per 0.104 brewers lb | | | | 0.84 | 0.84 | Wort syrup |
| Cost of 1 brewers lb — available | | | | 9.86 p | | |
| Cost of 1 brewers lb — realised | | | | | 10.15 p | |

Thus the grist cost of the 1.064 brls of 1.0378° SG wort required in FV to produce 1 brl RBK beer in container may be calculated:

Brewers pounds = Brls x 360 (SG - 1)

= 1.064 x 360 (1.0378 - 1)

= 14.48

But raw material cost of 1 brewers pound in FV = 10.15 p

Hence cost of 14.48 brewers lb = <u>£ 1.470</u>

Total grist + duty cost

| | |
|---|---|
| Excise Duty | £ 13.455 |
| Grist | £ 1.470 |
| Total | £ 14.925 |

Thus the solids in duty-paid wort are ~ 10 times more valuable than the carbohydrate raw materials from which they are derived. The rewards from improved utilisation of wort components during fermentation are therefore ten times greater than those resulting from a similar improvement in grist extraction or reduction in grist costs.

Consider a typical large brewery group, producing the equivalent of 4 m. brl/annum of beer OG 1037.8°. The grist plus duty cost of the wort required to produce this beer would therefore be 4 m x £ 14.925 = £ 59.7 m./a. (1971). By apportioning this cost to wort components in proportion to their contribution to extract, the financial scope of modifications in wort composition can be seen. From the fermentation mass-balance the following costs (in 1971) are calculated:-

| | % wort solids | | Carbohydrate raw material + duty cost for production of 4 m brls OG 1.0378 REK beer in 1971 (£ m.) | |
|---|---|---|---|---|
| Fermented sugars (as disaccharide) | | 56.26 | | 33.6 |
| Unfermented carbohydrates | | 35.64 | | 21.3 |
| a ... assimilated | 1.88 | | 1.1 | |
| b ... residual | 33.76 | | 20.2 | |
| b1 - 'dextrins' | (25.72) | | 15.4 | |
| b2 - fermentable | ( 8.04) | | 4.8 | |
| Nitrogenous constituents | | 4.9 | | 2.9 |
| a ... assimilated | 1.6 | | 0.95 | |
| b ... residual | 2.4 | | 1.43 | |
| c ... precipitated | 0.9 | | 0.54 | |
| 'Ash' content | | 2.1 | | 1.26 |
| a ... assimilated | 0.3 | | 0.18 | |
| b ... residual | 1.8 | | 1.08 | |
| Other materials + balance unaccounted for | | 1.1 | | 0.66 |
| Total | | 100 | | 59.7 |

Two of the more remarkable features of this cost analysis are that £15 .4 m./a. is spent on 'dextrins' which contribute little to beer flavour and nothing to alcohol content, and that the annual cost of feeding the yeast is £ 2.23 m./a. There is therefore considerable scope for making financial savings and this will be discussed by considering in turn each of the major wort components.

Yeast growth

The grist + duty cost of wort components assimilated by yeast was shown to be £ 2.23 m./a. in 1971 for a 4 m. brl/a. brewery in which the average rate of yeast production is 4.65 lb/brl. On this basis the difference between the cost of yeast growth in CCV and CF fermentation of RBK wort can be calculated:-

| Fermentation system | Yeast growth lb/brl) | Grist + duty cost of assimilated components (£/a.) 1971 |
|---|---|---|
| CF | 4.95 | £ 2,370,000 |
| CCV | 4.15 | £ 1,990,000 |
| Difference | 0.80 | £ 380,000 |

It has been mentioned that the reduced amount of yeast growth in batch CCV fermentation probably results from diffusion limitation of growth, and that in the CF system yeast growth could be reduced by partial closure, obtained by yeast recycle, or by reducing yeast concentration in the outflowing beer through sedimentaion in a still zone at the overflow point. Partial closure increases yeast concentration and this is known to result in a reduction of yeast production, as does the use of high pitching rates in batch fermentation (126) (133). Yeast growth could also be limited by reducing the supply of oxygen, but control would need to be very precise as the growth response factor is high in the range of limiting oxygen supply (124). A further possibility exists in reducing the supply of wort assimilable nitrogen, since this is normally a growth limiting factor in CF. This might be achieved by using high proportions of low nitrogen-yielding materials in the grist. Reduction of yeast growth should not be too drastic since beer flavour is impaired at extremely low rates of yeast production (115).

Yeast production may also be limited by using a high proportion of pure carbohydrate adjunct. In a grist comprising 50% malt wort and 50% adjunct it was found (110) that cell reproduction was slower and less extensive than in fermentation of all malt wort. The rate of utilisation of carbohydrate in the second phase of increase in cell mass was slow and relatively little of the carbohydrate was incorporated into yeast dry matter. Rate of fermentation was slower than in all-malt brews, however, and it is unlikely that the beer produced would bear acceptable resemblance to conventionally produced beer.

## Dextrins

Malt starch is made up of 26-27% amylose and 73-74% amylopectin (96). Amylose can be entirely degraded by malt enzymes to fermentable sugars. The average chain length in malt starch amylopectin is 18 and thus assuming all amylopectin is degraded to a limit dextrin containing 5 glucose units, the theoretical amount of fermentable sugar formed from starch may be calculated (96).

| | |
|---|---|
| 26 - 27% from amylose | = 26.5% |
| 13/18 x 73-74% from amylopectin | = 53.1% |
| | 79.6% |

Harris thus showed that 79.6% of the original starch may be converted to fermentable sugars by malt enzymes, although this is not usually achieved, the gap being ~ 10-15%.

A barley variety has recently been found whose starch contains as much as 44% amylose (136). If the other important properties of this or similar new varieties are acceptable to farmers and maltsters then much more highly fermentable worts could be produced. A slightly more fermentable wort may be obtained by reduction of the mashing temperature (137) or of course by the use of a highly fermentable syrup adjunct.

An alternative approach is to add enzymes such as amyloglucosidase, pullulanase or fungal α-amylase to the mash or wort. Pullulanase is assumed to hydrolyse the α-1,6 linkages in any such structure which has a sequence of 4 glucose units linked α-1,4: α-1,6 : α-1,4 (138). In conjunction with β-amylase, which hydrolyse α-1,4 links, the use of pullulanase can result in the complete conversion of amylopectin to maltose and glucose (139). Fungal α-amylase hydrolyses α-1,4 linkages to form maltose and is thus also used to improve wort fermentability (140). Amyloglucosidase hydrolyses both α-1,4 and α-1,6 linkages and is capable of hydrolysing gelatinised starch completely to glucose. Such enzymes when used during mashing or fermentation result in a high yield of alcohol, but when added to beer after removal of yeast the sugars produced by the enzyme action increase sweetness (141).

The contribution of 'dextrins' to beer quality is not clearly understood, but there are some indications that it is not very great. Dextrins appear to have little effect on beer texture or astringency but may impart a malty, sweet or fruity flavour (142). Taylor (143) reported that the powder produced by separating small quantities of the dextrins from wort and beer was tasteless. He tempered this finding with the comment that some foreign beers, although almost devoid of fermentable sugars, had a full and almost sweet taste.

The inclusion of dextrins in RBK wort was shown to cost £ 15,400,000 per annum (1971) for a production of 4 m brl/a. This is a high price to pay for wort components of such dubious value. Large savings could be made by reducing the dextrin content of beer whilst maintaining its alcohol content but the reduction in OG involved could provoke adverse publicity in the Press or from consumer associations. Conversely there might be a considerable market for a 'starch-reduced' beer of equal or even elevated alcoholic content in comparison with its present counterpart.

Residual fermentable sugars

In an unprimed beer the residual fermentable sugars are almost exclusively maltose and maltotriose (113-5). Their role in beer is generally accepted as being the provision of sweetness. A measure of the quantity of these sugars in beer is given by the AG-AL value. Maltose, however, is less sweet than sucrose and much less sweet than fructose as table below reveals. Maltotriose is probably even less sweet than maltose, as the higher saccharides are in general less sweet than the simple sugars.

RELATIVE SWEETNESS OF SUGARS

| Reference | (144) | (145) | (146) | (147) | (148) |
|---|---|---|---|---|---|
| fructose | 173 | 175 | 173.3 | 110 | 114 |
| invert sugar | 130 | 130 | - | 93 | 65 |
| sucrose | 100 | 100 | 100 | 100 | 100 |
| glucose | 74 | 70 | 74.3 | 74 | 69 |
| galactose | 32 | - | - | - | |
| maltose | 32 | 30 | - | 33 | 46 |
| lactose | 16 | 15 | - | 16 | 39 |

In the fermentation mass-balance it was shown that the residual fermentable sugars in RBK beer were equivalent to 8% of wort solids. If the beer were fermented to the limit (AL), equal sweetness could subsequently be provided as sucrose primings equivalent to only 3-4% of wort solids. The materials plus duty cost of the 4-5% of wort solids 'saved' in this way would be up to £ 3,000,000 per annum (1971) on the basis of 4 m. brl/a. production. An even greater advantage would result from the use of fructose in primings which might be made possible by use of glucose isomerase.

Non-carbohydrate wort-constituents

Nitrogen compounds residual in beer include important flavour components but also high molecular weight (HMW) proteins which can add little to beer flavour and lead to the development of haze. Furthermore, a proportion of the proteins, upon which Duty has been paid, are precipitated during fermentation as the pH falls and alcohol content rises. A reduction in the HMW protein content of wort would therefore be economically attractive but the content of assimilable nitrogen could not be allowed to fall, particularly for continuous fermentation in which nitrogen is limiting. A proteolytic enzyme treatment of the wort might be developed, releasing assimilable nitrogen from the HMW protein, but there would be problems to overcome if reliance was made on the foam stabilising properties of wort proteins in the finished beer.

Mineral salts, tannins, glycerol, esters, organic acids and other materials make a disproportionately high contribution to beer flavour, thus justifying their place in beer.

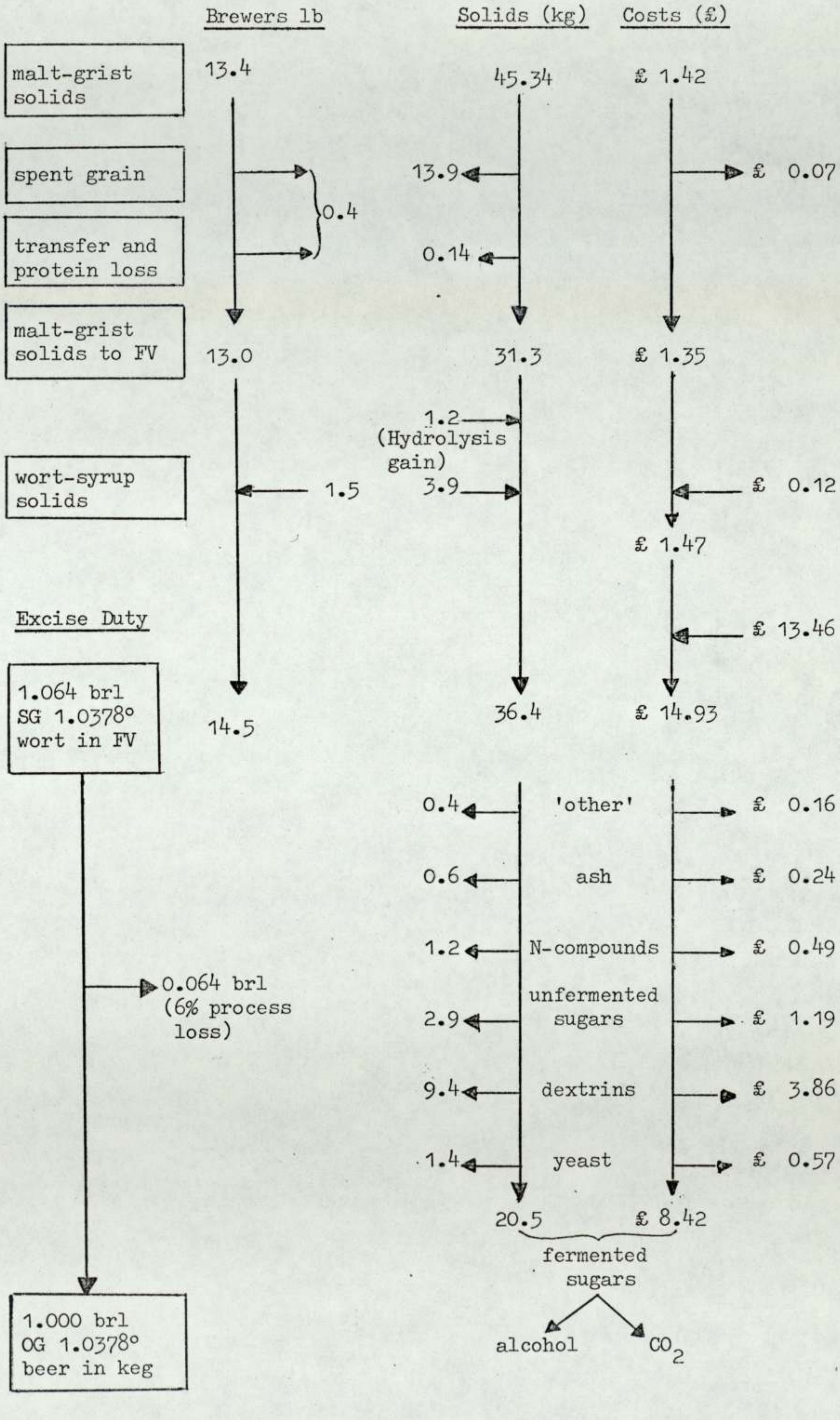
SECTION 3. OVERALL MASS-BALANCE AND ECONOMICS

The mass-balance and carbohydrate raw-material cost of wort prepared from RBK-grist were considered in Section 1. Fermentation mass-balance and its raw-material plus Excise-Duty costs were considered in Section 2. These data are related in Table 51, p. 222, which summarises the overall mass-balance, available-extract balance and raw-material plus duty costs of the brewing of 1 brl. of keg beer from RBK-grist.

Reports of the National Board for Prices and Incomes in 1966 (2) and 1969 (149) show that Excise Duty accounts for 60-62% of the wholesale selling price of beer, excluding profits and purchased beer, and brewing materials 9% (carbohydrate raw materials ~ 6.5%, hops etc. ~ 2.5%). The remaining proportion of ~ 30% of beer wholesale-price comprises production and distribution labour: ~ 10%, packaging: 2%, depreciation: 3%, advertising + administration + selling costs etc.: 15%.

Raw material and duty costs therefore account for ~ 70% of wholesale beer price thus justifying the detailed consideration given to them in this work. Carbohydrate raw-material cost, 6.5%, is thus important and it has been shown that considerable savings can be made by using a proportion of wort syrup or unmalted adjunct in the grist. Excise Duty, 60-62%, is of overwhelming importance, however, and it has been seen that even marginal improvements in the utilisation of duty-paid wort solids, or reduction of losses, are of great financial importance to the brewer.

TABLE 51. MASS-BALANCE AND ECONOMICS OF RBK-BEER PRODUCTION (1971)



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COLLABORATION

Routine analyses of raw materials, wort and beer, were done by Courage Ltd. and Watney Mann Ltd. laboratory staff. Analyses of sugars were done by Mr. G.E. Otter of Courage Ltd.; alcohol and other volatiles were determined by Mr. R. Marshall of Watney Mann Ltd. Help was given by Spillers Technological Research Station staff in the amino-acid analyses and viscography. The pilot-brewery was designed in committee of which the author was a member but most credit for the design is due to Mr. J. Hampton, Engineering Manager of Courage (Eastern) Ltd.

No part of the work was done in collaboration except in so far as stated above or where specifically so described in the text.

This work has not been submitted for any other award.

Dated: October 18th 1971

Signed: A.P. Maule

A.P. Maule

# PUBLICATIONS

The work described here led to the publication of two papers.

1. Maule, A.P., & Greenshields, R.N., Process Biochem., (1970) 5 (2), 39.

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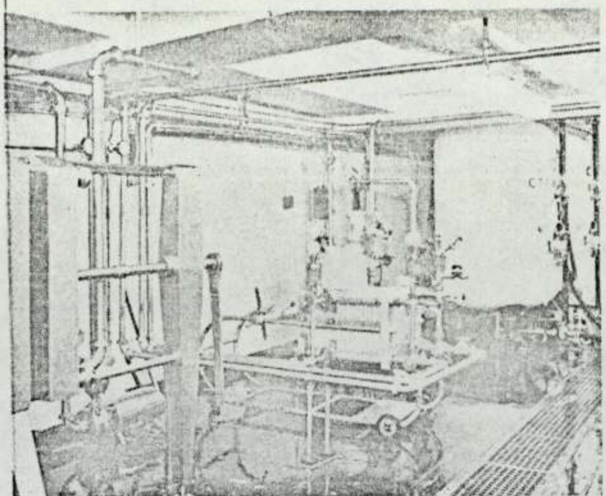
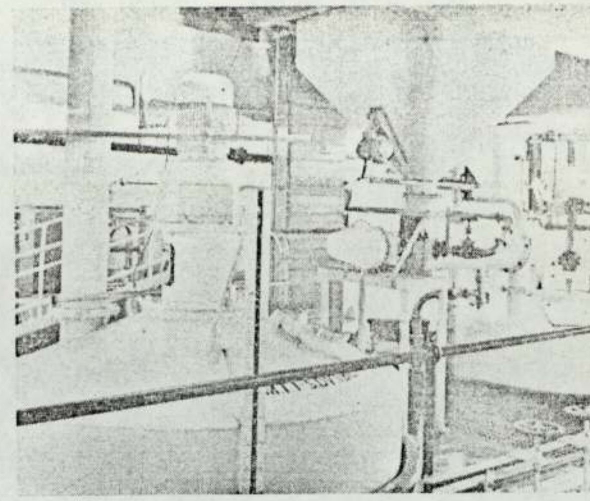


*Chilling and filtration plant*



*Copper and mash tun*

# Technology of Brewing Carbohydrates


## A. P. Maule* M.Sc., and R. N. Greenshields† Ph.D., F.R.I.C., M.I.Biol.


IN the Horace Brown Memorial Lecture of 1967,[1] Mendlik drew attention to the problem of the relation between scientist and production manager. The brewing scientist often devoted himself to research work of a fundamental and, possibly, abstruse nature, whereas the brewing manager gave his attention to the control of production. Kreiss[2] had said, 'For if research is to play its proper part in an industry, its results must be made understandable to those whose business it is to apply them; thus liaison between the fundamental scientist and the producer assumes extreme significance, and high qualities are required from those who will contribute to it, and also from those who will devise schemes of experimental work which will help forward the development of the industry'. There is thus a need for those who are conversant with scientific research and who at the same time are familiar with the needs and the language of the practical brewer.

Hall[3] also drew attention to the gulf between advances in the laboratory and implementation in the brewery. At a time when so many new and often revolutionary materials were being offered by suppliers, it was important not only to develop analytical methods for these materials, but to assess their influence on the brewing process and the quality of the finished beer. The most suitable method was to brew beer with them. Full-scale trials, however, can lead to process problems so it is wise to screen the materials in the laboratory and then evaluate fully in a pilot-brewery.

### Raw materials

The importance of raw material costs, particularly those of carbohydrates, is not being overlooked by most large brewery groups, since there is scope for a considerable financial saving. One company have recently built a pilot-brewery of 30 brl capacity, providing for two lines of 15 brl for comparison at the fermentation stage. It is also fully equipped with conditioning, carbonation, cold storage and filtration equipment which is important in the production of a commercially acceptable beer. Facilities for racking into keg, cask and bottle are provided and the laboratory and engineering facilities of a large brewery are available. The newer carbohydrate materials are an important field of study and have a high priority in the experimental programme.

Curtis[4] pointed out that the contribution of raw materials to the overall cost of beer was often considered to be small in comparison with other overheads. Consequently, economies had been sought in other fields and some brewers were reluctant to adopt processes aimed solely at economy in the use of raw materials. Nevertheless, reference to the National Board for Prices and Incomes report, 1966,[5] entitled 'Costs, prices and profits in the Brewing Industry', reveals that raw materials costs are as much as a quarter of the total, excluding excise duty. From information supplied by brewer's producing about half of the country's total output of beer, the Board estimated the figures shown in Table 1 for 1966.

The magnitude of brewing materials cost, and hence the scope for economies, can best be illustrated by reference to an example. In 1968, the cost of carbohydrate raw materials for a brewery producing, say, 1 million brl of beer at an original gravity of 1,037 (equivalent to 13·3 brewer's lb/brl) would have been about £1 million (see Table 2).

Annual cost of extract = annual barrelage × extract × cost/unit extract

$$= £\frac{1{,}000{,}000 \times 13{\cdot}33 \times 1{\cdot}47}{20}$$

$$= £977{,}000 \text{ p.a.}$$

A 5% reduction of cost by use of cheaper carbohydrate materials and increased utilisation of hops would lead to a saving of about £50,000 p.a. Savings of this order may be made by using wheat flour in the grist. In Table 3, the cost of carbohydrate materials for a conventional grist at 1969 prices is compared with that of grists including 10 or 20% wheat flour as malt replacement. Using 10% wheat flour, the cost reduction is $1{\cdot}514 - 1{\cdot}467 = 0{\cdot}047$s./brewer's lb extract. The overall percentage cost reduction is thus $0{\cdot}047/1{\cdot}514 = 3{\cdot}1\%$. Similarly, using 20% wheat flour the saving would amount to 6·1%. In a brewery producing 1 million brl p.a., the savings would be about: 10% wheat flour—£31,000 p.a.; 20% wheat flour—£62,000 p.a.

The relative prices of brewing materials do vary from year to year, but these figures illustrate that there is considerable scope for cost reduction in carbohydrate materials.

Certain commercial wort syrups now available show potential in that the carbohydrate spectrum is similar to that of conventional hopped wort, but the extract cost is often lower, as shown in Table 4. These two examples, a wheat flour and a wort syrup, have been selected to underline the importance of development work in this field, particularly in pilot-scale brewing trials with full technological and economic evaluation of results. There are, of course, many other raw materials worthy of attention, including wheat and barley flours, syrups derived by different processes from various cereals and hop extracts. Review articles that have recently appeared are those of Harris[6,7] and Macey[8] who reviewed various carbohydrate sources with particular emphasis on process economics; Imrie[9,10] who discussed the use of wort syrups derived enzymically from wheat and barley; and Russell-Eggitt[11] on wheat flour in brewing.

### Wheat and barley flours

The diastatic activity of malt is usually more than sufficient to convert the malt starch itself.[12] Thus, other starch-rich materials may be used although their own diastatic activity may be negligible. Adjuncts commonly used are flaked maize, maize grits, flaked barley and, more recently, wheat flour. Rice is currently too expensive in this country to merit consideration.

Wheat flour is generally cheaper than other adjuncts and is readily available both as 'straight run' flour and air-classified low-nitrogen flour. Straight run flours are derived from wheat low in nitrogen content and are prepared by the normal milling process in which bran and germ are removed and the endosperm reduced to a fine powder. Air classification can be used to eliminate some of the protein debris. A particle size range of 17–35 $\mu$ is usually selected,[11] thus eliminating the

**Table 1. Cost of brewing, bottling and distribution**

| | (%) |
|---|---|
| Brewing materials .. .. | 23 |
| Bottling materials .. .. | 5 |
| Production labour .. .. | 17 |
| Distribution labour .. .. | 11 |
| Other costs .. .. | 37 |
| Depreciation .. .. | 7 |
| Total .. .. | 100 |

Excise duty represented 62% of the wholesale selling price, excluding profits and purchased beer.

finer debris and aggregates of starch granules held in a proteinaceous matrix. The nitrogen content may be reduced from 1·5–1·6% (on dry) to 1·2% (on dry) by air classification. Barley flour is also available and is often combined with some husk to assist run-off from the mash tun. Both wheat and undried barley are unsuitable for milling on the conventional malt mills, used in most breweries. It has been found that such mills tend to flatten rather than break the hard unmodified barley.[13] Martin[14] had some success in crushing barley in a malt mill by passing the material twice through the mill, but the utilisation of this material was 10% lower than usual. Elsewhere,[15] successive passages through a roll mill have been used, giving a finely-powdered endosperm but leaving the husk relatively undamaged. Wheat and barley may be hammer-milled. In one process,[16] feed barley is hammer-milled, and subsequently milled in a roll mill and in another[17] dressed grain is screened and fed into a hammer mill which reduces its size until the 'meal' is forced through a $\frac{1}{16}$-in or $\frac{3}{16}$-in aperture screen for wheat and barley, respectively. A considerable amount of barley husk remains relatively undamaged which helps to improve drainage in the mash tun. Steeped barley can be milled in a differential roll mill if the moisture content is between 35 and 40%.[18] Below 35%, the grain is too hard, but above 40% an adhesive slurry if formed. In breweries equipped with wet-mills, it is advantageous to steep the barley for 1 hr before grinding. Wheat flour has a bulk density of 35 lb/ft$^3$,[11] much higher than malt, so that storage costs are lower. Wheat flour is not free-flowing, as is malt, so hopper sides must be inclined more steeply and vibrators used. However, flour is very readily conveyed pneumatically and thus transferred from bulk tanks to brewer's bins.

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**Table 2. Materials' costs of a typical grist in 1968**

| *Material* | *% of total extract* | *Approximate cost (s./brewer's lb)* | *Contribution to cost of 1 brewer's lb grist extract (s.)* |
|---|---|---|---|
| Pale malt .. .. | 76·0 | 1·46 | 1·11 |
| Coloured malt .. | 4·0 | 1·80 | 0·07 |
| Maize .. .. | 7·5 | 1·30 | 0·10 |
| Sugar .. .. | 12·5 | 1·52 | 0·19 |
| | | | Total 1·47 |

**Table 3. Raw materials' costs of wheat flour grists and normal grist—1969**

| *Grist* | *% grist extract basis* | | *Brewery extract* | *Cost (s./brewer's lb)* | *Cost for 1 brewer's lb of grist (s.)* | |
|---|---|---|---|---|---|---|
| *Normal grist* | | | | | | |
| Malt .. .. | 78·7 | | 98·3 lb/qr | 1·53 | 1·204 | |
| Maize .. .. | 8·8 | | 103·0 lb/qr | 1·36 | 0·12 | |
| Sugar .. .. | 12·5 | | 31·0 lb/cwt | 1·52 | 0·19 | |
| | Cost of grist extract (s./lb) | | | | 1·514 | |
| *Wheat flour grists* | *10% WF* | *20% WF* | | | *10% WF* | *20% WF* |
| Malt .. .. | 68·7 | 58·7 | 98·3 lb/qr | 1·53 | 1·05 | 0·898 |
| Maize .. .. | 8·8 | | 103·0 lb/qr | 1·36 | 0·12 | 0·12 |
| Sugar .. .. | 12·5 | | 31·0 lb/cwt | 1·52 | 0·19 | 0·19 |
| Wheat flour (WF) | 10·0 | 20·0 | 103·0 lb/qr | 1·07 | 0·107 | 0·214 |
| | Cost of 10 and 20% flour grists extracts (s./lb) | | | | 1·467 | 1·422 |

**Table 5. Properties of wheat and barley flours**

| *Material* | *Straight-run wheat flour* | *Air-classified wheat flour* | *Ground barley* | *Milled pale malt* |
|---|---|---|---|---|
| Extract (as is) brewer's (lb/qr) | | | | |
| Laboratory .. .. | 107–108 | 110–112 | 70–87 | 101–102 |
| Brewery .. .. | 104–106 | 107 | 75–85 | 98–99 |
| Utilisation (%) .. .. | 96–99 | 96–99 | 89–92 | 97–98 |
| Total carbohydrate (as glucose % dry) .. | 91–96 | 99 | 71 | 75 |
| Starch .. .. .. (as glucose % dry) | 82–94 | 94 | 61–63 | 64 |
| Enzyme activity | Mainly β-amylase | Mainly β-amylase | Proteolytic enzyme inhibitors + β-amylase | Largely α-amylolytic |
| Price (s./brewer's lb) .. | 1·0–1·1 | 1·1 | 1·0 | 1·5 |
| *Particle size (%) (sieve apertures)* | | | *Various e.g.* | *Various e.g.* |
| > 1·5 mm .. .. | 0 | 0 | 17 | 40 |
| 0·15–1·5 mm .. .. | 0 | 0 | 61 | 50 |
| < 0·15 mm .. .. | 100 | 100 | 22 | 10 |
| Particle size (μ) .. | 0–150 | 17–35 | — | — |
| Nitrogen (% on dry) .. | 1·2–1·9 | 1·2 | 1·3–1·8 | 1·6 |

Table 6. Wheat and barley flour grists

| Material | % of grist in mash tun | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Pale malt | 65 | 55·5 | 75 | 46 | 29 | — | 67 | 67–75 |
| Green malt | — | — | — | 20 | 28 | 40 | — | — |
| Distiller's malt | — | — | — | 10 | 14 | 25 | — | — |
| Crystal malt | 6 | 6 | — | 4 | 3·5 | 6 | 5·5 | 5 |
| Wheat flour | 18·5 | 20 | — | 20 | 24 | 30 | 24 | 10–15 |
| Barley flour | 10·5 | 18·5 | 25 | — | — | — | — | 10–15 |
| Malt extract | — | — | — | 1 | 1 | — | 4 | — |
| Reference | 13 | 13 | 15 | 18 | 18 | 18 | 18 | 14 |

Table 7. Carbohydrate composition of traditional sweet worts

| | % of total carbohydrates | | | | | |
|---|---|---|---|---|---|---|
| Reference | 26 | 26 | 25 | 27 | Mean | |
| Fructose | 2·2 | 3·5 | 10·5 (Fructose + Dextrose) | 9·8 (Fructose + Dextrose) | 2·5 | 61·5 RFS (Fructose to Maltose) |
| Dextrose | 8·8 | 10·6 | | | 8·8 | |
| Sucrose | 4·7 | 5·6 | 6·5 | 5·2 | 5·5 | |
| Maltose | 49·6 | 41·4 | 42·3 | 45·3 | 44·7 | |
| Maltotriose | 14·0 | 12·1 | 14·0 | 14·5 | 13·6 | 13·6 SFS |
| Maltotetraose | 20·7 (Maltotetraose + Higher sugars) | 2·1 | 5·7 | 25·2 (Maltotetraose + Higher sugars) | 24·9 | 24·9 NFS |
| Higher sugars | | 24·7 | 21·0 | | | |

RFS—readily fermentable sugars SFS—slowly fermentable sugars NFS—non-fermentable sugars

Table 8. Effect of adding sucrose or invert solids on the carbohydrate composition of traditional sweet wort

| | Sweet wort ex-mash tun | | Copper wort | |
|---|---|---|---|---|
| | % total carbohydrate | % total solids | % total solids | % total carbohydrate |
| RFS | 61·5 | 56·6 | 49·5 + 12·5 = 62·0 | 66·7 |
| SFS | 13·6 | 12·5 | 11·0 | 11·8 |
| NFS | 24·9 | 22·9 | 20·0 | 21·5 |
| Other matter | — | 8·0 | 7·0 | — |

Table 9. Minor constituents of wort[26]

| | | |
|---|---|---|
| Free pentoses | Xylose<br>Arabinose<br>Ribose | 1·5 mg/100 ml wort<br>1·4 mg/100 ml wort<br>0·2 mg/100 ml wort |
| Disaccharides | Nigerose, maltulose<br>Isomaltose | Less than 0·2 mg/100 ml wort |
| Trisaccharides | Gluco-di-fructose | Less than 0·2 mg/100 ml wort |

Table 10. Wort syrup production[34]

| | A | B | C |
|---|---|---|---|
| Carbohydrate source | Maize or wheat starch | Barley | |
| Method | Controlled enzyme action | 'Foreign' enzymes | Green malt enzymes |
| Result | Syrups of specified carbohydrate proportions | Wort syrup | |

Some of the more important brewing properties of flours are compared with milled malt in Table 5. These figures are derived from various sources and are not strictly comparable, as much depends upon the material removed from the grain in the milling process. Wheat flour is normally used in admixture with malt in the mash tun at rates of up to 25% of the grist on extract basis. Wheat flour starch is readily attacked by normal diastase enzymes.[12] It has been emphasised[12,18] that the flour should be perfectly mixed with the malt, using a mechanical feeding device, and

**Table 4. Comparison of a wort syrup with conventional hopped wort**

| | *Syrup (%)* | *Wort (%)* |
|---|---|---|
| Readily fermentable sugars . . . . | 60–65 | 67 |
| Maltotriose . . | 10 | 12 |
| Maltotetraose and higher sugars . . | 25–30 | 21 |
| Approximate cost of extract (s./lb) . . | 1·3 | 1·5 |

kept evenly mixed up to the point of ejection into the tun. A Steele's masher is recommended[18] and a thick mash, 2–2·25 brl/qtr, preferred as this helps to prevent separation of the finer particles in the tun. If fine material is drawn down forming a layer above the mash tun plates, wort run-off is slowed and there is increased risk of reduced extraction. There is some indication[11] that a fairly coarse malt grind may help to prevent separation of fines in the tun.

In order to exceed a 25% wheat flour level in commercial-scale brewing, the use of a highly enzymic malt, such as green malt or six-row high-nitrogen distiller's malt, or the improvement of drainage from the tun by the use of wet-milling have been suggested as possible techniques.[19] On the laboratory or model brewery scale, levels of 50% wheat and raw barley have been used,[19] but raw barley was found to give inefficient extraction (89–92%) at this level, and at 70% gave low fermentability and incomplete extraction. Various grist compositions have been used, some of which are listed in Table 6.

The optimum mash temperature is commonly quoted as 150°F. The temperature of mashing liquor used (striking heat) should be a little higher than usual as there is lower heat of hydration when using wheat flour.[11] The use of wheat and barley flours, especially at high levels, tends to give reduced rates of run-off from the mash tun. Little detailed or truly comparable data has been published on this subject. Flour occupies very little space in the tun, as it packs into the interstices between the malt grits, thus increasing tun capacity but decreasing bed porosity.

There are several important effects of flour usage on wort and beer properties. The concentration of nitrogen in wort is decreased as compared with all-malt brews.[19,20] This effect is more pronounced with barley due to the presence of proteolytic enzyme inhibitors[20,21] particularly with respect to the amino-acid fraction. In wheat flour worts it appears[22] that the proportion of high-molecular-weight nitrogen compounds is increased, suggesting that the malt enzymes assist solubilisation of the wheat flour proteins without hydrolysing them to any extent. Conversely the free amino-acids content was generally reduced by 16–24%. It has been found that wheat flour contributes no amino-acids to the wort.[22,23]

Birtwistle[24] found that using 25% wheat flour, beer nitrogen and anthocyanogens were reduced by 20%, shelf-life was improved, wort fermentability was unchanged, bitterness and head retention were improved by 12% and 15%, respectively. The superior head retention has been attributed to the salt-precipitable protein contributed by the wheat flour.[22] Taste tests have shown little difference between wheat flour and traditional beers,[11] and such differences as were found were slight but not disadvantageous.



**Syrups and sugars**

The total solids content of copper wort in pale ale brews is made up of material derived by extraction of the grist in the mash tun and of carbohydrates added in the form of sugars and syrups to the copper. About 12·5% of the total extract of pale ale is traditionally derived from sugar added in the copper. The carbohydrate compositions of sweet worts ex-mash tun have been reviewed[10,25–27] and the data has been recalculated to a common total carbohydrate basis in Table 7. The effect of fermentable sugar addition at 12·5% total extract to the 'mean' sweet wort of Table 7 is shown in Table 8.

Brewer's yeast is unable to ferment maltotetraose or higher polymers;[26] thus the theoretical fermentability of the carbohydrate spectrum of a wort may be defined as: (sugars up to maltotriose)/(total carbohydrate). The theoretical fermentability of the hopped wort described in Table 8 would be: (66·7 + 11·8)/100 = 78·5%. This theoretical value is seldom attained; some maltotriose and maltose usually remains at the end of fermentation. In general, lower mashing temperatures and the more highly diastatic malts give the more fermentable worts. MacWilliam[26] mentions that small amounts of other sugars are also found in malt worts (Table 9).

During fermentation of wort by yeast, sugars disappear in the following order: sucrose, fructose, glucose, maltose. Maltotriose is slowly fermented and is thought to be important during 'secondary fermentation'.[28] Glucose and fructose are incorporated by facilitated diffusion.[29,30] Maltose and maltotriose require active transport and must be hydrolysed within the cell before fermentation can occur.[30] Thus the fermentation of maltose and maltotriose requires two permeases and maltase. These are inducible enzymes and are lost at the end of a batch process. For these reasons the sugars in wort are often classified in accordance with fermentability (Table 7). The sugars added to the copper are traditionally invert, or sucrose. The present cost of sucrose is lower than that of invert (cost of invert ≫ sucrose. Invert = 1·8s./brewer's lb, glucose syrup = 1·33s./brewer's lb), and a further cost advantage is realised by 'hydrolysis gain': solid sucrose yields 87·11 brewer's lb/224 lb, but this quantity yields 235·79 lb of invert solids (glucose and fructose) on hydrolysis. Extract derived from sucrose is slightly more expensive than mash tun extract on a materials basis, but this is offset by process savings in not having the expense of mashing. The advantages of adding sugar to the copper are: dilution of nitrogen compounds, increased throughput per brew and increased wort fermentability.

In addition to sucrose and invert-glucose, a range of syrups of complex

*An automatically-controlled solid bowl centrifuge used for primary mash separation*

(Courtesy of R. & W. Paul)

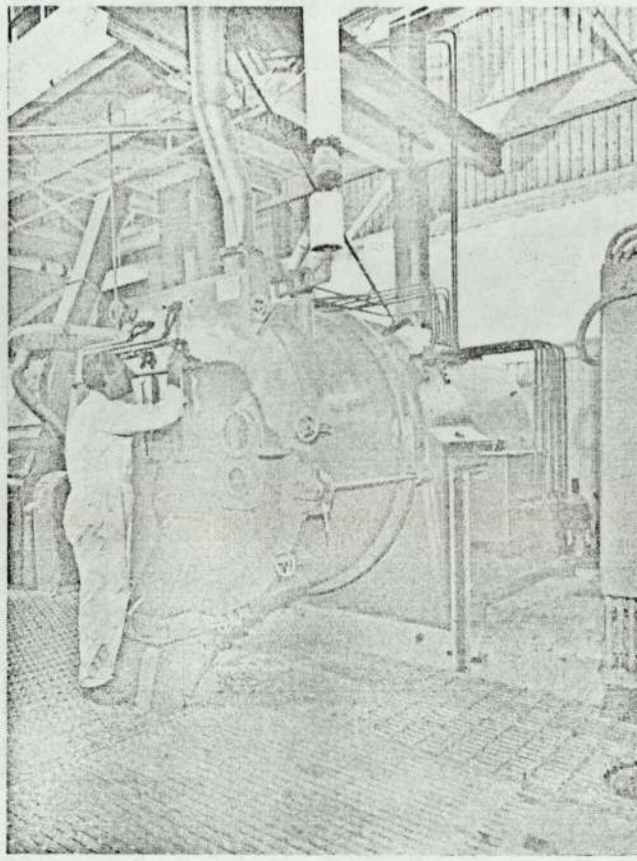


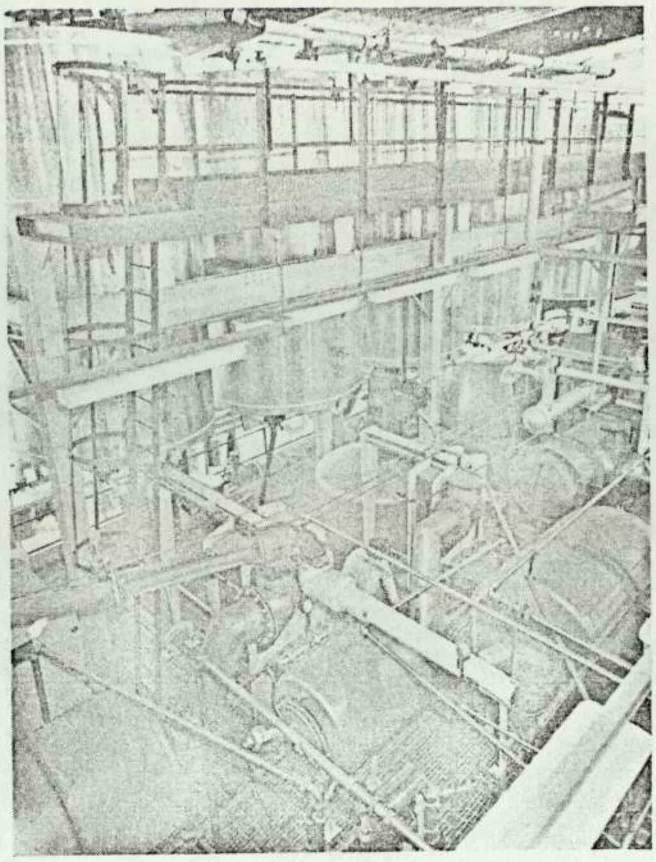
**Table 11. Enzymatic activities of barleys and malts**

| *Wieg*[36] | *Amylase ASBC* | *β-amylase* | *DP* | *Proteinase* |
|---|---|---|---|---|
| *Cambrinus* (malting) | | | | |
| Barley . . | 0 | 8·7 | 95 | Insufficient |
| Malt . . . . | 36·2 | 6·5 | 240 | Sufficient |
| *Impala* (feed)[36] | | | | |
| Barley . . | 0 | 7·5 | 100 | Insufficient |
| Malt . . . . | 38·6 | 9·7 | 290 | Sufficient |
| *MacLeod*[35] | *(after Klopper)* | | *(after Sandegren)* | |
| *Cambrinus* | | | | |
| Barley . . | 0 | 12 | — | 3 |
| Malt . . . . | 35 | 7 | — | 6 |
| *Delisa*[35] | | | | |
| Barley . . | 0 | 13 | — | 3 |
| Malt . . . . | 50 | 7 | — | 7 |

**Table 12. Preparation of wort syrup from barley using enzymes[35]**

| *Enzyme* | *Concentration* | *Stage* |
|---|---|---|
| Bacterial α-amylase . . | 0·5% | amylolysis |
| Bacterial proteinase . . | 0·5% | proteolysis |
| Highly-diastatic malt . . | 5–10% | saccharification |

carbohydrate spectra is now available. Moreover, the extract cost of these syrups is usually lower than that of invert-glucose, sucrose or mash tun grist. Some of these syrups may be considered not only for replacement of traditional copper sugars but also mash tun grist. Maize syrups may satisfactorily be used[31] as substitutes for invert sugar, leading to savings. They have also been used[6] in place of flaked maize, at 30% malt replacement, with no evidence of quality deterioration. Saletan[32] compared the use of 20% wheat flour on extract basis in the mash tun as against 20% wheat flour syrup added to the copper. The wheat flour syrup brew was satisfactory and gave a more highly-fermented beer. Harris[6] reported that beers brewed at 30% malt replacement by wheat syrups gave normal analyses and no evidence of



*Foreground shows APV triple-effect plate evaporator; bulk storage vessels for syrup in the background*
(Courtesy of R. & W. Paul)

**Table 13. Carbohydrate components of SG 1038·8 worts prepared from barley syrups (% of total carbohydrate)**

| | *Carbohydrate component* | | | | | |
|---|---|---|---|---|---|---|
| | *Dextrin* | *Maltotriose* | *Maltose* | *Glucose* | *Sucrose* | *Fructose* |
| Conventional pale ale wort | 21–25 | 13–15 | 45·5–49 | 8–11 | 2–5 | 1–4 |
| Barley syrup *A* Range of seven syrups | 24–27 | 13·5–15·5 | 46–50·5 | 7–9·5 | 0·5–2 | 0·5–2 |
| Barley syrup *B* Range of four syrups | 19–22 | 7·5–12 | 48–51 | 12–19 | 0·5–5·5 | 1–2 |

**Table 14. Nitrogenous components of SG 1038·8 worts prepared from barley syrups (mg/litre)**

| | *Total nitrogen* | *α-amino nitrogen* | *α-amino N (% of total N)* | *High mw N* | *High mw N (% of total N)* |
|---|---|---|---|---|---|
| Conventional pale ale wort | 650–750 | 140–191 | 21·5–25·5 | 154–225 | 25–28 |
| Barley syrup *A* | 618–680 | 150–168 | 20·8–24·9 | 170–250 | 25–36 |
| | (range of seven samples) | | | | |
| Barley syrup *B* | 840–960 | 170–220 | 20·0–23·0 | 145–260 | 16–30 |
| | (range of four samples) | | | | |

the adverse effects found with wheat flour.

Brewing trials have been made with syrup derived from unkilned malt.[33] At over 50% malt replacement the flavour of the beer produced was noticeably different though not necessarily inferior. Beer brewed from 100% unkilned malt syrup was hazy, but this haze could be removed by filtration and the finished beer was less susceptible to the development of 'non-biological' haze than traditional beer.

Imrie[9] listed barley, oats, wheat and rye as suitable raw materials for the production of wort substitutes. If malt were completely replaced the market for syrups would exceed 500,000 tons p.a.

The available tonnages in the UK in 1967 were: barley, 8,280,000; wheat, 7,879,000; oats, 1,234,000; and rye, 33,000 tons. Since oats and rye are not produced in sufficient quantity, barley and wheat are the most likely carbohydrate sources. Maize grown outside the UK is also available in large quantities.

Kirsop[31] broadly reviewed the different ways in which wort syrups may be produced and these are summarised in Table 10. Green malt syrup C could be expected to give wort similar to traditional wort except for differences due to the absence of the embryo activity present in malting. These differences could be greater in the barley syrup B as 'foreign' enzymes are used and these might also produce small amounts of undesirable substances.

Maize starch syrups may be produced by the acid/enzyme process to give high dextrose equivalent (de) syrups. The enzyme can be either α-amylolytic and dextrinising or α-glucamylase which converts starch direct to dextrose. The enzyme action may be stopped prematurely to give relatively low de syrups containing higher sugars and dextrins. The carbohydrate spectra of such syrups differ markedly from traditional wort. In the dual enzyme process the first stage may be effected by a bacterial α-amylase[6] followed by fungal α-amylase to give maltose-rich syrups similar in carbohydrate composition to wort. When glucamylase (amyloglucosidase) is used in the second stage, however, the product is a syrup rich in glucose. Wheat and maize starch syrups may be prepared in this way. Maize syrups are produced free of nitrogen but wheat starch syrups always contain nitrogenous constituents.

Although malted barley is the starting material for the normal brewing process, as MacLeod[35] said, '... there is nothing natural about the malting process'. Therefore the use of enzymes similar to those found in malt but obtained from other sources can be considered for the production of wort from barley. Unless barley is malted, there is a deficiency in amylolytic and proteolytic enzymes. In Table 11, the enzyme contents of several barleys and their malts are compared. The proteolytic activity of the raw grain is insufficient for the production of adequate supplies of amino-acids for yeast nutrition. The diastatic power of raw barley is poor, α-amylase activity being developed in the malting process. Furthermore, the β-amylase of barley is less extractable than that of malt.[35] When preparing worts, or syrups from barley it is therefore desirable to add α-amylase, proteolytic enzyme and β-amylase usually as malt. One process for the production of barley wort is reported[6] to use β-amylase as part of the enzyme system, in which a proteolytic stage is also included in the enzymic hydrolysis of raw barley. A proportion of malt may be used so that 10% malt, ground barley and enzymes are mixed in a mash mixer, a proteolytic stand is given and then the temperature is raised to promote amylolysis.

Clayton[35] described the methods used by one company to prepare wort syrup from barley using the enzyme system in Table 12.

Using coarsely-ground dehusked barley it was possible to use a mash tun, adding the bacterial enzymes at mashing-in. The proteolytic stand was 1·5 hr at 50–55°C. The mash temperature was raised to 75°C and held at this temperature for 15–30 min to allow starch liquefaction. It was then reduced to 63°C and the ground malt added for a saccharification period of 30–45 min at that temperature. Alternatively, the barley was finely ground and stirred tanks used for the enzyme stages, the syrup being recovered by centrifugation and filtration. Clayton went on to describe a more sophisticated process in which finely-ground dehusked barley was slurried together with the bacterial amylase and liquefied in a tubular reactor at 85–90°C, the reaction being continued in stirred vessels for a period of 2–5 hr. The liquefied slurry was then cooled and the pH adjusted; the malt and proteinase added to the medium in stirred jacketed saccharifying tanks. Finally, solids were removed in a filter press and the syrup concentrated by evaporation.

Rainbow[35] compared the properties of two different wort-syrups derived from raw barley, with conventional pale ale wort. The carbohydrate spectra were very similar (Table 13) and there were only relatively minor differences in the measured nitrogenous constituents (Table 14).

These results indicated that the high molecular weight (hmw) nitrogen figures were more variable in the barley syrup worts which might be reflected in the foam and haze-forming potential of the beers prepared from them. A table of the properties of some syrups currently available is given in Table 15. The figures quoted are compounded from the literature and from manufacturers' specifications, and have been recalculated where necessary to common units so that comparisons can be made.

ACKNOWLEDGMENT

We wish to thank Mr. L. Taylor, group chief chemist for Courage, Barclay & Simonds Ltd., for his active encouragement. We would also like to gratefully acknowledge Dr. C. Rainbow of Bass Charrington for his help.

**Table 15. Properties of some brewing syrups**

| Code no. .. .. | *A* | *B* | *C* | *D* | *E* | *F* | *G* | *J* | *K* | *L* | *M* | *N* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source .. .. | maize | maize | maize | wheat | wheat | wheat | wheat | barley | barley | green malt | sweet wort | copper wort |
| Extract (lb/cwt) .. | 34·5 | 35·0 | 34·0 | 35·0 | 35·0 | 34·9 | 35·1 | 32·6 | 35·3 | 34·0 | — | — |
| % total solids .. | 79·4 | 80·7 | 78·4 | 80·7 | 80·7 | 80·4 | 80·9 | 75·2 | 81·3 | 78·4 | — | — |
| % carbohydrate (on total solids) | 98 | 97 | 98* | 97* | 97* | 97* | 97* | 91·1 | 85 | 92·4 | 91 | 92 |
| Sugars (% of total CHO): | | | | | | | | | | | | |
| Hexose (RFS) | 40·7 | 42·1 | | | | 41 | 54·1 | 27·0 | 15·3 (hexose + sucrose) | 5·6 | 11·3 | |
| Sucrose (RFS) | 0 | 8·5 | 59–64 (hexose + sucrose + maltose) | 59–64 (hexose + sucrose + maltose) | 70–75 (hexose + sucrose + maltose) | | | 0 | | 7·7 | 5·5 | 66·7 (hexose + sucrose + maltose) |
| Maltose (RFS) | 31·0 | 25·4 | | | | 16·4 | 12·2 | 60·2 | 50·1 | 54·5 | 44·7 | |
| Maltotriose—SFS | 8·4 | 7·1 | 13 | 10 | 12 | 13·1 | 13·3 | 7·7 | 11·8 | 9·1 | 13·6 | 11·8 |
| Dextrins—NFS .. | 19·9 | 16·9 | 21–27 | 25–30 | 13–18 | 29·5 | 20·4 | 5·1 | 22·8 | 23·1 | 24·9 | 21·5 |
| % N (on total solids) | 0 | 0 | 0 | 0·22 | 0·22 | 0·13 | 0·13 | 0·62 | 0·72 | 0·64 | 0·75 | 0·7 |
| Lundin fraction *A* .. | — | — | — | 16·5 | 16·5 | 0 | 0 | | 29 | | 24 | |
| *B* .. | — | — | — | 17·5 | 17·5 | 0 | 0 | | 15 | | 13 | |
| *C* .. | — | — | — | 66 min | 66 min | 100 | 100 | | 56 | | 63 | |
| Cost (s./ brewer's lb extract) .. .. | 1·38 | 1·54 | 1·38 | 1·31 | 1·31 | 1·35* | 1·35* | 1·5* | 1·5 | 1·586 | 1·44 | 1·45 |
| Remarks .. .. | | | | | | | | Not yet marketed | | | Traditional worts | |

*Estimates only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# Carbohydrate Balance and its Economies in Brewing

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THE traditional carbohydrate raw material in brewing is malt. There has been remarkably little change in the proportions of carbohydrate materials used in brewer's grists during the past few decades.[1] The average composition by weight of brewer's grist in 1970 was:

| | |
|---|---|
| Malt | 77·9% |
| Unmalted corn | 1·7% |
| Flakes and grits | 5·0% |
| Sugars | 15·4% |

These and previous figures (Table 2) show that despite the publicity given to wheat flour, brewing syrups and other adjuncts, malt has held its ground very successfully. During 1970, however, the price of barley rose by as much as 40% and this was reflected in a steep rise in the price of malt to the brewer. In contrast to this, the price of refined white sugar rose by only 2–3%. Before deciding to reduce the percentage of malt in his grist in favour of sucrose, the brewer, conservative as he is, must decide whether this change in price differential is likely to persist. This can only be done by studying the factors which led to these recent price changes, and it is the purpose of the first part of this article to relate how natural forces affected the UK and world supply and demand situation, and thus the market prices of the carbohydrate raw materials of brewing. The materials cost of brewing, however, is small in comparison with the total manufacturing cost of beer.[2] Thus it is fairer to describe as 'level-headed', rather than 'conservative', the brewer who makes no sudden grist changes in response to what might be no more than a fluctuation in the commodities market. By the time that the cost of production, distribution and Excise Duty have been added, the brewer has at his command a mixture of sugars that is 13–14 times as expensive as the grist from which it was produced. It is therefore not surprising that he should devote much of his energies to the achievement of maximum utilisation of his wort sugars, and it is the aim of the second part of this article to discuss this.

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## Market trends

### *Home crops*

The acreage under barley in the UK has been increased by close to 80% since 1960, but production has been almost doubled, due to the improved yields (see Table 4).[3] Malting and distilling account for one-sixth of the crop, some is exported but most is retained on the farm or sold as feed. The home barley crop in 1970, however, was the smallest for several years.[4] An effect of the low rainfall in May/June was a high level of residual nitrogenous fertilisers in the soil.[5] In the wetter June/July period this nitrogen was taken up directly into the developing barley ears so that malts made from 1970 barley contained the high levels of 1·8–2·0% or more of nitrogen. An extra 0·1% of nitrogen represents a loss in extract to the brewer of 0·5–1%, and since the average nitrogen level was up by some 0·3%, brewery extracts were reduced by 2–3%. The nitrogen situation was serious enough for the Brewing Industry Research Foundation to issue a leaflet in November 1970[6] offering practical advice to brewers to mitigate the position. The home barley crop rose from 8·15 million tons in 1968 to 8·65 million tons in 1969, but was reduced to 7·4 million tons in 1970.[7] The shortage of good-quality barley in the UK and Europe forced maltsters to accept higher nitrogen levels and led to most of the available barley being offered to maltsters, thus making the barley shortage even more acute and increasing demand for wheat. The net result was a sharp increase in barley and wheat prices (Table 3).

The short supply of feed barley increased demand for feed wheat, causing a price rise to that of milling quality. The net effect on the home market was that farmers made prices well above government support.

### *World market*

Prices in the European Economic

Community (EEC) are higher than in the UK but the rise in price of the UK barley crop led to a greater demand from EEC buyers due to the nature of the bridging levy on imports which is reduced as the UK price rises.[8] In 1969, Canada had a big surplus of wheat and farmers were offered $6/acre for land which was changed from wheat to summer fallow. The Canadian government's cash incentives resulted in a cut in production from 18 million tons in 1969 to 8·9 million tons in 1970. The US and the EEC produced 5–7% less wheat in 1970, whereas Argentina had a poor crop with no exportable surplus.[7] In America and Canada farmers have also recently been encouraged to reduce their barley acreage and stocks had been reduced in response to increased bank interest rates.[8] These factors resulted in a reduced world supply of both wheat and barley and a consequent upward price trend.

A further influence on the market was the reduction of the US maize crop due to maize leaf blight. The 1969 yield was 114·5 million tons and, by July 1970, it seemed that the crop would exceed 120·5 million tons, but the unexpected spread of leaf blight from the south reduced the crop to an estimated 102·7 million tons by the end of the year.[7] The reduced US crop was partially made up for by good crops in the EEC and parts of Asia.[9] Maize production at 12·55 million tons was 20% up on 1969 in France, Italy and W. Germany. World production excluding China and the USSR, for 1970 was 216 million tons, some 4 million tons less than in the previous year. Demand for maize in the US was high, on account of the shortage of other cereals, so that less than usual was available for export and prices rose.

### *Sugar*

The supply of sugar in the UK is controlled by the Sugar Board. Under the Commonwealth Sugar Agreement, the UK buys some 1·7 million tons from Commonwealth producers, supplying approximately two-thirds the UK requirement, most of the remainder of which is supplied from domestic beet. The negotiated price for Commonwealth sugar in 1969 was £47/ton against an average world price of £34, hence the Board incurred a deficit.[10] The British Sugar Corporation is required to buy all the domestic beet, and the Sugar Board has to make deficiency payments to BSC when the world sugar price is low. These deficits are met by a surcharge on all sugar for human consumption in the UK and the surcharge is changed in inverse ratio to the world sugar price in order to maintain a stable price. The UK price stabilisation is shown in Fig. 1. The UK price varies within fairly narrow limits. In 1969, the bracket was £3·7–3·9/cwt, and increased by only 2–3% to £3·8–4·0/cwt in 1970. Estimated world sugar production for 1970/71 is less than 1% down on 1969/70, at 73·8 million t.

### *UK prices*

It has been seen that the shortage and poor quality of the 1970 barley crop, coupled with the partial failure of the American maize crop, have resulted in sharp price increases in maize and barley in particular. Shortage of barley and maize put pressure on the demand for wheat so that the price of this commodity also rose,

**Table 1(*a & b*). Comparative cost of extract from various brewing carbohydrate raw materials (Feb. 1971)**

*A*

| *Grist components* | *Cost (p/brewer's lb*)* |
|---|---|
| Raw wheat .. .. .. | 4·8 |
| Raw barley .. .. .. | 5·4 |
| Wheat starch (unpurified) .. | 5·7 |
| Wheat flour .. .. .. | 5·9 |
| Flaked barley .. .. .. | 6·8 |
| Sucrose and maize syrups .. | 8·0–8·1 |
| Wheat syrups .. .. .. | 8·2 |
| Flaked maize .. .. .. | 8·2 |
| Torrefied barley .. .. .. | 9·0 |
| Barley syrups .. .. .. | 10·0 |
| Malt .. .. .. .. | 10·1 |

*The excess weight in lb of a brl of wort over that of a brl of water is known as brewer's lb

*B*

| *Grists* | | *Cost (p/brewer's lb)* | *Percentage cost reduction over all-malt grist* |
|---|---|---|---|
| All-malt 100% .. | | 10·1 | 0 |
| Malt<br>Wheat-starch | 85%<br>15% | 9·5 | 6 |
| Malt<br>Maize syrup | 80%<br>20% | 9·7 | 4 |
| Malt<br>Flaked maize | 90%<br>10% | 9·9 | 2 |

1 Brewer's lb/brl = 360 (specific gravity − 1)

**Table 2. Brewer's grists (average composition percent. by weight during 1960-70)**

| | *1960* | *1962* | *1964* | *1966* | *1968* | *1970* |
|---|---|---|---|---|---|---|
| Malt .. .. | 80·8 | 80·7 | 80·4 | 79·5 | 79·4 | 77·9 |
| Unmalted corn, flakes and grits | 5·0 | 5·0 | 5·6 | 6·7 | 6·5 | 6·7 |
| Sugars .. .. | 14·2 | 14·3 | 14·0 | 13·8 | 14·1 | 15·4 |

**Table 3. Barley and wheat prices (p/cwt)**

| | *1969* | *Peak Sept. 1970 price* |
|---|---|---|
| Feed barley .. | 100·0 | 155·7–160·0 |
| Best malting barley | 137·5 | 200·0 |
| Feed wheat .. | 113·7 | 147·5 (feed and milling wheat) |
| Milling wheat .. | 117·4 | |

Figures derived from Public Ledger,[7] see also Table 2.

whereas the UK price of sugar rose only slightly as a result of government control. Malt prices have therefore risen by up to 40%, as have the adjuncts such as flaked, pearled and torrefied barley, barley flour and barley syrups. Flaked maize and maize syrup prices have risen by 15–20%, as have the prices of wheat flour and wheat syrups. The price of sugar, as previously mentioned, has risen by only 2–3%. In the past year, then, price differentials between the various brewing carbohydrates have been altered considerably. Whereas last year, for example, barley syrups were more expensive than malt in terms of extract cost,[2] they are now at similar prices. Sucrose was considerably more expensive than maize syrups, but the gap is narrowing. In Table 1*a*, an attempt has been made to list some of the more common brewing carbohydrate materials in order of cost of extract, and costs of some different grists are shown in Table 1*b*.

*Future*

The attention of the brewer is drawn to carbohydrate costs when these are rising more rapidly than the price of beer, and to the possibilities of using adjuncts when the gap between the price of these and malt widens. In 1970, there was cause for renewed and selective interest in adjuncts on both these considerations. The present government policy of reducing deficiency payments and raising internal prices is likely to maintain current high-price levels even if subsequent crops are improved. The minimum price level for imported cereals will ensure that there will be no reduction of internal price as a result of pressure from any world surplus. Furthermore, if Britain is to join the EEC, the economy will have to be adjusted to higher farm prices. An important question that remains to be answered in relation to joining the EEC is the extent to which the use of adjuncts in brewing would be allowed. The 'Purity Laws' that operate in West Germany allow the use of little other than malt and hops in brewing. Much will therefore depend on their influence in the Council of Ministers. It has recently been pointed out[11,12] that the Council is currently considering a proposal that would allow certain adjuncts to be used at a level of up to 30% of the grist. Brewers and allied traders alike in Britain can only hope that a decision will be made enlightened by the accumulated biochemical evidence which strongly indicates that the products of starch conversion by the action of the enzymes derived from *Bacillus subtilis* and *Aspergillus niger* are in no important particular different from those formed by the diastatic enzymes of malt.

## Carbohydrate utilisation

The extract raw material cost of a barrel of beer brewed from an all-malt grist is no more than £1·35, even at the current high unit cost of 10p/brewer's lb. A Prices and Incomes Board report[13] has indicated that in 1968/69 an average manufacturing cost was £4·34 and Excise Duty £12·20. Since that time there has been an increase in the rate of duty and, in the 18 months

**Table 4. Production of barley**

| *Year* | *Acreage* | *Estimated produce (cwt)* |
|---|---|---|
| 1930 .. .. | 1,128,942 | 17,612,000 |
| 1935 .. .. | 871,272 | 14,700,000 |
| 1940 .. .. | 1,399,000 | 22,080,000 |
| 1941 .. .. | 1,475,000 | 22,880,000 |
| 1942 .. .. | 1,528,000 | 28,920,000 |
| 1943 .. .. | 1,786,000 | 32,900,000 |
| 1944 .. .. | 1,973,000 | 35,040,000 |
| 1945 .. .. | 2,215,000 | 42,160,000 |
| 1946 .. .. | 2,211,000 | 39,260,000 |
| 1947 .. .. | 2,060,000 | 32,380,000 |
| 1948 .. .. | 2,082,000 | 40,540,000 |
| 1949 .. .. | 2,060,000 | 42,580,000 |
| 1950 .. .. | 1,778,000 | 34,220,000 |
| 1951 .. .. | 1,908,000 | 38,780,000 |
| 1952 .. .. | 2,281,000 | 46,680,000 |
| 1953 .. .. | 2,226,000 | 50,420,000 |
| 1954 .. .. | 2,063,000 | 44,880,000 |
| 1955 .. .. | 2,295,000 | 58,720,000 |
| 1956 .. .. | 2,323,000 | 56,000,000 |
| 1957 .. .. | 2,622,000 | 59,140,000 |
| 1958 .. .. | 2,755,000 | 63,400,000 |
| 1959 .. .. | 3,057,000 | 80,320,000 |
| 1960 .. .. | 3,372,000 | 84,820,000 |
| 1961 .. .. | 3,828,000 | 99,480,000 |
| 1962 .. .. | 3,980,000 | 115,440,000 |
| 1963 .. .. | 4,713,000 | 131,980,000 |
| 1964 .. .. | 5,032,000 | 148,080,000 |
| 1965 .. .. | 5,395,000 | 161,243,000 |
| 1966 .. .. | 6,130,000 | 171,720,000 |
| 1967 .. .. | 6,027,000 | 181,380,000 |
| 1968 .. .. | 5,933,000 | 162,800,000 |
| 1969 .. .. | 5,960,000 | 170,540,000 |

**Table 5. Beer processing losses (after Soltoft[18])**

| | *Percentage of alcohol produced in fermentation* | | |
|---|---|---|---|
| | *Gain* | *Loss* | *Net* |
| Fermentation .. .. .. | 100·00 | | 100·00 |
| Evaporation .. .. .. | | 0·08 | 99·92 |
| Pitching yeast .. .. | 0·43 | | |
| Starting tank sludge .. .. | | 0·04 | |
| Yeast crop .. .. .. | | 1·30 | |
| Storage tank bottoms .. | | 0·43 | |
| Stabilising tank bottoms .. | | 0·70 | |
| Sludge going to waste .. | | 0·12 | |
| Beer loss at transfers in cellars | | 1·38 | |
| Beer going into filter .. .. | | | 96·38 |
| Beer loss at filtration .. .. | | 1·38 | |
| Spent kieselguhr .. .. | | 0·25 | |
| Beer loss at filling .. .. | | 0·10 | |
| Beer loss at fobbing up .. | | 0·29 | |
| Beer loss at pasteurisation .. | | 0·93 | |
| Beer loss at rinsing of plant .. | | 0·18 | |
| Bottled beer .. .. .. | | | 93·25 |
| Net loss .. .. .. | | 6·75 | |

since May 1969, cost increases in brewing, wholesaling and distribution have averaged 14%.[14] The duty cost of brewer's wort is therefore 10 times greater than the carbohydrate materials cost and the manufacturing plus duty cost is some 13–14 times greater. Duty is normally levied on the unfermented wort in the fermenting vessel so that from this stage onwards in the brewing process it is of utmost importance that the brewer should make optimum use of his very costly wort carbohydrates.

One of the many attractions of beer is its content of alcohol, derived by fermentation from the wort sugars. During the course of fermentation, however, much of the original carbohydrate is lost as carbon dioxide and in the cell material produced in yeast growth. The Balling Equation[15] indicates that only 48·4% of the fermentable carbohydrate ends up as alcohol (Table 6).

There is a mixture of sugars present in breweries wort of which the average degree of polymerisation in the carbohydrates fermented is 2·0 hexose units/molecule (Table 7). Therefore the formula for a disaccharide must be used in the stoichiometric equation to describe the fermentation of brewer's wort.

Thus:

$$C_{12}H_{22}O_{11} + H_2O \xrightarrow{\text{hydrolysis}} 2C_6H_{12}O_6$$

$$2C_6H_{12}O_6 \xrightarrow{\text{fermentation}} 4CO_2 + 4C_2H_5OH$$

Net:

$$C_{12}H_{22}O_{11} + H_2O \longrightarrow 4CO_2 + 4C_2H_5OH$$

$$100\,g + 4{\cdot}71\,g \longrightarrow 51{\cdot}2\,g + 53{\cdot}6\,g$$

but considering yeast growth (see Table 5) then the balance is modified:

$$100\,g + 4{\cdot}71\,g \longrightarrow 46{\cdot}3\,g + 48{\cdot}4\,g + 5{\cdot}3\,g \text{ yeast}$$

An alternative approach is to consider the carbon mass balance of fermentation.

Since the sugars fermented are built up of hexose units, and isotopic analysis has revealed that alcohol is formed from the carbon atoms in the 1, 2, 5 and 6 positions, fermentation can be visualised as in Fig. 2.

**Table 6. Fate of wort fermentable carbohydrate**

| *Percentage of fermentable carbohydrate* | *Substance formed* |
|---|---|
| 46·3 | carbon dioxide |
| 5·3 | yeast |
| 48·4 | alcohol |

**Table 7. Fermentable sugars in brewer's wort[2]**

| | *Total carbo-hydrates (%)* | *Glucose (units per molecule)* |
|---|---|---|
| Mono-saccharides | 11·3 | 1 |
| Disaccharides | 50·2 | 2 |
| Trisaccharides | 13·6 | 3 |
| Dextrins | 24·9 | non-fermentable |

Thus two-thirds of the sugar carbon is transformed to alcohol, excluding yeast growth. Measurements of the increase in yeast weight during fermentation and its carbon content show that 5% of the carbon is usually lost in the yeast crop:

e.g. Yeast production 4·8 lb/brl pressed weight

Pressed yeast 27% dry matter

Dry matter 47% carbon

Therefore yeast carbon produced per barrel of beer = 0·608 lb

Now 1 brl of 1,038° brewer's wort has solids content 9·44%

91·9% of solids as carbohydrate 8·67%

Hence 142 kg carbohydrate as glucose per barrel or

31·3 lb carbohydrate as glucose per barrel

Thus carbon content:

$$= \frac{\text{m.w. carbon} \times 6 \times 31{\cdot}3}{\text{m.w. glucose}}$$

$$= \frac{72}{180} \times 31{\cdot}3 \qquad = 12{\cdot}55\text{ lb}$$

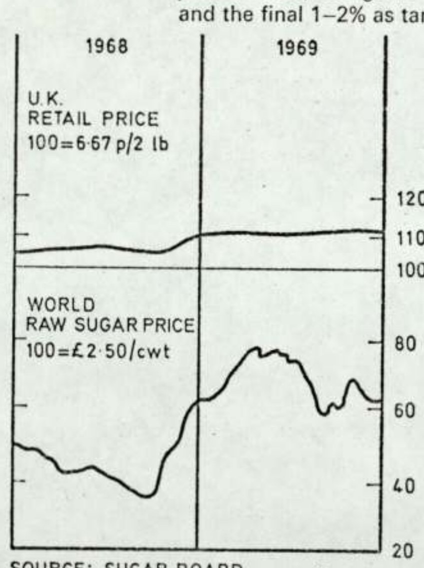
Thus percentage carbon lost in yeast crop

$$= 0{\cdot}608/12{\cdot}55 \qquad = 4{\cdot}85\%$$

A carbon balance of the sugars fermented can now be drawn:

$$\underset{\text{carbohydrates fermented}}{100C} \longrightarrow \underset{\text{alcohol}}{63C} + \underset{\text{carbon dioxide}}{31C} + \underset{\text{yeast}}{5C}$$

Carbohydrates alone do not account for the whole of the extract from the malt grist. MacWilliam has indicated[16] that carbohydrates account for 91–92% of extract, proteins 5%, inorganic constituents 2% and the final 1–2% as tannins, lipids, etc.




SOURCE: SUGAR BOARD ANNUAL REPORT 1970[10]

*Fig. 1* (left). *Stability of UK sugar price in relation to fluctuations in the world price of raw sugar*

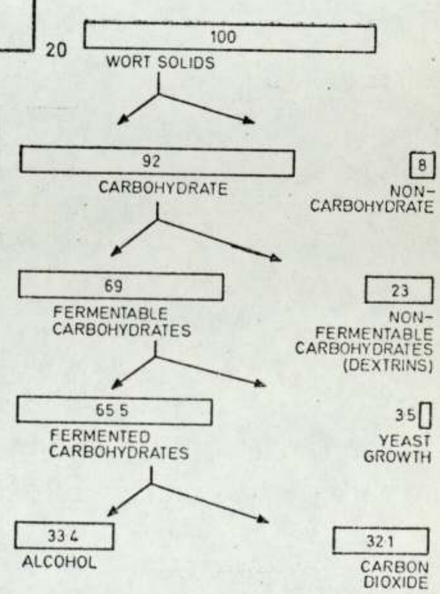



*Fig. 3* (right). *Mass balance of wort solids (% by weight of original wort solids)*

Furthermore, some 25% of the carbohydrates present are unfermentable,[2] and not all the fermentable sugars are fermented, some remaining in the beer to provide sweetness. One is now in a position to construct a mass-balance. Fig. 3 shows that 33·4% by weight of the original wort solids are converted to alcohol provided that the beer is fully fermented.

The value to the consumer of the residual dextrins in beer is debatable. Dextrins are virtually tasteless but it is claimed by some that they add body to the beer and, of course, to its calorific value. It is possible to convert these dextrins into glucose by the action of amyloglucosidase, this treatment producing a sweeter beer. If this enzyme is added during fermentation, however, the glucose produced is fermented by the yeast and the resulting beer will have a considerably enhanced alcoholic strength although it may taste thinner. In these days of the breathalyser, however, the extra alcohol may be unwelcome to the consumer. Furthermore, there are an increasing number of people who drink for social reasons rather than to become euphoric. Nevertheless, amyloglucosidase remains a useful tool for sweetening beer without the addition of sugar, and for the preparation of 'diabetic beers' of low carbohydrate content.

The loss of carbohydrate as carbon dioxide is inevitable and is directly linked, as has been seen to the production of alcohol. This major loss could only be reduced in conjunction with a reduction in the alcohol content. Loss of carbohydrate in yeast growth, however, can be reduced. In the Tower fermentation system, for instance, it is possible to ferment brewer's wort with only a very small rate of production of yeast. Ault[17] has reported an apparent rise in original gravity of 2–3% during fermentation, due to the reduction in yeast growth. This anomaly arises from the fact that the original gravity is calculated on the basis of the Balling formula in which, as has been mentioned, it is assumed that some 5% of extract is 'lost' in yeast growth. Unfortunately, it was found that the beer flavour was not up to standard and it was necessary to promote a nearly normal growth of yeast by oxygenating the wort in order to achieve an acceptable flavour.

In the UK, duty is paid on only 94% of the volume of wort collected in the fermenting vessel, a 6% allowance being made for subsequent processing losses. This may seem to be a surprisingly high level of loss, but has recently been confirmed by Soltoft[18] for a modern lager brewery. The percentage loss, in terms of alcohol, in various process stages between the beer in the fermenting vessel and beer in bottle have been calculated from Soltoft's figures and are reproduced in Table 5. The net loss of 6·75% indicates that the Excise allowance of 6% would be insufficient to cover the true processing losses of a similar brewery sited in the UK.

In a traditional brewing process, therefore, the brewer can only hope to convert one-third of his expensive duty-paid wort solids into alcohol, and then processing losses will account for 6–7% of the product even in a well-managed modern brewery. Nothing can be done to reduce the wasteful diversion of fermentable carbohydrate into carbon dioxide, but yeast growth can be reduced in continuous fermentation systems or by yeast strain selection.[19]

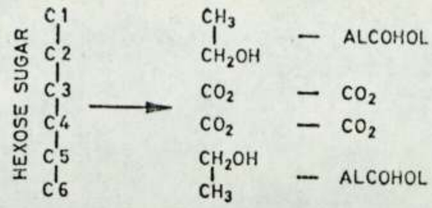



*Fig. 2* (above). *Fermentation of hexose sugars. Alcohol is formed from the carbon atoms in the 1, 2, 5, 6, positions*

tion of wort includes nitrogenous constituents which are essential for yeast growth, but the higher molecular weight nitrogen components have little positive value and can cause protein haze in the beer or create filtration problems. The brewer might profitably consider ways of reducing his wort protein content and thus avoid paying duty on an unwanted component. The dextrin content of beer can be reduced, not only by the use of amyloglucosidase, but also by increasing the proportion of sucrose or highly-fermentable syrups in the grist. Finally, beer processing losses can be reduced, particularly in the production of strong ales, by the use of a continuous fermentation system such as that recently described bv Bishop[20] and others.

## Summary

Recent price increases resulting from poor cereal crops emphasise the importance of carbohydrate costs to the brewer. Duty costs are much greater, however, thus justifying the conservatism of brewers in the use of a high proportion of malt. The mash-tun is therefore likely to survive many more years before being replaced, although cereal adjuncts and the barley-conversion processes are obvious factors to be considered in the future either in unfavourable economic situations or where completely new brewery requirements are to be envisaged. Carbohydrate utilisation is of utmost importance to the brewer, and therefore in view of the high rate of duty levied the more modern continuous and semi-continuous fermentation systems are likely to be favoured on account of their reduced losses, low capital lock-up and increased flexibility.

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