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Brewing

The evolution of a tradition into a technology

Although the methods of brewing beer, as well as its popularity, have remained virtually unchanged for the past century, recent years have seen an increase in malting and brewing productivity. Graham Stewart describes how technology has optimised processes and improved efficiency in the brewing industry.

The facade of Shepherd Neame's Faversham Brewery, where beer has been brewed without a break since 1698 *(photo: Shepherd Neame)*

Biotechnology has been defined as 'creating products from raw materials using living organisms'. By this definition, the brewing of beer is one of the oldest biotechnology industries. Brewing was one of the earliest processes to be undertaken on a commercial scale, and of necessity, it became one of the processes to be developed from a craft into a technology. Of all the elements contributing to the transformation of the modern brewing industry, technology is perhaps the least known, and certainly the least understood, by the consumer. The essential nature of beer, and the way that it is brewed, has remained unchanged for the past one hundred years or so.

The production of beer is a relatively simple process. Yeast cells are added to the nutrient medium (the wort) and the cells take up the nutrients and utilise them so as to increase the yeast population. The cells excrete ethanol and carbon dioxide into the medium together with a host of minor metabolites, many of which contribute to beer flavour. The fermented medium, after the yeast is removed, is the 'green' beer – so called because it often smells of green apples. The beer is then aged (matured), clarified, carbonated and packaged. The progress of brewing science and technology in the twentieth century has remained conservative when compared with many other industries. Nevertheless, there were important changes in brewing technology, for example, in refrigeration, fermenter design, in-place cleaning systems, pasteurisation and filtration of beer (particularly bottled and canned beer) and in-plant (barley) breeding. Although these changes were introduced gradually in the first half of the twentieth century, they certainly became more apparent as they gathered pace after 1960.

Over the past 25 years, the brewing industry, along with most industrial concerns, has not been immune to the economic realities that prevail in most countries. As a consequence, process optimisation and increased efficiency have been a priority for many brewing companies. Process intensification has become a part of this endeavour and has focused on a number of areas: reduced capital expenditure, increased rates of fermentation and final attenuation, high quality yeast viability and vitality, decreased maturation times, more efficient stabilisation and filtration, together with enhanced overall quality and stability.

Enhancement of the actual brewing process has also been accompanied by developments in the fabric of breweries, together with:

- on-line process control
- in-place cleaning
- stainless steel replacing mild steel, wood, slate and even concrete vessels
- energy recovery
- a better understanding of fluid flow
- more efficient water usage and effluent disposal.

In addition, the advent of micro/pub breweries has introduced a novel dimension to the process and has opened opportunities for continuous processing, which will be discussed later.

The brewing industry in the United Kingdom and in many other countries has significantly improved its efficiency over the past two decades. Improvements in gross value added per employee between 1984 and 1995 for brewing and malting compared to general manufacturing are shown in Figure 1.

General manufacturing shows gradual improvement in overall productivity, whereas malting and brewing productivity over the same period has been far greater. A similar trend has occurred in Canada where, over the past ten years, the number of breweries operated by the two major companies has decreased by 50%, and the total volume of beer produced nationally has remained approximately the same. Although there has been some expansion in physical capacity, most of the increased beer production has been by process changes such as high gravity brewing, faster primary fermentation and shorter maturation times, all of which are discussed in this article.

There are many areas that could be covered in detail, but here I will review the following five:

- yeast quality
- beer maturation and ageing
- beer stability
- high gravity brewing
- batch versus continuous fermentation.

The top working level of the fermenting vessel farm at the Bass Burton Brewery north brewhouse *(photo: Bass)*

Yeast quality

Brewing is the only major alcoholic beverage process that recycles its yeast (in the production of wine, whisky and rum the yeast is used only once). It is therefore important to protect jealously the quality of the cropped yeast because it will be used to *pitch* (inoculate) a later fermentation and will therefore have a profound effect on the quality and stability of the beer resulting from it. When yeast is pitched into wort (unfermented beer), it is introduced into a complex medium consisting of simple sugars, dextrins, amino acids, peptides, proteins, vitamins, ions, nucleic acids and other constituents too numerous to mention. One of the major advances in brewing science during the last 30 years or so has been the elucidation of the mechanisms by which the yeast cell, under normal circumstances, utilises in an orderly manner this plethora of wort nutrients.

Yeasts are non-photosynthetic, relatively sophisticated, living unicellular fungi. They are considerably larger in size than bacteria. All brewer's yeast strains multiply by budding (Figure 2). Yeasts are of significant benefit to mankind because they are widely used for the production of beer, wine, spirits, foods and a variety of biochemicals and therapeutic agents.

The characteristic flavour and aroma of any beer is, in large part, determined by the yeast strain employed for fermentation. Although ethanol is the major excretion product produced by yeast during wort fermentation, this

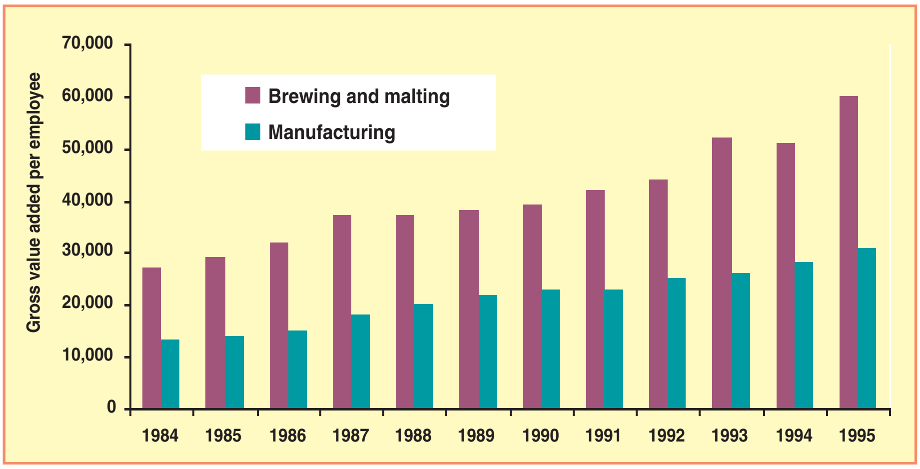

Figure 1: British brewing productivity compared to other manufacturing industries

alcohol has little impact on beer flavour. It is the type and concentration of the many other excretion products formed during wort fermentation that primarily determine beer flavour. The formation of these excretion products depends on the overall condition and metabolic balance of the yeast culture, and there are many factors that can alter this balance, and consequently, beer flavour. Yeast strain, fermentation temperature, wort composition and strength, and fermenter design are all influencing factors.

Wort fermentation in beer production is largely anaerobic, but when the yeast is first pitched into wort, some oxygen must be available to it. Indeed, it is now evident that this is the only point in the brewing process where oxygen is beneficial. Oxygen must be excluded, as far as possible, from all other parts of the process because it will have a negative effect on beer quality. Specifically, it will promote beer flavour instability. This presents the process engineers with challenging opportunities! The widespread adoption of high-gravity brewing procedures has increased our awareness of the importance of oxygen during wort fermentation and has stimulated basic and applied research on the mechanisms of oxygen interactions during yeast cell growth and the application of this knowledge to the brewing process.

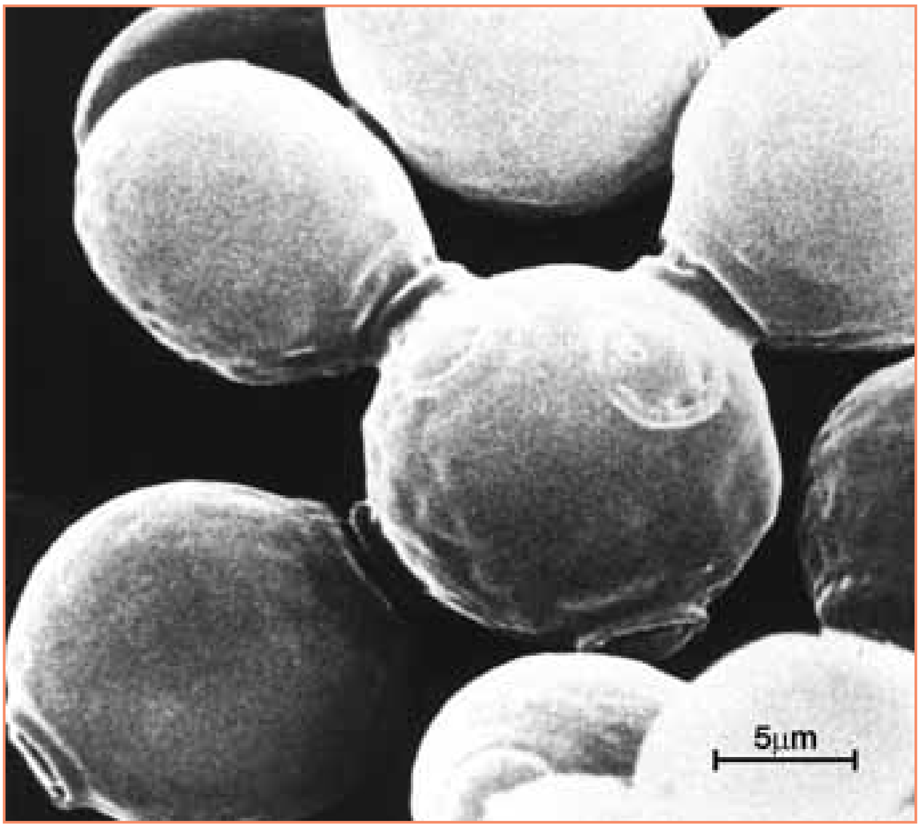

Figure 2: Electron micrograph of budding yeast cells

Beer maturation and ageing

'Ageing', 'storage', 'maturation', 'secondary fermentation' and 'lagering' are all terms used to describe the process of holding beer in a tank at refrigerated temperatures (0–5ºC) for a period of time (up to four months, sometimes longer) following primary fermentation. A storage period is not essential, but is desirable, for beer production. In Britain, ales are often produced without a storage period – they are put directly into kegs and casks following primary fermentation. However, a storage period is normal for lagers with the following objectives:

- flavour maturation (including reduction in the levels of unwanted compounds such as hydrogen sulphide (rotten egg flavour), acetaldehyde (green apple) and diacetyl (butterscotch));
- enhancement of the physical stability of beer to ensure that it remains 'bright' for the longest period of time;
- carbonation.

Maturation periods today usually range from a few days to four weeks. In exceptional cases, with some lagers produced in central Europe, secondary fermentation/ageing periods can be as long as three months (and even nine months in one case).

Beer stability

Beer has many unique features when compared to other alcoholic beverages. One such feature is that it is unstable when in its final container (bottle, can or keg). Packaged beer has a limited shelf life. Beer stability can be considered under a number of categories:

- microbiological
- flavour
- physical/colloidal
- light
- foam.

The flavour stability of beer primarily depends on the oxygen content of the packaged product. In many foods, such as milk, butter, vegetable oils and beverages, staling is caused by the appearance of various unsaturated carbonyl compounds, and it is becoming increasingly clear that the same is true of beer staling. Despite intensive investigation, the mechanism(s) of staling is still not fully understood. Although the compounds causing the sweetish, leathery character of very old beers have not been identified, there is evidence that the papery cardboard character of two- to four-month-old beer is due to unsaturated aldehydes.

The stability of the foam on a glass of beer is considered by many consumers to reflect the quality of the product. The increasing use of adjuncts (unmalted cereals, syrups and cane/beet sugar) and the associated decrease in malt being employed today, have a negative effect on foam stability in many beers. In addition, as will be described later, the move to high gravity brewing techniques has a negative effect on beer foam stability.

Beer is also sensitive to light. An off-flavour compound in beer is 'light-struck' flavour, also known as 'skunky' aroma. This results when iso-acids from hops react with sulphur compounds in the presence of light, to yield 3-methyl-2-butenethiol (MBT) or 'skunky thiol' because the aroma is similar to the smell of a skunk. The average beer drinker can identify MBT in beer at levels as low as 8 parts per trillion. Cans, kegs and brown (amber) glass bottles offer light protection to beer, but beer in green or clear glass bottles is particularly susceptible to the formation of this skunky thiol.

High-gravity brewing

High-gravity brewing has been progressively introduced into breweries around the world over the past 30 years. It is a procedure that employs wort at higher than normal concentrations and consequently requires dilution with water (usually de-oxygenated) at a later stage in processing. By reducing the amount of water employed in the brewhouse, increased production demands can be met without expanding existing brewing, fermentation and storage facilities, resulting in considerable savings in capital expenditure. Processing a lower volume of beer while retaining a constant liquid output results in efficiency gains in energy usage, labour and cleaning costs.

High-gravity brewing also offers great flexibility in the types of beers that can be offered for sale. For a single 'stock' of high-gravity beer, a brewer can offer a number of different products with differing original extracts and alcohol levels (for example, light and low-/high-alcohol beers) without the need to maintain a separate inventory for each beer type.

Furthermore, with the advent of carbon dioxide hop extracts, high-quality malt extracts, syrups and natural colouring materials, the potential range of marketable product types is further expanded.

Batch versus continuous fermentation and maturation

Although continuous fermentation for beer production was first attempted before 1900, it was during the 1950s and 1960s that there was great expectation that significant improvements in process control would be gained by switching from batch to continuous fermentation. Another important motive for engaging in continuous processing was (and still is) economy, particularly in the quality and overall intensification of breweries. As already discussed, such economies will be evident in reductions in fixed and variable operating costs. A considerable amount of effort and investment was devoted to continuous processing, but by the late 1970s, all of the continuous fermentation systems employed on a production scale, with the exception of that used by a brewing company in New Zealand, had failed to perform to expectation and ceased operation.

The interior of the Bass Burton Brewery north brewhouse *(photo: Bass)*

Why did the brewing industry fail to make a commercial success of continuous fermentation in the past? Essentially, batch fermentation is a simpler concept. A vessel is cleaned, sterilised and rinsed and then filled with wort and pitched with the required quantity of yeast. The primary fermentation cycle can be pre-programmed and little further attention is required until maturation. Operation by trained but not highly qualified staff

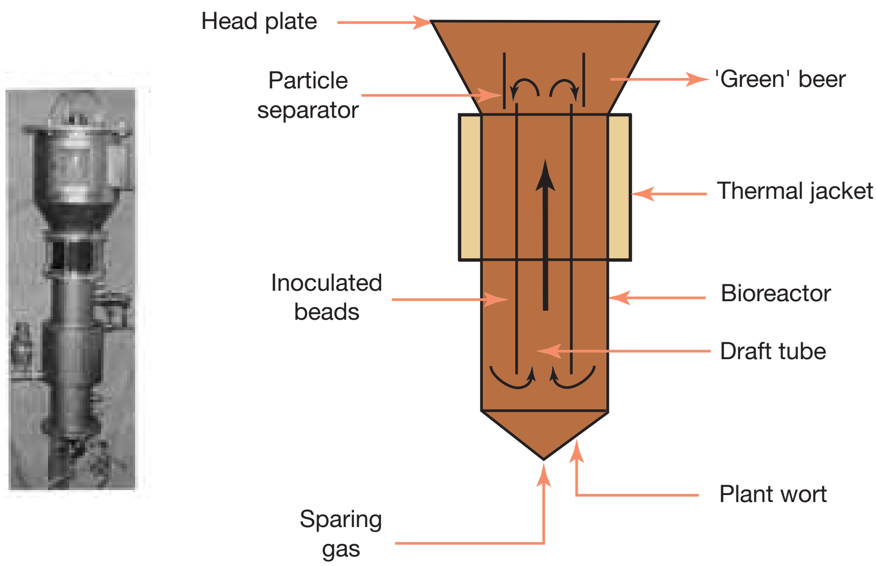

Figure 3: Pilot scale gas lift draft tube bioreactor for primary fermentation of wort

is required. On the other hand, continuous fermentation requires ongoing laboratory monitoring and complex automatic control of flow rates, temperature gradients, yeast recycle and oxygen flow specifications. Engineering support to correct possible faults in control systems, pumps and heat exchangers must be available 24 hours a day, 7 days a week. The advent of on-line control and rapid microbiological and analytical methodology will make what was an impossibility in the late 1970s, a reality in the twenty-first century.

The use of immobilised cells for continuous primary and secondary fermentation of beer currently generates interest worldwide, especially (but not exclusively) for micro brewing systems. Immobilisation methods most commonly used for whole cells such as yeast include physical entrapment, adsorption to a preformed carrier, containment behind a barrier and self-aggregation or flocculation of cells. A variety of materials for the physical entrapment of yeast cells have been studied, including calcium alginate, agarose, DEAE cellulose and carrageenan. Carrageenan is a food grade material and has been favoured for cell encapsulation due to its superior strength compared to other gels. A pilot scale draft tube reactor has been developed (Figure 3) for continuous wort fermentation with a carrageenan-entrapped lager yeast strain. With a typical high-gravity wort, complete fermentation has been achieved in 24 hours compared to the 7 days fermentation required for a typical batch fermentation.

Although studies with primary fermentation employing immobilised cell systems are at the development stage, immobilised cell systems for reduced maturation times are employed on the production scale. The Finnish company, Cultor, working in association with the Sinebrychoff and Bavaria Breweries, has developed a process using immobilised cells for the accelerated maturation of beer (Figure 4). This process removes in a matter of hours a number of unwanted compounds from the immature beer (including the butterscotch flavoured compound diacetyl) that under conventional maturation methods, would take days and even weeks to remove.

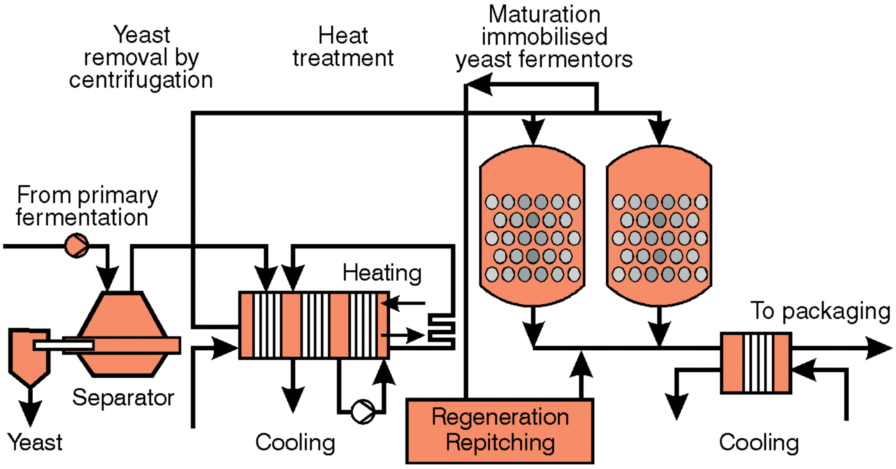

Figure 4: A two-hour continuous maturation system

A mash conversion vessel (right) and an Edwardian teak mash tun (left) *(photo: Shepherd Neame)*

The future

Process optimisation and increased efficiency will continue to be a priority for most brewing companies. Process intensification will continue to be part of this endeavour and will focus on a number of areas including:

- high-gravity wort fermentation
- efficiency of wort sugar uptake
- novel yeast strains
- immobilised yeast cells for primary fermentation and maturation.

All of these activities will result in reduced capital expenditure and increased process efficiencies. Large-scale batch operations will continue to be the processing systems of choice, particularly for primary fermentation. However, continuous processing will be introduced, principally on a small scale, in pub breweries and similar facilities.

Graham Stewart is the Director and Professor of the International Centre for Brewing and Distilling, Heriot-Watt University, Edinburgh, Scotland. He holds degrees from the Universities of Wales and Bath. Prior to taking up his present position in 1994 he was employed for 25 years by an international brewing company based in Canada. He has published over 200 papers, reviews, books and patents.