THE CONTINUOUS BREWING OF BEER

Beer is produced commercially by the controlled fermentation of wort, a liquid rich in sugars, nitrogenous compounds, sulphur compounds and trace elements extracted from malted barley. Fermentation is the process by which glucose is converted to ethanol and carbon dioxide and is expressed chemically as:

$$C_6H_{12}O_6 + 2PO_4^{3-} + 2ADP \rightarrow 2C_2H_5OH + 2CO_2 + 2ATP$$

Behind this simplified chemical reaction is a series of complex biochemical reactions. These reactions (known as the 'Glycolytic pathway' or 'Embden-Myerhof-Parnas pathway') involve a number of enzymes and the reactions take place anaerobically inside the cells of brewing yeast.

DB Breweries carry out this fermentation by a continuous process in which the beer moves through a series of stirred vessels for a period of 40 to 120 hours. After the ethanol has formed the beer is transferred to maturation vessels the flavour is naturally refined. Following this the product is developed into a variety of different brands.

Breweries across the world generally use the system of batch fermentation to produce beer, it is the writer's belief that at this time, only DB Breweries in New Zealand is successfully using continuous fermentation to produce full strength beers.

INTRODUCTION

Brewing has been mentioned in history as early as Egyptian times and has continued on to the present day with relatively few changes to the basic recipe. Malted barley is the main ingredient, which, when milled and heated in water to extract its nutrients, provides a nourishing sugar- and protein-rich solution named wort (pronounced wert), an ideal medium in which yeast may grow and ferment. In comparatively recent times hops were added to the boiling wort as it was discovered that hops had anti-bacterial properties which preserved the wort and fermented beer and which gave the beer a refreshing bitter taste.

For many years the only known method of fermenting beer was a slow batch fermentation process carried out in a single fermentation vessel. This method had disadvantages in economic and quality aspects. The slow fermentation times meant that large numbers of tanks were required to house all the fermenting batches of beer (high costs of vessels and the associated costs for holding these vessels at the required temperatures and testing the quality of each batch). In addition, there was no guarantee that the beer would have a consistent flavour, something which is particularly important in these times of quality awareness.

In the late 1950's Morton Coutts of Dominion Breweries (now DB Breweries) introduced the concept of continuous fermentation (CF) and won international acclaim in the brewing world. Continuous fermentation involves recycling part of the fermented beer back to the wort at the start of the fermentation process and requires a continuous supply of wort into the system. The result is a continuous flow of beer out the other end of the process. Whereas in a batch fermentation system wort will be brewed then cooled to fermentation temperature then pitched with yeast and fermented, the wort brewing stage in a continuous system may be carried out at a time appropriate for the brewery (eg brewing may be organised to allow maximum power usage at off-peak times, or may be carried out around the clock for several

days and then a period with no brewing to allow plant maintenance, shut-down for holiday period etc).

Continuous fermentation employs a system of cold wort storage; the boiled wort is chilled to 0□C (the wort does not freeze at this temperature because of its high sugar content) and held in storage tanks where protein material (which would otherwise make the beer appear cloudy or 'hazy') precipitates out. The wort remains in the storage vessel until it is required to be steadily transferred to the fermentation. One wort storage tank will continuously feed into the fermentation for several days.

THE CONTINUOUS FERMENTATION PROCESS

The fermentation system itself is made up of a cascading series of three stirred vessels and a fourth unstirred vessel where the beer is separated from the yeast (see **Figure 1**). The system uses a flocculent yeast strain which settles quickly at the end of fermentation. From the fourth vessel the clarified beer flows to a warm Maturation Vessel where the flavour is refined by yeast action (from the small amount of residual yeast in the beer). The total residence time in these four vessels can be anything from 40 to 120 hours, depending on production requirements.

At the time of printing, all DB brands except Mako are produced by this process[1]. All the different types of beer are produced on the same continuous process line, and their respective differences are produced after the maturation stage. DB has two continuous fermentation lines but usually, except in the lead-up to Christmas, only operates one at a time.

Step 1 - The hold-up vessel (HUV)

The incoming wort is oxygenated to stimulate yeast growth and a steady flow of yeast and beer from later in the fermentation process is mixed with the wort as it flows into this first small vessel. The introduction of yeast into wort can be somewhat stressful for the yeast because of the high nutrient levels; by mixing the wort with partially fermented beer the concentration of nutrients is reduced and this allows for a more rapid commencement of fermentation. The yeast recycled back to the hold-up vessel is still in an active fermentation state, so again there is no significant lag phase before the fermentation begins. The recycled partially fermented beer reduces the pH in this vessel (from pH 5.0 to pH 4.3) and increases the concentration of ethanol. This creates an unfavourable environment for any competing micro-organisms such as bacteria or wild yeast (any yeast which is not the 'culture' yeast of a given brewery) and thus minimises the potential for microbiological spoilage. The beer/wort mixture has a residency time in this first vessel of approximately 3 to 4 hours.

[1]DB brews Heineken using a completely separate batch process.

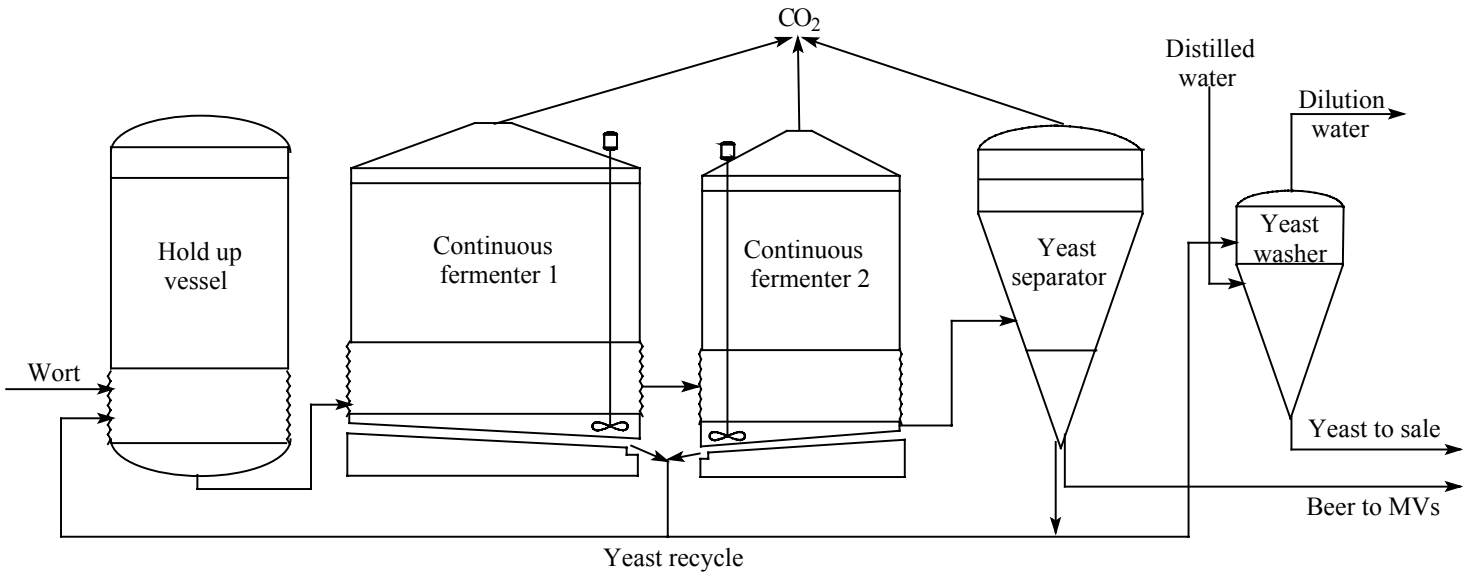

Figure 1 - The continuous fermentation plant

Step 2 - CF1
Continuous Fermenter 1 is the main fermentation vessel, it comprises roughly 60% of the volume of the CF and it is from this vessel that the partially fermented beer is recycled back into the hold-up vessel. The residence time in this vessel is normally 30 hours or more, depending on production demands.

Step 3 - CF2
Continuous Fermenter 2 makes up just under a third of the volume of the CF and is an important vessel for the fine-tuning of the finished fermented beer (that is, ensuring that the desired amount of ethanol is produced). Residence time in this vessel is 12 hours or more.

Step 4 - Yeast separator
This is an unstirred vessel with a cone-shaped base. As the beer flows into the vessel most of the yeast settles to the bottom of the cone and is piped back to the beginning of the fermentation where it mixes with the incoming wort. Normally, more yeast is produced during fermentation than is required by the brewery. The surplus yeast is washed to recover as much beer as possible (this wash-water is used for dilution later in the beer-making process) and the yeast may then be sold.

Step 5 - Maturation Vessel
The purpose of this vessel is largely to remove a fermentation by-product with a disagreeable toffee/butterscotch-type flavour. The flavour belongs to a diketone compound, 2,3-butanedione. The precursor to this flavour compound, "-acetolactate, forms during the fermentation. The warm temperature and low pH[2] of the maturation vessel hasten the conversion of α-acetolactate to 2,3-butanedione. Once the flavour is formed it is rapidly absorbed by the low level of remaining yeast cells to produce a compound with no noticeable flavour, 2,3-butanediol.

After two days maturation the beer is ready for cold storage to aid sedimentation and removal of haze particles[3]. Brand diversification also occurs during these post-fermentation steps. Finally the beer is filtered and packaged.

YEAST BIOCHEMISTRY

Sugar Metabolism - The Glycolytic Pathway
There are five sugars which may be present in wort which are readily utilised by standard brewer's yeast in fermentation; glucose, fructose, sucrose, maltose and maltotriose. These sugars are the main source of carbon compounds for all the structural materials of yeast cells.

---

[2]The finished beer has a pH of about 4.0 - 4.1. This is slightly more acidic than the wort/beer mixture used in the hold-up vessel as the yeast removes amino acids from the beer solution and so reduces its buffering capacity.

[3]Haze is due to complexes of polyphenols and proteins (see wine article). If these are not removed they reduce the clarity of the beer.

The sugars are always taken up by the yeast in the same sequence; first glucose, fructose and sucrose then maltose and lastly maltotriose. Sucrose is hydrolysed by the invertase enzyme in the yeast's cell wall and splits into one glucose molecule and one fructose molecule, both of which may be assimilated into the glycolytic pathway. The enzymes responsible for the transport of maltose and maltotriose through the yeast cell membrane (permeases) are 'blocked' by the presence of the simpler monosaccharides and so their uptake is delayed. Once within the yeast cell, both maltose and maltotriose are converted to glucose by the enzyme 'maltase'. The fate of the sugars is depicted in **Figure 2**. The details are beyond the scope of this text. Although the process requires some energy input there is a net gain of energy in the form of ATP (adenosine triphosphate).

Ester Production

Esters are formed by the combination of reactive acids and alcohols in the beer. Since the alcohol present in by far the largest quantity is ethanol, most of the esters produced are ethyl esters. Two examples are ethyl acetate (solventy, slightly gluey aroma) and ethyl hexanoate (red apples and aniseed aroma). The flavour balance of the esters produced is dependant on the yeast strain used. For instance, some strains of *Bretannomyces* yeast (wild yeast) produce enormous quantities of ethyl acetate, causing a UHU glue-type off-flavour in beer.

Alcohols

The production of alcohols other than ethanol is linked with nitrogen uptake by yeast. The yeast requires nitrogen (in the form of amino acids extracted from the malt) in order to make protein and other nitrogenous cell components. Examples of higher alcohols formed as by-products of nitrogen metabolism are propanol, isobutanol and isoamyl alcohol. Shortages of critical amino acids can lead to the development of off-flavours such as diacetyl (2,3-butanedione), a buttery flavour which tends to be produced if valine levels are low in the wort. This flavour can be avoided by allowing the beer adequate maturation time after the fermentation is complete.

THE ADVANTAGES OF CONTINUOUS vs. BATCH FERMENTATION

Continuous fermentation allows better vessel and space utilisation through faster fermentation. The fermentation proceeds more rapidly because it is stirred and higher yeast concentrations are present than in standard batch fermentations. Capital and labour costs are reduced since there is only one fermentation to control and test. The fermentation system can be tuned according to market demands; in peak periods the CF can be run at a high flow rate, during the off-peak season the flow rates are reduced so that beer is produced more slowly by the system. Because of the blending effect of the recycle from CF1 to the HUV there is excellent product consistency. A number of parameters (such as yeast concentration, wort oxygenation rate and flow rate) can be used to fine-tune the flavour and quality of the beer produced from the system. The control of the fermentation also has the advantage of being automated.

DISADVANTAGES OF CONTINUOUS FERMENTATION

Hygiene requirements are much higher than those required for batch fermentation since a CF system has the potential to run for a year or more during which time the vessels cannot be cleaned.

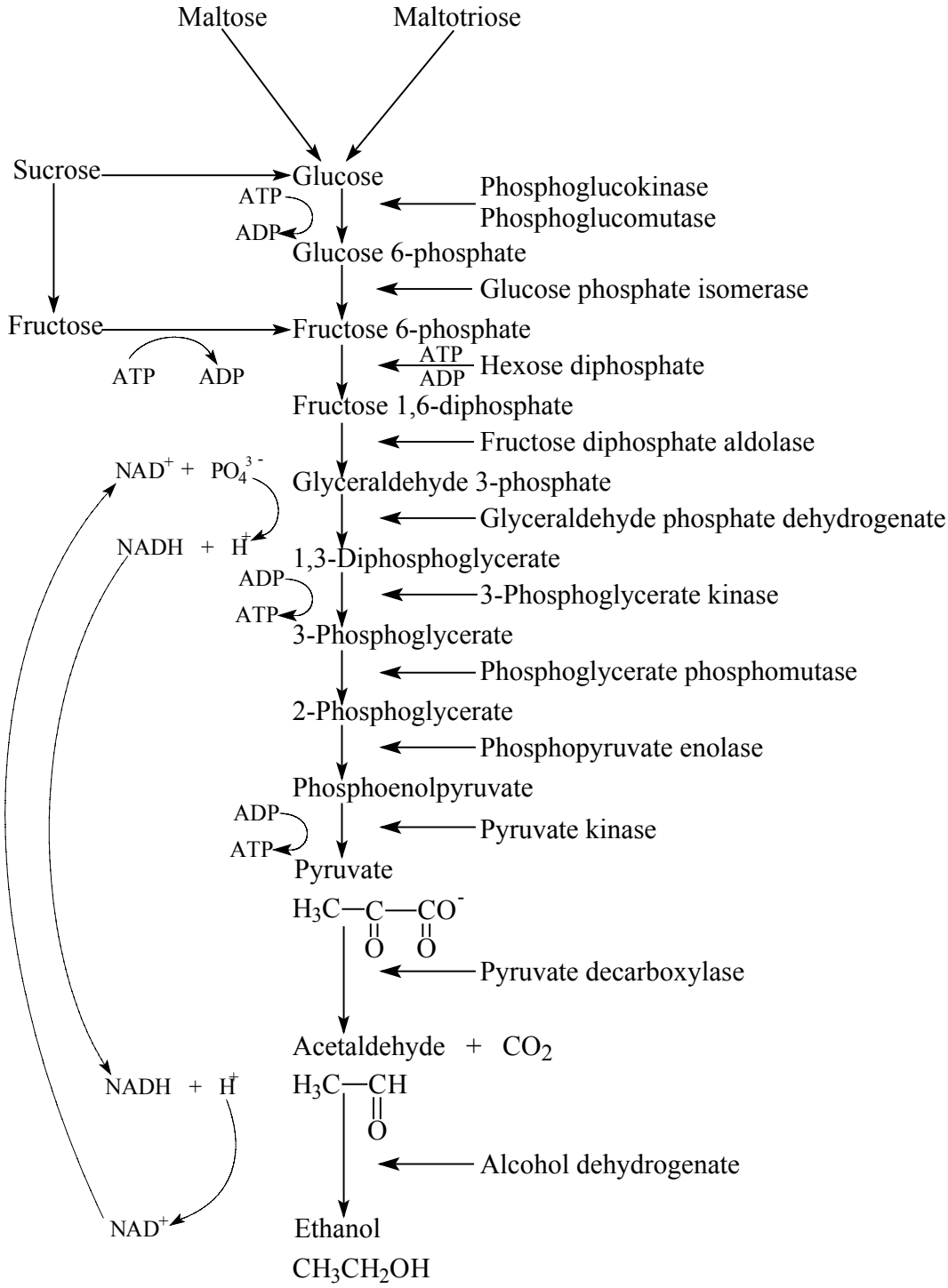

Figure 2 - The glycolytic pathway (the Embden-Myerhof-Parnas pathway)

ENVIRONMENTAL IMPLICATIONS

Carbon dioxide is a major fermentation product which has the potential to pose a risk to the environment as a 'greenhouse gas'. Not all the CO_2 produced remains dissolved in the beer since the fermentation operates at only a low head pressure (high CO_2 concentrations in the fermenting beer can have adverse effects on yeast performance and production of flavour components such as esters). The excess CO_2 is collected off the top of the fermenting

vessels, rather than allowing it to vent to atmosphere. The CO_2 is 'scrubbed' to remove impurities and the surplus may be sold for a profit to gas suppliers or in some cases, injected back into the finished product to boost the carbonation level.

ECONOMIC IMPLICATIONS

- Reduced wastage: CF avoids losses caused by stop-start operations. Surplus yeast from the CF is collected and washed countercurrent with de-aerated water to extract any beer residues. The water (containing beer extracts) is then used to dilute the fermented beer and the yeast is sold as a food material.

- Excess CO_2 is collected and may be purified and re-used. Batch plants have the disadvantage that during the first few days of fermentation, CO_2 levels are relatively low so that it is not feasible to collect until approximately the third day. CF provides a continuous supply of CO_2 which can be used in other parts of the process.

- Energy, production labour and testing costs are reduced since only five vessels are involved in the fermentation process.

- Capital costs are lower for CF since fewer fermentation tanks are required.

ROLE OF THE LABORATORY

The continuous fermentation plant generally operates in a 'steady state' fashion; test results from any one vessel in the system do not vary a great deal from day to day. The key variables tested are:

- Alcohol - measured by automatic analyser or by distillation followed by density determination

- Specific Gravity (SG) - decreases during the fermentation since the ethanol produced has a much lower specific gravity than the sugars consumed by the yeast (ie SG is highest in the Hold Up Vessel and lowest in the Yeast Separator)

- Yeast in suspension - high in CF1 and CF2 but dropping down significantly in the beer in the Yeast Separator

- pH - decreases during fermentation, yeast takes up amino acids which exist for the most part in their zwitterion forms in wort (ie their charges are neutral overall) thus conferring a relatively high buffering capacity on unfermented wort

It is the laboratory's responsibility to inform production staff if these variables fall outside the usual range of results.

Article written by Sarah L. Campbell (DB Breweries Ltd.).