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Development of a quality assurance plan for a microbrewery

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Development of a quality assurance plan for a microbrewery

By

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USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.

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DEFINITION OF TERMS

AS/NZS ISO 9000: a series of general quality system standards, being the Australian/New Zealand implementation of the ISO 9000 series.

Control (verb): To take all necessary actions to ensure and maintain compliance with criteria established in the HACCP plan.

Control (noun): The state wherein correct procedures are being followed and criteria are being met.

Control chart: a line graph used to demonstrate the trend or performance of a process.

Control measure: Any action and activity that can be used to prevent or eliminate a hazard or reduce its effect on safety to an acceptable level.

Corrective action: Any action to be taken when the results of monitoring at the QCP indicate a loss of control.

Critical Control Point (CCP): A point, place, operation or group of operations in a food manufacturing process where suitable control is exercised to eliminate or reduce the effect of a potential hazard to consumers.

Critical limit: A criterion that separates acceptability from unacceptability.

Deviation: Failure to meet a critical limit.

Flow diagram: A systematic representation of the sequence of steps or operations used in the production or manufacture of a particular beer product.

HACCP (Hazard Analysis Critical Control Point): A system by which hazards and risks associated with the manufacture, storage and distribution of foods are identified and assessed, and appropriate controls which either eliminate or reduce these hazards are implemented at specific points.

HACCP plan: A document prepared in accordance with the principles of HACCP to ensure control of hazards which are significant for the manufacture of safe food.

Hazard: The contamination of food by either microbiological, chemical or foreign body agents, such that consumers are at risk of either death, or permanent or temporary injury or illness.

Hazard analysis: The process of collecting and evaluating information on hazards and conditions leading to their presence to decide which are significant for the manufacture of safe food and therefore should be addressed by the HACCP plan.

ISO 9000: a series of general quality system standards and supporting documents published by the International Organisation for Standardisation (ISO) and serving as models for the development and implementation of quality management systems.

Microbrewery: a brewery that produces less than 15,000 barrels (1 barrel=117.3L) per year.

Monitoring: the act of conducting a planned sequence of observations or measurements of control parameters to assess whether a QCP is under control.

Quality: the totality of features and characteristics of a product that bear on its ability to satisfy stated or implied needs.

Quality assurance: all those planned and systematic actions necessary to provide adequate confidence that a product will satisfy given requirements for quality.

Quality Control Point (QCP): A step at which control can be applied and is essential to prevent or eliminate a beer quality hazard or reduce its effect on quality to an acceptable level.

Safe Quality Food (SQF) 2000: a standard that specifies quality system requirements particularly for small food producers and manufacturers, providing objective evidence of their ability to supply products that are safe and which meet customer and legislative requirements.

Verification: The application of methods, procedures, tests and other evaluations, in addition to monitoring to determine compliance with the HACCP plan.

ABSTRACT

Quality assurance (QA) has become a key factor to business success in the marketplace. Within Australia, companies normally approach QA by implementing formal systems which maintain the consistency of manufacturing processes, and hence, the quality of subsequent output. These systems have increasingly been based upon the international series of standards, ISO 9000.

In the food industry, safety is a minimum requirement for food quality. As Governments and food authorities have endeavoured to reduce the incidence of foodborne illnesses, they have promoted the implementation of additional systems developed to a specific standard for food safety, namely Hazard Analysis Critical Control Point (HACCP). However, the cost of developing and maintaining separate systems to ISO 9000 and HACCP is prohibitive to many food companies, particularly smaller operators. As a consequence, a number of alternative standards have been recently developed that are more relevant to the needs of these companies (e.g. SQF 2000, HACCP-9000).

The purpose of this study was to develop a QA plan which could be successfully applied by a particular small food manufacturer (Westoz Brewing). This was achieved by adopting a technique used in a number of these alternative standards, i.e. application of HACCP to both safety and wider quality issues. Due to time constraints, the study focussed on applying HACCP only to quality issues rather than to both quality and safety issues. In particular, these issues were associated with lager-style products manufactured at one of the client's breweries.

As a result of this research, the client was provided with a practical plan suitable for the application of a QA system to the production of a Westoz beer. In addition to reducing costs associated with maintaining an integrated system, further savings would be made due to the preventative nature of HACCP, i.e. minimisation of product reworking and waste by ensuring that more products are manufactured "right first time". The developed plan also represented an initial step towards certification to recognised quality standards such as SQF 2000.

DECLARATION

I certify that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any institution of higher education; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Signature:

Date: 17/06/98

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SECTION 1: INTRODUCTION

"Quality assurance are all those planned and systematic actions necessary to provide adequate confidence that a product will satisfy given requirements for quality " (AS/NZS ISO 8402:1994:Section 2.1).

Quality is a factor upon which business survival and success can hinge in the current marketplace. Consumers, faced with an unprecedented number and variety of products, have come to purchase items that consistently satisfy their personal requirements. As a consequence, quality assurance has assumed a role of vital importance in business.

In the food industry, quality assurance has traditionally been separated into two distinct areas, namely food safety and wider quality issues. Safety has been given priority as it represents the minimum requirement of any product in the marketplace. Internationally, food safety assurance has increasingly become preventative in nature, being based on the management system Hazard Analysis Critical Control Point (HACCP). HACCP involves the identification and control of points at which problems can arise within the manufacturing process that may present hazards in terms of food safety. A particular feature of HACCP is that it requires the establishment of processing parameters that are connected to the achievement of product safety specifications. However, assurance of food quality issues other than safety is important to companies also as it determines market competitiveness and ultimately, commercial success. This wider quality assurance has been increasingly based on management system standards such as ISO 9000. However, these standards have increasingly been seen to be more appropriate for large manufacturers than for smaller operators.

The cost and inefficiencies of maintaining separate systems for managing food safety and quality, coupled with particular criticisms of ISO 9000 by small businesses, have led to the development of a number of new, integrated systems such as the Safe Quality Food (SQF) 2000. Some of these are either partially or fully based on HACCP, attending to both food safety and quality issues simultaneously. Many experts oppose this wider

application of the HACCP system, but few challenge its subsequent benefit including the achievement of an effective quality assurance that is more practical for small-medium manufacturers.

The purpose of the present study was to adopt the concept of HACCP and develop a plan for quality assurance at a small manufacturing company, Westoz Brewing. Westoz Brewing is a new company that aims to manufacture and market beer products in Western Australia. It is currently constructing a number of small production plants or "microbreweries" around the State. These plants are a particular type of microbrewery, known as a "brewpub", i.e. premises where beer is both manufactured and marketed to consumers. In response to certain in-house research (Bagshaw, personal communication, March 22, 1997), the client aims to gain a share of the 18-25 year old market in Western Australia, predominantly marketing "lager-style" beer to these consumers.

Due to time constraints, this study focussed on the application of HACCP to quality issues other than safety. This was not intended to detract from the importance of attending to safety issues; these issues are stated in State food hygiene regulations and the national Food Standards Code. Rather, this focus was selected due to quality being perceived by the client to be of more direct relevance to his commercial interests. Another limitation of the study was that the client's microbreweries were not yet fully operational. Therefore, it was proposed that an open-structured quality assurance plan would be developed that concentrated on the manufacture of all lager-style beer at one of these microbreweries. The plan would be developed around the design of the manufacturing process for this plant. Finally, again due to time constraints, it was decided that the plan would concentrate on quality issues of most concern to of one of the client's intended niche markets- young Western Australian females (18-25yrs old).

This study should be of major significance to the client, it gaining a practical method of quality assurance. Conversely, it is though that its significance to the wider microbrewery community will be limited as it was developed for a particular brewing system. However,

much of the data obtained should be considered valuable to quality assurance development in other microbreweries. In addition, this study will add to the literature on quality assurance in microbreweries.

SECTION 2: LITERATURE REVIEW

2.1 Quality assurance

2.1.1 Definition of quality

The term "quality" has a variety of interpretations. Many of those given in dictionaries refer to the notion of a "degree of excellence". This leaves the implication that there is some scale with which products can be compared and their quality rated. However, this is not feasible as individuals have different perceptions of what constitutes product excellence. Therefore, this definition of quality does not enable manufacturers to establish and pursue any tangible goals. This has led to the development of a number of alternative definitions.

Dr Edwards Deming (1986), a pioneer of the quality movement in the 1950s, states that quality products are those that have a "predictable degree of uniformity and dependability at low cost, and are suited to the market". The concept of quality products meeting market or customer requirements has subsequently been fashioned into the phrase "fitness for use", explicitly stating the need for products to deliver expected benefits (Juran, 1988, p.2.8; Crosby, 1989, p.75). Feigenbaum (1991) asserts that quality is determined by the totality of product features and their associated benefits. In addition, he conveys a general sentiment that these customer requirements cannot be stated from within the organisation, they have to be obtained from customers through market research.

In recent times, a standard definition has been sought to eliminate the confusion caused by these different definitions of quality. Standards Australia have adopted the definition given by the International Organisation for Standardisation (ISO), stating that quality is "the totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs" (AS/NZS ISO 8402:1994:Section 2.1). Sole concepts like "fitness for use" are judged to be insufficient as they refer only to final products and do not mention other influential business activities in the "quality loop" (AS/NZS ISO 8402:1994:Section 2.1: Note 5).

This definition of quality was adopted in the present study to keep in the spirit of Standard Australia's attempts to remove the barriers to the understanding of quality, enabling its development within local industry. This conformity also allows the resulting quality assurance plan to be readily included in any future plans for certification to ISO 9000.

2.1.2 Quality as a business strategy

Quality has become a major business strategy in the last fifty years, first in Asia and more recently in the Western world. Its proponents claim that the pursuit of quality improves an organisation's market competitiveness and increases its market share. Deming (1986, p.3) asserts that these benefits are achieved in a chain reaction which begins with greater efficiencies being achieved within an organisation, and ultimately leads to business growth though the marketing of products of better quality at a lower price (see Figure 1).

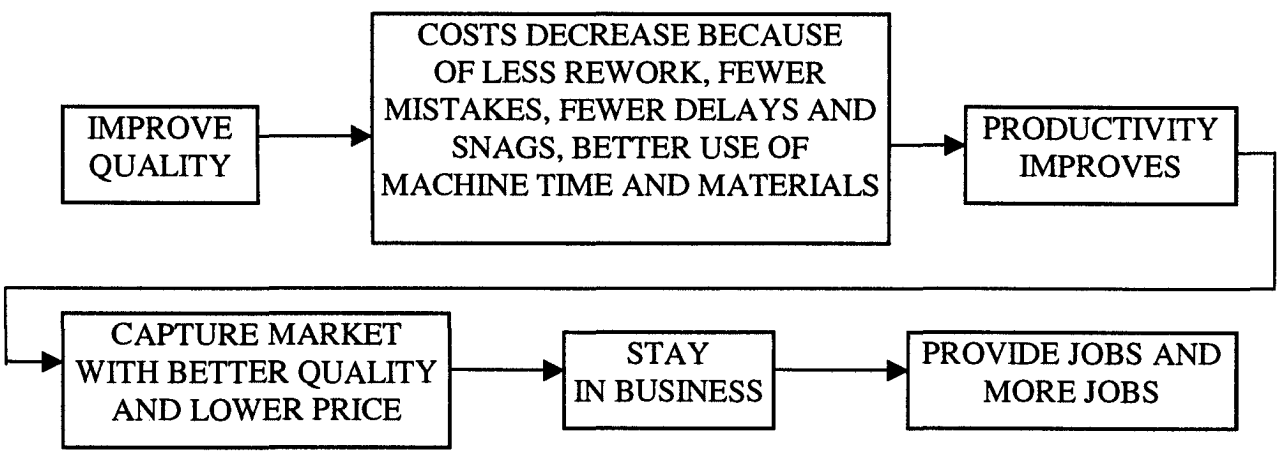

Figure 1. Deming's chain reaction

Source: Deming, 1986, p.3

The orientation to quality involves the adoption of operational methods that contrast with more traditional approaches to the management of production. In traditional manufacturing, product quality has been inspected at the end of the production line, before products are released in the marketplace. If this quality has been found to be unacceptable, products have been either reworked or discarded. This has been at a

significant cost to the organisation; Feigenbaum (as cited in Deming, 1986) states that between 15-40% of manufacturing costs are due to wasted human effort, wasted machine-time and non-productive use of labour during manufacturing.

The new "quality manufacturing" as Deming (1986) describes it, involves quality being built into products as they are being assembled. Monitoring and corrective action during processing replace final inspection and reworking of product to a certain extent, as products are increasingly manufactured "right first time". Price (1984) aptly describes quality as the "doctrine of thrift" where available resources are maximised during production. These efficiencies allow businesses to market products that are not only of improved quality but that can be offered at a lower price, sometimes being referred to as "value for money" (Creech, 1994, p.3).

As previously mentioned, the importance of being able to market quality products has become critical to business survival and success. Price (1984) states that in a marketplace where there is an excess of money pursuing a shortage of goods and services, quality is of secondary importance to the consumer. However, where there is an excess of goods, rival brands compete for consumer expenditure. Price wars are too costly for organisations to support for too long, so quality emerges as the primary arbiter.

Evidence to support a relationship between quality and business success is predominantly anecdotal. Much has been written on the supposed link between the rise of the Japanese economy during the 1960s and 1970s and the dramatic increase in quality of Japanese products (Groocock, 1986, p.4; Deming, 1986, p.3; Barrier, 1992, p.25; Newnham, 1993, p.20). This and many local success stories do indicate a cause and effect relationship, but these are not quantitative assessments that prove this success has been solely due to quality (Groocock, 1986, p.4). Some quantitative studies have been attempted to prove this relationship (PIMS as cited in Groocock, 1986; Crosby Associates Australasia 1990; Eisen & Mulraney 1992; Fisher, 1993), but they have often been criticised on the grounds of unsound methodology.

2.1.3 Major approaches to quality assurance

Two different approaches to quality assurance are currently adopted by industry. The first attends to quality at an organisational cultural level, this being commonly referred to as Total Quality Management (TQM). The other approach involves companies developing and implementing formal quality assurance systems in accordance with generic standards devised for such systems. Appropriately, this latter approach is often referred to as the Standards approach. A brief review is now made of these two approaches.

2.1.3.1 Total Quality Management

Total Quality Management (TQM) is regarded as a philosophy of business, rather than an approach to quality. The origins of TQM can be traced to the work of Walter A. Shewhart at Bell Telephone Laboratories in the 1920s. He used statistical techniques and data to effectively monitor and manage process performance. Deming took these techniques and developed a management philosophy around them, successfully trialling this philosophy in Japan during the 1950s.

There are many books and papers written on the subject of TQM, with numerous interpretations of what it involves. However, a few concepts appear to underpin its philosophy. It is heavily reliant on teamwork and decision by consensus, involving total employee involvement in an organisation. Elliot (as cited in Ferguson 1994) asserts that it is about giving people control of their work environment. Customer satisfaction is of paramount importance. A lack of customer focus leaves an organisation vulnerable to the manufacture of a product which is "a 100% quality but which no-one is interested in purchasing" (Newnham, 1993, p.20). The use of statistics is a key concept in TQM (Roberts, 1989, p.18). It eliminates management error caused by increasing the rationality in decision-making. However, Newnham (1993) contends that what really sets TQM apart from other management philosophies is the notion of continual improvement. In TQM, management is obligated to continually look for opportunities to reduce waste and improve quality.

While there has been much literature devoted to the theory of TQM, relatively little has been written to describe its implementation. Smith and Sibler (1994) prescribe some steps to implementation, however they, like Deming's 14 steps (see Table 1), are very broad in nature.

Table 1. Deming's 14 points.
Source: Deming, 1986, p.23

1. Adopt the new philosophy.
2. Cease dependence on inspection to achieve quality.
3. End the practice of awarding business on the basis of price tag alone. Instead, minimise total cost by working with a single supplier.
4. Improve constantly and forever every process for planning, production and service.
5. Institute training on the job.
6. Adopt and institute leadership.
7. Drive out fear.
8. Break down barriers between staff areas.
9. Eliminate slogans, exhortations and targets for the workforce.
10. Eliminate numerical quotas for the workforce and numerical goals for management.
11. Remove barriers that rob people of pride and workmanship. Eliminate the annual rating or merit system.
12. Institute a vigorous system of education and self-improvement for everyone.
13. Put everybody in the company to work in order to accomplish the transformation.
14. Create consistency of purpose for improvement of product and sevice.

2.1.3.2 Standards-based approach

Many Western companies have tended to forego TQM, preferring to develop formal quality assurance systems. These systems have increasingly been modelled on existing standards, the most prominent of these standards being Quality Awards criteria and the ISO 9000 series.

2.1.3.2(a) National quality awards

A number of Quality Awards currently exist around the world. Many of these have been based on the Deming Award, which began in Japan in the 1950s. Some of the more prominent awards include the European Quality Awards, the Malcolm Baldrige National Quality Awards (United States) and the Australian Quality Awards. These have not only

been established to recognise quality within industry, but also to provide a national vision for quality (Sproull, 1994, p.1).

The criteria for these Quality Awards are generally designed to represent a holistic view of a company, much in keeping with TQM. The Australian Quality Awards expands the criteria used in other similar awards by also placing considerable emphasis on the results of organisations (see Table 2). Organisations are asked to submit a summary of their operating results, financial results, employee satisfaction results and results that impact on shareholders (Sproull, 1994, p.1). This is in acknowledgement of the need for quality initiatives to improve the primary goal of companies, namely bottom line profits. In contrast, there have been many incidences of American recipients of the Baldrige Award being in financial difficulty or out of business (Cohen & van Ewyk, 1994, p.36).

Thousands of booklets outlining the criteria for the Australian Quality Awards are distributed to organisations nation-wide ("AQA Guidelines", 1995). While a large proportion of companies do not apply for these Awards, the criteria in these booklets offer businesses a template for quality assurance.

2.1.3.2(b) ISO 9000

The ISO 9000 is a series of international standards for quality assurance systems. These standards require organisations to define and detail their quality assurance procedures. Companies that develop systems to these standards gain another level of quality assurance through system auditing by a third party. If systems comply with the ISO 9000 standard, applicants are awarded certification. These certificates are valid for a three-year period with regular audits being conducted to ensure continuing conformity. It is thought that

Table 2. Australian Quality Awards criteria.

Source: Pelly 1996, p.37.

LEADERSHIP Roles of senior executives, the extent of involvement and how it enables continual learning throughout the organisation.
STRATEGY Policy and planning- development and deployment and the way in which the entire workforce is involved in the improvement of the organisation.
INFORMATION AND ANALYSIS How data is collected, analysed and used. Evaluates the capacity of the information processes to support a responsive, prevention-based approach to management.
PEOPLE Efforts to realise the potential of the workforce and how those efforts promote communication, trust, empowerment and pride in performance.
CUSTOMER FOCUS Ability to satisfy customers in an efficient and cost-effective manner.
QUALITY Of process, product and service. How processes are linked to optimise performance.
ORGANISATIONAL PERFORMANCE Evaluating success in achieving objectives. Participants must then follow a matrix which permits a translation of a subjective opinion of performance into a more objective measure and which facilitates benchmarking.

continuing conformity to these standards provides a basis for quality assurance (Hutchins, 1993, p.69).

The ISO 9000 series contains three standards for which certification is possible: ISO 9001, ISO 9002 (see Appendix 1) and ISO 9003. These differ in the scope of activities within the organisation that is seeking certification (Brown & Van-Der-Wiele, 1996, p.57). It must be emphasised that in all of these standards, wider concepts of TQM such as management culture and employee involvement are not examined (Ryall & Kruithof, 1995, p.26).

2.1.4 Criticisms of current quality assurance methods

TQM and particularly ISO 9000, have received mixed appraisals from industry. Many companies that have implemented such approaches, have expressed disappointment with the lack of results experienced (Clout, 1993, p.43; Fisher, 1993, p.181; Hinchcliff, 1993, p.42; Cohen & Van Ewyk, 1994, p.36; Ferguson, 1994, p.74).

Haigh (1993) states that a major reason for a lack of benefits experienced by many organisations has been the fact that too much has been tried too fast. The adoption of a TQM approach is a quantum leap for most businesses, and plans have been established without important aspects, such as organisational culture, being considered. Gome (1996) mentions that many consultants have been ill prepared, having little training and business knowledge, and they have offered organisations ISO 9000 kits which have been too general to be adequate when applied to specialist businesses. Cohen and van Ewyk (1994) argues that there has been a fixation on gaining certification while key quality management precepts have been ignored. In 1997, some of the founding institutions of the quality movement entered this debate with the release of *Quality, Productivity and Competitiveness*, a critical reflection on the previous decade of quality within Australia industry. Collaborating institutions included the Wider Quality Council, Australian Quality Council, Standards Australia and the Joint Accreditation System Australia and New Zealand. The report does not reject the philosophy, principles and techniques of the movement, but it does offer reasons for the problems experienced thus far (Gome, 1997, p.31).

In particular, much of the criticism surrounding ISO 9000 relates to its perceived inappropriateness for small businesses. It has been evident that small companies working towards achieving ISO certification are put under great stress (Lawson, 1993, p.41; Gome, 1995, p.52; Gome, 1996, p.39). Lawson (1993) estimates that the cost to a small firm of satisfying ISO 9000 requirements is about $15 000. This does not include the non-cash cost of staff time consumed maintaining the documentation required by the standard. In addition, studies reveal that the majority of small businesses do not recognise the benefits of such plans, generally seeking ISO accreditation out of pressure

from external sources (Bergman, 1995, p.42; Ryall & Kruithof, 1995, p.24). John Sprouster, the chief executive officer of the Australian Quality Council and one-time promoter of ISO 9000, recently indicated a change in opinion toward the standard. He states that "not only is it too expensive but it is also far too sophisticated [for small business]" (as cited in Gome, 1995). In 1996, the (then) Small Business Minister, Geoff Prosser, acknowledged another criticism of the standard, stating that "if you do the paper trail around making a product which isn't that flash, then the paper just reflects that- it doesn't make the product better" (as cited in Gome, 1996).

The present study considered the application of an alternative model- Hazard Analysis Critical Control Point (HACCP)- in quality assurance system development, an approach that is being increasingly recommended for small businesses. This approach was used to develop a quality assurance plan for one particular small business, a microbrewery.

2.2 Microbreweries

2.2.1 Definition of microbrewery

"Microbrewery" is an American term used to describe a brewery that produces less than 15,000 barrels (1 barrel=117.3L) per year (Major, 1994, p.16; Scarpa, 1996, p.112). However, this term has increasingly become a misnomer in the United States where many microbreweries have grown beyond this level of output. Experts suggest that "craft brewery" could replace this term, thus referring to a small brewery that produces distinctly flavoured beer, made with fresh, high-quality ingredients and traditional methods (Reese, 1993, p.15; Goldwyn, 1995, p.91; Scarpa, 1996, p.112). This is the type of beer that has become synonymous with this sector of the industry.

The present study adopts the term microbrewery as it remains appropriate in an Australian context, where most small breweries are presumed to be producing less than 15,000 barrels per year.

2.2.2 Manufacturing process of microbreweries

The principles underlying the general manufacturing processes have remained unchanged for centuries (see Figure 2). However, production technology has changed dramatically during this period, with a disparity emerging between technology employed in large breweries and microbreweries. This section details the major stages in the brewing process from a microbrewery context, with particular emphasis on the various technologies involved.

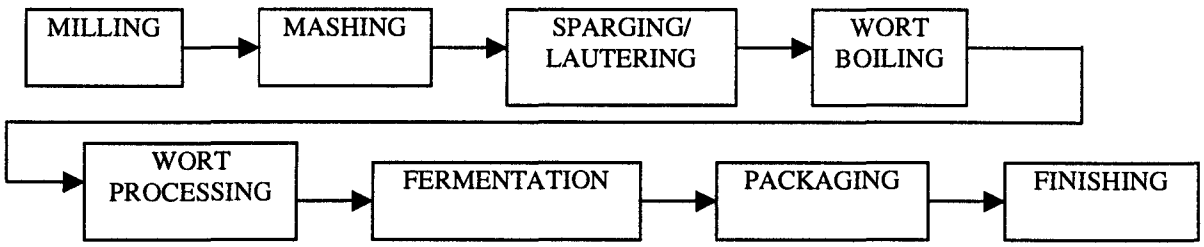

Figure 2. Principles of the brewing process.

2.2.2.1 Milling

The brewing process normally commences with the milling of malted barley. Barley is used in brewing as it contains high levels of starch, material that yields fermentable extract. It requires malting as it lacks certain attributes: diastatic enzymes to degrade starches, friability for effective milling, and the colour and flavour associated with beer. The term that is used to refer to these and all other changes that occur to barley during malting is known as "modification" (Varnam & Sutherland, 1994, p.302; Lewis & Young, 1995, p.71).

During milling, brewers aim to grind malt endosperm particles finely in order to expose a maximum amount of starch, while ensuring that malt husks remain intact to assist later in the process. In practice, this task is normally a compromise between these goals with the ideal bulk of milled malt or "grist" consisting of a spectrum of particles (Hough, 1985, p.54; Iserentant, 1995, p.47; Lewis & Young, 1995, p.85).

The favoured milling technology in the brewing industry is the roller mill, due to its superior ability to maintain malt husks (see Figure 3) (Grant, 1995, p.101; Iserentant, 1995, p.47; Lewis & Young, 1995, p.85). Large breweries tend to employ mills with multiple pairs of rolls and vibrating screens between each roll pair (Lewis & Young, 1995, p.86; Rehberger & Luther, 1995, p.258). This enables milling of different types and qualities of malt to be conducted at the same time. Conversely, microbreweries

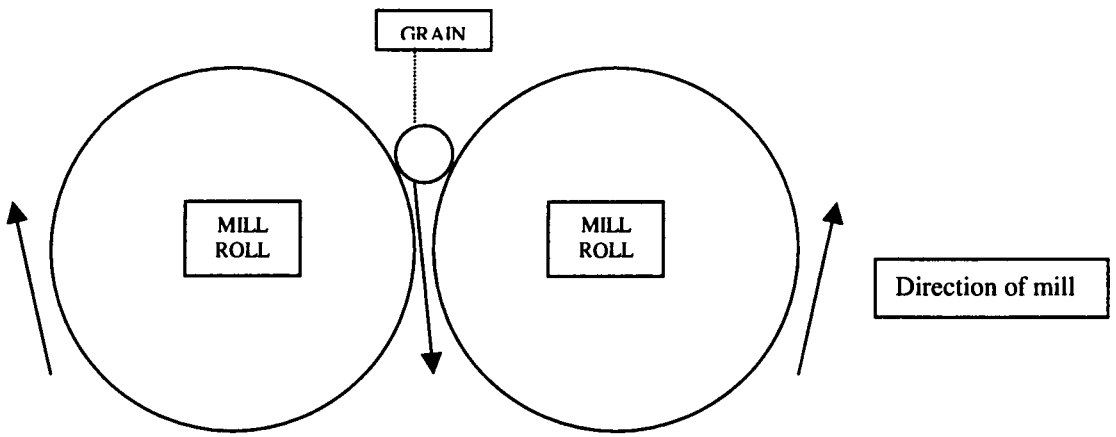

Figure 3. Action of roller mill.

normally use two-roll mills, which have single pairs of rolls. This restricts milling to well modified malts of the same type, as other malts cannot be effectively ground through a single pair of rolls with a fixed roll gap setting (Lewis & Young, 1995, p.86). However, the two-roll mill does offer microbreweries major savings in set-up and energy costs (Hough, Briggs, Stevens & Young, 1981, p.311; Lewis & Young, 1995, p.86).

2.2.2.2 Mashing

The grist is added to the mash tun with warm water, referred to as "mashing liquor" (N.B. this process step is referred to as the "mash-in"). The contents of the mash tun are then left to percolate. Alpha and beta enzymes are activated and combine to degrade malt starches to fermentable sugars, primarily maltose and disaccharide.

Large breweries tend to use a mashing process that involves a series of different temperatures (Iserentant, 1995, p.48; Rehberger & Luther, 1995, p.273). In this process, four temperatures or "rests" are used to condition poorly modified malt in order to compensate for its lack of enzymatic activity. An alternative process, involving a single mashing temperature, can also be used. This is known as "infusion mashing" and involves grist being added to the mash tun with mashing liquor of a particular temperature, referred to as the "strike temperature"; this temperature is that required for overall mash temperature of between 63-68°C, after heat losses to the grist and the mash tun itself. It is at this temperature that the amylase enzymes are activated. This temperature is subsequently maintained via insulation provided by the tun's stainless steel casing. Due to the use of a single temperature, infusion mashing requires use of well-modified malt. Microbreweries are more inclined to use this form of mashing as it incurs significantly lower energy costs (Hough, 1985, p.58; Lewis & Young, 1995, p.89).

2.2.2.3 Sparging/lautering

The dextrinous liquid or "wort" produced during mashing, is clarified or "lautered"as it passes through malt husks remaining on the bottom of the mash tun, on its way to the kettle. Hot water or "sparging liquor" is gradually added to the tun to rinse or "sparge" spent grains of remaining extract and to deactivate amylase enzymes.

While large breweries often perform sparging and lautering activities in a vessel known as a lauter tun, microbreweries often economise by using adapted mash tuns (see Figure 4) (Lewis & Young, 1995, p.99; Rehberger & Luther, 1995, p.278). In either alternative, the vessel is equipped with a false perforated bottom to allow wort to flow or "runoff" to the kettle. Malt husks gather on this bottom to form a natural filter bed. Wort is then allowed to runoff to the kettle, with sparging liquor being gradually introduced to the mash tun when wort is reduced to approximately 1-2 inches above the mash bed. Sparging liquor is added at a temperature ranging between 72-78°C in order to reduce

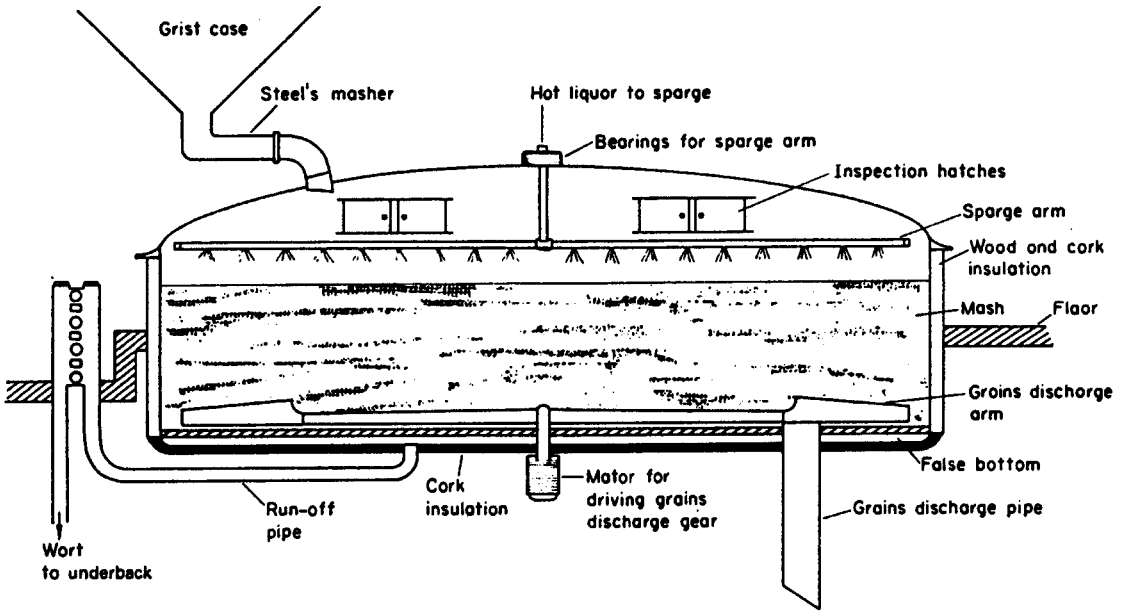

Figure 4. An adapted mash tun.

Source: Hough, 1985, p.58.

wort viscosity for easy runoff, to maximise extract solubility and to inactivate amylase enzymes (Hough et al, 1981, p.293).

2.2.2.4 Wort boiling

Wort is boiled with hops for a period of between 45-90 minutes. Hops impart resins and essential oils to the wort, with their subsequent isomerisation giving the wort bitterness and hop aroma, respectively. In addition, hop polyphenols assist certain protein precipitation during boiling.

Boiling has a number of secondary effects on the wort. Microorganisms that cause off-flavours in beer are eliminated, and the wort is sterilised. Some clarification occurs as phenolic substances react with protein matter forming large molecular complexes, collectively referred to as either "hot break" or "trub". These complexes precipitate and sediment (Hough, 1985, p.86; Rehberger & Luther, 1995, p.292). Many volatiles that cause off-flavours such as dimethyl sulphide are removed by distillation. This distillation also causes some concentration of the wort. Wort colour and flavour develop during

boiling due to non-enzymatic browning reactions, caramelisation and oxidation of polyphenols.

Wort is boiled in "kettles" which are large cylindrical vessels, normally constructed from stainless steel. These vessels have internal heating systems and utilise the insulation of stainless steel casing to maximise energy efficiency. However, it is not uncommon for this casing to be made from copper in microbreweries, although this is usually done more for aesthetic appeal than for any production purposes (Grant, 1995, p.101).

2.2.2.5 Wort processing

Hot break is removed, and the wort is cooled and aerated to provide optimal conditions for yeast metabolism during fermentation.

Large breweries tend to remove hot break in a vessel known as a "whirlpool" (Hough, Briggs, Stevens & Young, 1982, p.157; Moll, 1991, p.159; Varnam & Sutherland, 1994, p.335). This device is a vertical cylinder into which wort is added at high velocity and at an angle to the side of the vessel. Sustainable circulation is induced and the hot break forms a compact cone on the base of the vessel. However, microbreweries often remove hot break in the kettle, using finings and introducing a standing period to maximise sedimentation (Varnam & Sutherland, 1994, p.335; Lewis & Young, 1995, p.144) (N.B. finings are highly negatively-charged alginates that tend to coagulate positively-charged proteins to increase the weight of the hot break). Often, microbreweries maximise this sedimentation by creating a swirling action with paddles.

Wort cooling is achieved in all breweries via a heat exchanger. Air or oxygen is most commonly supplied to the wort by artificial injection. However, microbreweries using dried yeast often aerate wort by simply agitating the wort as it enters fermenting vessels (Hough, 1985, p.91; Gamble, personal communications, July 30, 1997). This is adequate as many dried yeast's require lower levels of oxygen.

2.2.2.6 Fermentation

Fermentation commences as the wort is inoculated, or "pitched", with yeast. Yeast metabolises fermentable matter in the wort, creating by-products of ethanol, carbon dioxide (CO_2) and a large number of minor compounds. This conversion was first recognised by Gay-Lussac (see Figure 5).

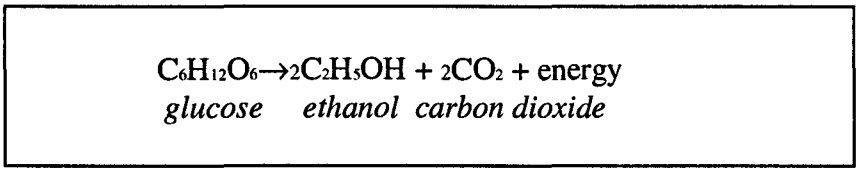

Figure 5. Gay-Lussac equation.

Source: cited in Hough, J.S., Briggs, D.E., Stevens, R., Young, T.W., 1981-1982, p.783

This conversion begins with the aerobic formation of pyruvate via the Embden-Meyerhof Parnas pathway, the enzymatic pathway for the breakdown of glucose (Varnam & Sutherland, 1994, p.297; Munroe, 1995, p.337). Pyruvate is subsequently converted to acetaldehyde when the yeast has expended wort oxygen, with acetaldehyde itself being later reduced to ethanol, CO_2 and the other products of fermentation.

All brewing strains of yeast are of the species *Saccharomyces cerevisiae.* However, brewers tend to retain an earlier classification that differentiates between two types of yeast: *S. cerevisiae* and *S. carlsbergensis* (sometimes referred to as *S. uvarum*) (Hough, 1985, p.121; Lewis & Young, 1995, p.173). These two yeasts have traditionally been used to produce two distinct beer styles, *S. cerevisiae* in ale production *and S. carlsbergensis* in lager production. Ale yeasts perform at optimal temperatures of between 15-25°C, with fermentation being completed within 3-5 days. Excessive production of CO_2 causes the yeast to float to the top of the wort. Lager yeasts operate between 8-15°C with fermentation being completed in 5-7 days. Consequently, CO_2 evolves gradually and yeast is allowed to remain toward the bottom of the wort. Lewis and Young (1995) state that this distinction between different types of yeast is artificial as

the characteristics of both beer styles is more dependent on choice of raw materials and manufacturing process. In addition, breweries are now producing lagers with ale-yeasts which are being encouraged to accumulate at the bottom of fermenting vessels at the end of fermentation (Hough, 1985, p.121; Munroe, 1995, p.343).

Although microbreweries often adapt vessels such as dairy tanks to economise, specially designed cylindroconical vessels are used in fermentation (see Figure 6). These vessels allow for simple harvesting of the yeast after fermentation (Varnam & Sutherland, 1994, p.320; Iserentant, 1995, p.49; Munroe, 1995, p.349). In addition, their vertical shape allows fermentation to be completed rapidly as evolving CO_2 bubbles agitate the wort.

2.2.2.7 Finishing

Newly fermented wort or "green beer" is immature in flavour, excessively turbid and undercarbonated. These factors are corrected by a series of processes or alternatively, by the traditional practice of secondary fermentation.

In large breweries, "finishing" involves a short period of maturation, followed by filtration and the injection of CO_2. Green beer is normally stored at low temperatures for 7-10 days after fermentation. The major purpose for this storage is to mature beer flavour by reducing certain objectionable constituents such as diacetyl (Hough, 1985, p.138; Lewis & Young, 1995, p.213). As an additional benefit, a large proportion of yeast and protein matter forms a sediment which can then be separated from the beer. This sedimentation is aided by the addition of finings that attach to and consequently increase the weight of yeast and proteins. As a consequence of the capacity of cylindroconical

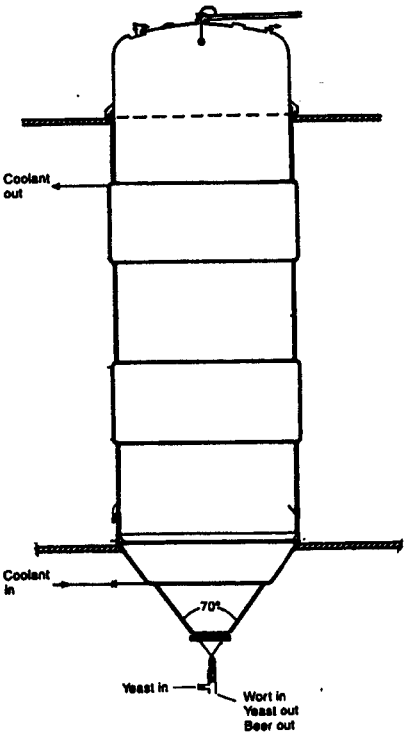

Figure 6. Cylindroconically-shaped fermentation vessel.
Source: Lewis & Young, 1995, p.164.

fermentation vessels to allow an easy yeast harvest, fermentation and maturation can now occur in a single vessel.

Once this period of maturation has completed, the beer is filtered. Cartridge filters are occasionally employed when beer is of low turbidity or when small quantities of beer are being processed. However, depth filters using filter aids such as kieselguhr (diatomaceous earth) are more regularly employed (Lewis & Young, 1995, p.215; Lucarotti, personal communications, August 27, 1997). Filter aids gather to build a filter bed that consists of numerous long and complex routes through which the beer must pass. The beer is clarified as suspended particles, unable to thread these routes, become caught on the filter aid.

Finally, filtered beer or "bright beer" is carbonated. This is done either in-line or in a holding tank. In-line carbonation can be carried out whenever beer is being transferred, except upstream from kieselguhr filtration where CO_2 bubbles disturb the filter bed.

While some microbreweries perform these finishing methods, many do not as they require significant capital investment. Instead, microbreweries normally apply the traditional practice of secondary fermentation (Hough, 1985, p.136; Lewis & Young, 1995, p.211; Munroe, 1995, p.360; Cook, personal communications, June 11, 1997). This process involves some yeast being allowed to remain in beer so as to ferment a limited amount of residual sugars. This is either done as beer is packaged or while it is held in a pressurised tank at the brewery. Beer absorbs evolving CO_2 while the additional time in storage matures beer flavour. Beer is partially clarified in accordance with Stokes Law; i.e. suspended particles gradually sediment in beer due to its low density and viscosity (Hough et al, 1982, p.701; Lewis & Young, 1995, p.213). However, due to time constraints and agitation in distribution, some turbidity inevitably remains. Consequently, the application of secondary fermentation is usually restricted to the manufacture of ales and other dark coloured beer which are able to partially mask this turbidity (Cook, personal communications, June 11, 1997; Gamble, personal communications, July 30, 1997).

2.2.2.8 Packaging

Beer is normally packaged in glass bottles, aluminium cans and stainless steel kegs. Due to both market and economic reasons, local microbreweries primarily package beer in kegs.

Kegs have spears or extractors screwed into their openings which allow gas to be transferred to the beer surface, pressurising beer through extraction tubes for dispense. They are filled either under pressure or with gravity with the spear acting as a seal, preventing the introduction of air.

In large breweries, kegged beer is normally pasteurised to kill vegetative cells that shorten the shelf life of the product. Microbreweries generally do not pasteurise beer as it has a deleterious effect on flavour (Hough, 1985, p.148; Nash, 1988, p.510; Kamimura & Kaneda, 1992, p.470). However, microbrewery beer that has undergone secondary fermentation is protected from this spoilage, as remaining yeast outcompetes these cells for available nutrients (Cook, personal communications, June 11, 1997). Other beer must remain in cold storage for as long as possible prior to its dispense, in order to minimise this spoilage.

2.2.3 Consolidation of the brewing industry

Microbreweries have existed within the brewing industry since its earliest beginnings. Indeed, up until the eighteenth century, brewing was considered a cottage industry, being entrusted to publicans and private brewers (Mathias, 1959, p.xxii; Bracegirdle, 1973, p.176). It was not until the Industrial Revolution that factors emerged which allowed the formation of large breweries, leading to the subsequent reduction in significance of microbreweries.

The development of new technologies was instrumental in the increase of brewery size. The introduction of pasteurisation and refrigeration increased the shelf life of beer and improved its stability in transit (Bracegirdle, 1973, p.333; Gourvish & Wilson, 1994, p.35). In conjunction with the expansion of the rail system, this allowed for wider distribution of bulk beer. As marketing zones grew, so too did the size of individual brewing plants (Gourvish & Wilson, 1994, p.44). Economies of scale were soon found in mass production and advertising; subsequent production savings being passed onto consumers in the form of lower prices. Microbreweries were generally unable to compete with these prices, with many being forced from the market (Monckton, 1966, p.221; Gourvish & Wilson, 1994, p.110).

Consolidation of the industry continued through most of the twentieth century. Prohibition, raw material shortages and intensifying competition through advertising and prices were factors that conspired to leave markets dominated by a small number of

brewing conglomerates (Bates, 1993, p.235; Grant, 1995, p.98). This significantly reduced the number and diversity of products in the market as these organisations, in pursuit of production economies, restricted their manufacturing to a limited number of products which were rather homogeneous in nature and predominantly in the "lager-style" (Re, 1990, p.30; Grant, 1995, p.98).

Towards the latter part of the twentieth century, growing consumer dissatisfaction saw microbreweries take opportunities to supply the market with small batches of alternative beer. It was found that consumers were willing to pay higher prices for this beer. The establishment and subsequent growth of this sector of the market has led to a period in brewing history that has been referred to the "Golden Age of Brewing" or the "Beer Renaissance" (Warner, 1991, p.28; Bates, 1993, p.237; Grant, 1995, p.99).

2.2.4 The Beer Renaissance

The Beer Renaissance has gradually become a worldwide phenomenon. However, evidence indicates that its origins are in the United Kingdom and North America. During the 1970s in the United Kingdom, an organisation called the Campaign for Real Ale (CAMRA) formed to draw attention to the demise of traditional British ale ("The Specialty Beer Revolution", 1988, p.37; Modern Brewery Age, 1989, p.29; Bates, 1993, p.235). At the time there was much public sentiment for retaining British traditions, and CAMRA subsequently received considerable publicity and public support (Modern Brewery Age, 1989, p.29). This demand was initially ignored by large breweries, which allowed a number of microbreweries to enter and supply small quantities of ale to the market.

Similar consumer demand also encouraged the establishment of a number of microbreweries in Canada and the United States during the 1970s. However unlike the British experience, these breweries have had a considerable impact on the market. It is reported that the US microbrewery sector grew at an annual rate of 40% throughout the 1980s and first half of the 1990s (Major, 1994, p.16; Melcher, Dallas & Woodruff, 1995, p.70; Student, 1995, p.34). In 1993, its annual production surpassed one million barrels

for the first time, at a retail value of $900 million ("The Business of Beer", 1994, p.25). This growth has been particularly startling considering that the general beer market has been steadily contracting since the 1970s.

2.2.5 Microbreweries in Australia

The history of the Australian brewing industry parallels that of its British and American counterparts. Harvey (1994) reports that consolidation of the industry throughout the twentieth century reduced the number of operating plants in Australia from 190 at the beginning of the century to 17 by 1980. In addition, the majority of these plants were owned by two major brewing conglomerates who accounted for 95% of domestic beer sales (Warner, 1991, p.28; Harvey, 1994, p.153). In the 1980s, changing consumer demand allowed a number of microbreweries to be established to supply niche markets. However, unlike in America and to a lesser extent in the United Kingdom, the success of Australian microbreweries was short-lived. This has been attributed to a number of factors.

In 1988, the Federal Government released a Budget that had severe repercussions on microbrewery profitability (Sageser, 1991, p.26; Thorpe, 1992, p.17; Hahn, 1995, p.40). Excise tax on beer was reduced by 50%, but a 20% sales tax was imposed on the wholesale price of beer. Microbreweries, having to market their products at relatively high prices to recoup relatively high manufacturing costs, consequently lost margin and profits. Microbrewery representatives have continued to lobby Government for a tiered taxation system, pointing to Germany where such a system allows large breweries and microbreweries to co-exist (Hahn, 1995, p.39). To date, the status quo has been maintained.

Carlton and United Breweries (CUB) and Lion Nathan, the two major brewing companies in Australia, gradually increased their marketing effort in the premium-priced end of the beer market (Kennedy, 1995, p.1; Strickland, 1996, p.17). This strategy was undertaken to protect profits that were diminishing due to the steady contraction of the total beer market. Where once they traded in a market with only limited competition from imported

beer, microbreweries now faced major competition from an increasing number of local brands. In addition, CUB and Lion essentially gained control of the market when they acquired successful microbreweries such as Matilda Bay Brewery and Hahn Brewery (Warner, 1991, p.28; Sampson, 1994, p.58).

The onset of the economic recession towards the end of the 1980s also had a significant impact on microbrewery profits. There was a significant fall in the purchase of most premium-priced goods including microbrewery beer. There are no official figures for this but it is indicated in the fall of imported beer sales which dropped from 14.5 million litres in 1989 to 10.5 million by mid-1992 (Gluyas, 1993, p.27).

These factors led to another period of consolidation within the local industry, with microbreweries either being forced out of the market or having to amalgamate in order to survive.

2.2.6 Factors influencing the potential expansion of microbreweries

Current market conditions are favourable for the establishment of a microbrewery. Experts claim that recent intense marketing by breweries has finally arrested the contraction of the beer market. Foskey (1997) claims that consumer attitudes toward both product quality and diversity have remained in the market, pointing to the revival of imported beer sales. Balfour (as cited in Strickland,1996) maintains that the Australian beer market remains the least developed of all Westernised countries. However, the beer market remains highly competitive and there seems to be certain factors that tend to influence the success of a new microbrewery.

One of these factors concerns the form of the microbrewery. Fay (1996) and Cook (1997) state that microbreweries are more profitable as brewpubs, i.e. locations where beer is both manufactured and marketed to consumers. This structure eliminates the distribution costs that are usually shared between wholesalers and retailers.

The operating capacity of individual microbreweries has to reflect consumer demand for their products. Overcapitalisation has been a common factor in the demise of many microbreweries in Australia and around the world (Fay, 1996; Gamble, personal communications, July 30, 1997). These operators have overestimated initial consumer demand and have been left with inefficient plants and outstanding bank loans.

As previously mentioned, microbreweries must now compete in a niche market where there are a number of competing brands. Product novelty is no longer able to compensate for inept business management (Hamel & Schreiner, 1988, p.47; Fay, 1996). Microbreweries must have these business skills available, particularly in the area of marketing.

However, Papazian (1990) and Fay (1996) have found that the major factor behind a microbrewery's growth and longevity is the quality of its products. It is, therefore, surprising to learn that few microbreweries maintain any type of formal quality assurance (Siebel, 1995, p.13; Yuil, personal communications, 1997).

2.2.7 Reasons for the lack of quality assurance in microbreweries

Many of the reasons for the lack of quality assurance in microbreweries are typical of those of small business. These include lack of capital, personnel, expertise and time. These constraints prevent companies from developing and maintaining quality assurance systems to standards such as ISO 9000. One aspect of ISO 9000 which is particular prohibitive to microbreweries is monitoring. While monitoring technology has developed rapidly in the brewing industry, this has largely been done for the purposes of large breweries. Consequently, much of this technology is not practical in microbreweries.

Weissler (1995) states that the brewing industry has always placed great significance on the quality of its beer, pointing to legislation such as the German Reinheitsgebot which outlawed the adulteration of beer. As the industry has matured, analytical technology has been developed to evaluate the quality of beer throughout the brewing process. During the twentieth century, international professional organisations of master brewers, brewing

chemists and brewery personnel have issued official methods of analyses. These methods have become the tools of quality assurance in the industry and have come to form the basis for raw material contracts (Thomas, 1989, p.17). However, these methods were specifically designed for the needs of large breweries and their use is impractical in microbreweries. One of the aforementioned organisations, the American Society of Brewing Chemists, has recognised this problem, including seminars in its annual meeting to discuss this matter (Papazian, 1991, p.24).

In this study, a quality assurance plan was developed which requires minimal use of these analytical procedures and which also did not require a burdensome level of record-keeping, in stark contrast to systems developed to standards such as ISO 9000. In so doing, quality assurance for the client's microbrewery becomes both effective and more practical. This plan was based on the concept of an existing quality system in the food industry, Hazard Analysis Critical Control Point (HACCP).

2.3 Hazard Analysis Critical Control Point (HACCP)

2.3.1 HACCP Concept

Hazard Analysis Critical Control Point (HACCP) is a system that aims to assure the manufacture of safe food. It achieves this by systematically identifying, assessing and controlling hazards to food safety that occur within the manufacturing process. It is preventative in approach, focussing on maintaining adequate measures to control these hazards rather than relying on product analysis and corrective action for quality assurance. In doing so, not only does it assure the manufacture of safe food, but it also eliminates the use of resources wasted on extraneous considerations.

HACCP was developed during a joint project of the Pillsbury Company, National Aeronautics and Space Administration (NASA) and Natick Laboratories in the late 1950s (Bauman, 1992, p.1; Campden Food and Drink Research Association, 1992, p.1; Mortimore & Wallace, 1994, p.2; Bavota, 1997, p.33). The objective of this project was to ensure food for the space plan that was 100% free of pathogens and toxins. The project team soon found that conventional quality systems involving end product testing

were inappropriate as 100% assurance would require every product unit to be tested. Unlike in other industries, this was not practical with food as testing would destroy all manufactured product.

Alternative quality systems were sought, and the team finally arrived at a proven engineering system called Failure Mode and Effect Analysis (FMEA). This system considers potential problems at each stage in an operation along with their possible causes and likely effect, before deploying effective control mechanisms. This approach differed from convention in that it was preventative rather than corrective, monitoring and controlling the quality of products during processing instead of maintaining control in post-production.

HACCP is a system derived from FMEA, and is based upon certain underlying principles. This system was originally based on three principles (hazard analysis and risk assessment; determination of critical points (CCPs); monitoring of CCPs), but in 1989 four additional principles were added to allow for more effective management of the system (Paulus, 1993, p.25). These seven principles are now described.

PRINCIPLE 1 Conduct a hazard analysis.

HACCP begins with the identification of all hazards that could occur at each stage in the manufacturing process along with control measures that either prevent them from occurring or minimise their effect on product safety to acceptable levels. These control measures may already exist within the considered process or may need to be included. This analysis is guided by a flow diagram, a full description of the sequence of steps in the manufacturing process, from incoming raw materials to the finished product.

PRINCIPLE 2 Identify the Critical Control Points (CCPs).

Once hazards and control measures have been identified, it is necessary to establish where control is critical to assure the manufacture of safe food. These are known as the Critical Control Points (CCPs).

PRINCIPLE 3 Establish critical limit(s).

Critical limits are criteria that separate acceptability and unacceptability at the CCPs.

PRINCIPLE 4 Establish a system to monitor control of the CCP.

Monitoring systems are developed to assess whether CCPs are operating within critical limits, i.e. whether they are "under control". These generally involve observation and measurement procedures.

PRINCIPLE 5 Establish the corrective action to be taken when monitoring indicates that a particular CCP is not under control.

Corrective actions are specified to bring the process back under control and deal with product that has been manufactured during process deviation.

PRINCIPLE 6 Establish procedures for verification to confirm that the HACCP system is working effectively.

Verification involves the application of methods, procedures, tests and other evaluations, in addition to monitoring to determine compliance with the HACCP system and its effectiveness.

PRINCIPLE 7 Establish documentation concerning all procedures and records appropriate to these principles and their application.

Records have to be kept to demonstrate that the HACCP system is operating under control and that appropriate corrective action has been taken for any deviations from the critical limits. This will demonstrate safe product manufacture.

These principles have steadily gained international acceptance. This acceptance has been assisted by official recognition from the United States National Advisory Committee on Microbiological Criteria for Foods (NACMCF) and the World Health Organisation (WHO), through the Codex Alimentarius Commission. These organisations have

published HACCP principles and guidelines for the application of HACCP (Codex Alimentarius Commission, 1991 ;National Advisory Committee on Microbiological Criteria for Foods, 1992). These guidelines are used as the basis for HACCP plan development in many manufacturing committees, consultancy groups, Government agencies and Food Research Organisations (see Appendix 2 for Codex's HACCP guidelines).

The indications from governments are that HACCP will eventually become a mandatory requirement for all businesses within the food industry. The British Government has recommended the use of HACCP following findings of the Richmond Report (1990). The US Department of Agriculture currently uses HACCP during meat and poultry inspections. The Council Derivative 93/43 of the European Union (EU) (1993) proposed the use of HACCP for all food manufacturers. In May 1997, the Australia New Zealand Food Authority (ANZFA) released a preliminary draft of its national food hygiene standard. McCaughey (as cited in "Food Authority Develops", 1997) stated that "the proposed food hygiene Standard is the fundamental structure that will underpin food hygiene regulations into the next century and around the world". This Standard obliges organisations to produce safe food through plans based on HACCP.

2.3.2 Relationship Between HACCP and ISO 9000

Quality management systems involve all activities that occur in a company to ensure that quality objectives are met. In this respect, HACCP can be considered such a system that specifically attends to one of these objectives, namely product safety. ISO 9000 is also a quality management system, but safety is only one of the quality issues that it considers. Experts state that an integral relationship exists between these two systems in the food industry.

ISO 9000 and HACCP compliment each other. Whereas ISO 9000 ensures that process specifications are satisfied 100% of the time, HACCP gives assurance that these specifications are appropriate for the control of product contamination. ISO 9000 does not guarantee product quality, whilst HACCP does not ensure product consistency. In a

way, HACCP can be viewed as a sub-system within the general framework of ISO 9000, ensuring that process specifications are connected to product safety. Many experts believe that it is only through implementation of both these systems that a company is assured of producing safe food consistently (Luther-Sproule cited by "The ISO/HACCP Debate", 1997, p.256; Mortimore & Wallace, 1994, p.191; Paulus, 1993, p.24). This coexistence is possible as various HACCP elements are identical to elements of ISO 9000.

This integral relationship between HACCP and ISO 9000 has been established with the recent development and trademarking of the HACCP-9000 system by the National Sanitation Foundation (USA) (McAlpine, personal communications, 1997; McGregor, 1996, p.41). This is system is now being promoted in Australia by Standards Australia. The system involves integration of HACCP, ISO 9000 and good manufacturing practices to provide a comprehensive approach to food safety. In addition, maintenance of the resulting system incurs significantly lower costs than those associated when a company maintains separate systems.

The Codex Alimentarius seems to support such integrated approaches. It states that, "the application of HACCP is compatible with the implementation of [other] quality management systems such as the ISO 9000 series, and is the system of choice in the management of food safety within such systems" (Codex, 1997; Randell, personal communications, October 08, 1997).

2.3.3 Application of the HACCP concept to food quality issues other than safety

Interest is growing in extending the application of HACCP to quality issues other than safety. The benefits of such an approach include assurance that process specifications are connected to wider product quality, and also the significant reduction of resource spent on product analysis and corrective action.

Many experts oppose this application of the HACCP system, mentioning that it should deal exclusively with food safety issues (Webb & Marsden, 1995, p.169; Campden Food

& Drink Research Association, 1992, p.58). They indicate that there is a great danger that the significance of HACCP as an internationally accepted method for product safety would be greatly diminished if its application was extended to other quality issues. However, there are few arguments that the philosophy inherent in the HACCP concept (ie identification of potential hazards and control measures to prevent them from occurring) is not equally applicable to other quality issues. The Codex Alimentarius Commission, while not formally supporting this wider application of the HACCP system, does acknowledge that the HACCP concept can be used to address other food quality issues. This is indicated in its HACCP guidelines, which reads "while the application of food safety was considered here, the [HACCP] concept can be applied to other aspects of food quality".

Safe Quality Food (SQF) 2000 was the first quality assurance system standard to adopt the HACCP concept to attend to both safety and wider food quality issues (see Appendix 3 for SQF 2000:1997). This system was developed in 1994 by the Western Australian Department of Agriculture's Trade and Development Unit. The system integrates the HACCP concept and elements of ISO to manage both safety and wider quality issues. It was specifically designed for small food producers and manufacturers that were unable to meet the costs involved with both ISO 9000 and HACCP systems (McAlpine, personal communications, 1997).

Other significant features of the SQF 2000 are

- some elements of ISO 9000 have been omitted in SQF 2000. These were deemed to be of lesser relevance to small business.

- in keeping with general opinion, safety issues are distinguished from other quality issues. CCPs remain synonymous with food safety, while process points where control is critical to other quality issues are referred to as Quality Critical Points

(QCPs). These QCPs are determined by quality specification tolerance, and the potential impact of their associated hazards on business.

- SQF 2000 is accredited by third parties, offering participating companies another level of quality assurance.

Early results from the SQF 2000 plan appear positive. The SQF 2000 pilot project focussed on the production of the Redglobe variety of table grapes within Western Australia. Reports claim that various growers implementing SQF 2000 plans have experienced increased sales of up to 1200% (McAlpine, personal communications, October 16, 1997). These results have encouraged a current total of 76 producers within Australia to gain certification; interest is also being shown abroad from foreign food authorities such as the Ministry of Agriculture and Fisheries (MAF) in New Zealand (Ryan, 1997, p.5).

In this study, this wider application of the HACCP concept was considered. In particular, it was used to develop an open-structured quality assurance plan for the client's brewery. Due to time constraints, safety issues were not considered. This was not a comment on the importance of attending to safety issues, and it was strongly recommended that provision be made for these in any quality system. However, the client perceived the selected focus of this study to be of more direct relevance to his commercial interests.

SECTION 3: METHOD

3.1 Developing the quality assurance plan adopting the HACCP concept

The following section describes the development of the quality assurance plan for the Westoz microbrewery. This involves the application of a series of steps which are examined in Section 3.1.1–3.1.8.

3.1.1 Assemble the study team to develop the plan

Appropriate product knowledge and expertise was necessary to develop an effective quality assurance plan. The client did not have this level of expertise, so information was gained from a number of other sources. This included a team of advisors, approached via telephone and the Internet. Physical assembly of the team was not possible, so the plan was developed by intermittent correspondence with team members.

The scope of the plan was also identified, taking into consideration the various constraints of the study.

3.1.2 Identify quality issues to address

It was necessary to identify which of the many attributes of lager-style beer the plan would attend to. In order to maintain a true quality focus, it was thought imperative that these should be identified by consumers. It was decided that due to time constraints, this study would focus on the quality issues of most concern to only one of Westoz's intended niche markets: young Western Australian females (18-25yrs old). Due to time constraints, this research was limited to focus group work. Stewart and Shamdasani (1990) and Meilgaard, Civille and Carr (1991) state that focus groups are commonly used to reveal information on a topic that is not really well-known. While it is normally recommended that this type of qualitative data is supported by quantitative evidence, this additional data could not be obtained due to the time constraints of the study. However, use of this qualitative data was considered permissible as it was supported by expert opinion.

The method devised for the focus group is now described.

Sample
Ten subjects were selected through convenience sampling.

Equipment/materials
- beer (Guinness, Belhaven Scottish Ale, Victoria Bitter, Cascade Pale Ale, Grolsch Premium Lager, Miller Genuine Draft, Emu Export Lager, 1857 Pilsner)
- sampling glasses

Procedure
A preceding beer sampling session stimulated the focus group discussion.

Subjects were evenly spread out across the classroom to minimise the effect of colleague suggestions on individual assessments. Subjects were given eight different samples over the session. Beers were sampled in lots of two to allow time for assessments to be made. Each sampling glass had been filled with 100mls of the particular beer out of view of the subjects. This had been done to eliminate the effect of branding on sensory perceptions, as found by Allison and Uhl (1964). Subjects were encouraged to record their personal perceptions of the samples.

Once the sampling had concluded, the group was assembled and quality issues of beer discussed. This discussion was recorded on audiotape.

Analysis
The focus group discussion was transcribed and analysed. All issues pertaining to beer quality were noted.

The specific results of this focus group are discussed later in Section 4.1.2.

3.1.3 Construct the flow diagram

A flow diagram was constructed to assist with later hazard analysis. This was undertaken in collaboration with the client. It depicted the general Westoz process to be used for manufacturing lager-style beer. Details included all process steps, raw materials and brewery equipment involved in production, and included the cleaning regime.

As the brewery construction was not completed during the course of this study, on-site verification of this flow diagram was not possible. For the purposes of the study, it was assumed to be accurate, although the client was strongly advised to validate the flow diagram once the microbrewery was operational. Any differences would require adjustments to be made to the quality assurance plan.

3.1.4 Conduct the hazard analysis

All hazards that were reasonably expected to occur at each step in the process were identified.

Control measures were then identified for each of these hazards. These included the necessary control measures that had and had not been already proposed by the client.

3.1.5 Determine Quality Control Points (QCPs)

Campden Food and Drink Research Association (1992) states that decision trees can be equally well applied to new processes during product development as well as to existing processes. In this study, QCP identification was guided by an adaptation of the Codex decision tree (see Figure 7).

The following are the series of questions associated with this QCP decision tree:

Q.1 Do control measure(s) exist for the identified hazard?

If the answer to this question was YES, then the study team considered Q.2.

If the answer to this question was NO, the team considered whether control was necessary at this step. If control was considered not necessary at this step, then it was not a QCP and the decision tree was applied to the next identified hazard. However, if it was necessary, then the step, process or product was modified to gain control over the specified hazard.

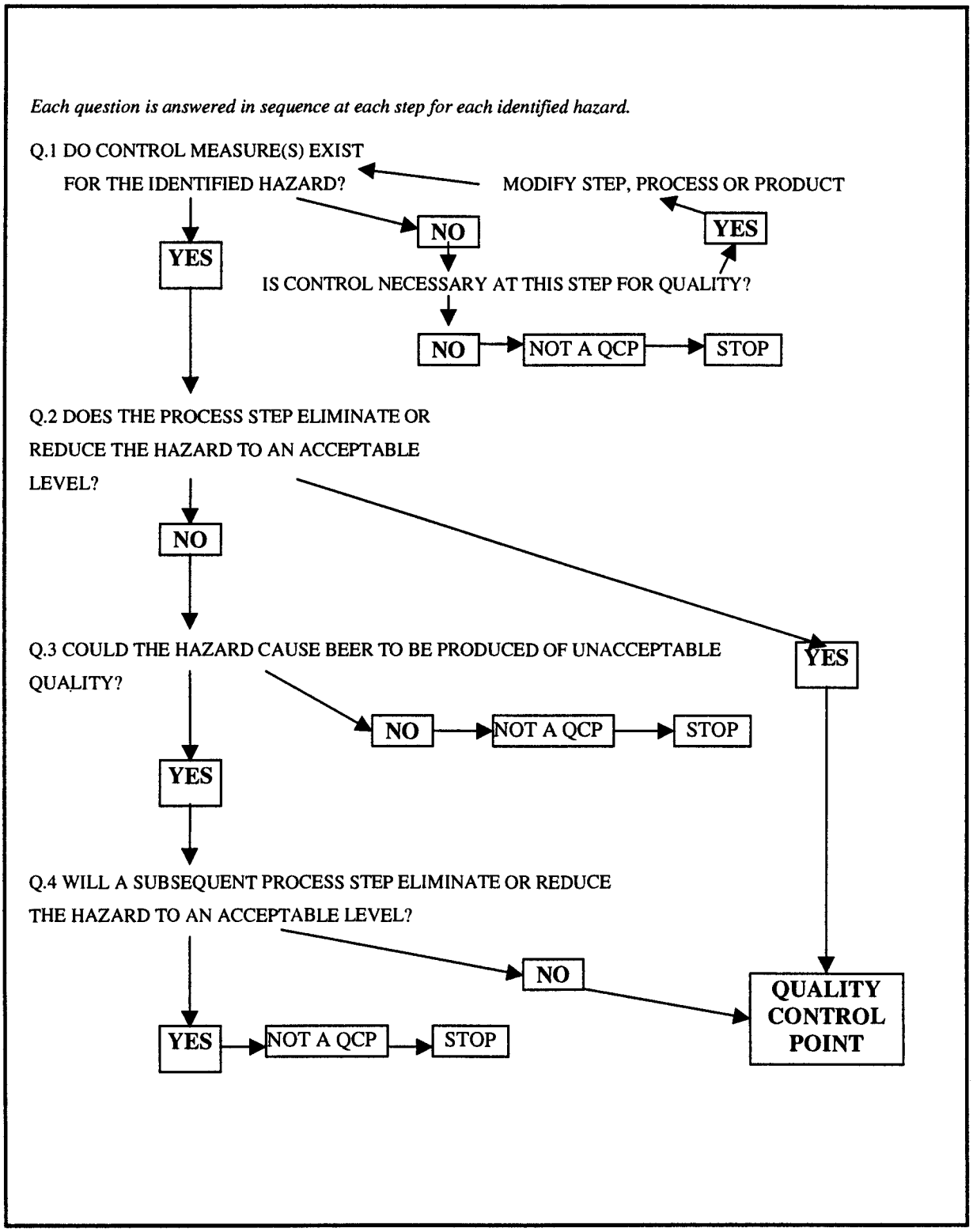

Figure 7. QCP decision tree.

Q.2 Does the process step eliminate or reduce the hazard to an acceptable level?
This question identified those process steps that were designed to eliminate or reduce the hazard to an acceptable level.

If the team considered the answer to Q2 to be YES then the process step under consideration was a QCP for that hazard.

If the answer to Q2 was NO then Q3 was considered for the same process step.

Q.3 Could the hazard cause beer to be produced of unacceptable quality?
The study team considered flow diagram data and drew on their own knowledge to answer this question. If the team was unsure of the answer to this, the YES response was always assumed.

If the answer to this question was NO, then the step was not a QCP and the decision tree was applied to the next identified hazard.

If the answer to this question was YES, then Q.3 was applied to the same hazard.

Q.4 Will a subsequent process step eliminate or reduce the hazard to an acceptable level?
The study team proceeded sequentially through the remaining steps in the process to consider if hazards are controlled at a later step. This question ensured that unnecessary QCPs were not attended to.

If the answer to this question was YES, then the step was not considered a QCP and the decision tree was applied to the next identified hazard.

If the answer to this question was NO, then the process step was considered to be a QCP. Again, it was then necessary to identify exactly what factors in the step were critical (e.g. an ingredient, process step) before applying the decision tree to the next identified hazard.

3.1.6 Establish control at QCPs

Control at QCPs is achieved in 3 stages: establishment of critical limits; monitoring of critical limits; and provision of corrective actions for critical limit deviation.

Critical limits

Many critical limits were specific to individual products manufactured at the brewery. It is recommended that these are determined by precedence or a more scientific method such as Regression Analysis (see Appendix 4 for description of Regression Analysis), in an operational brewery. As this study focussed on the development of an open-structured plan suitable for the production of numerous beers at the brewery, this data was not required. In addition, many of the critical limits that were common to the production of all beers also needed to be established on-site at the brewery due to the particular conditions of the Westoz manufacturing environment. Due to the delayed progress of brewery construction, these limits were also unable to be set.

Due to these constraints, this section focussed on identifying those critical limits that would be common to all products at the particular Westoz plant. In addition, it indicated critical limits that were specific to individual products, and those that were common to all but that had to be established on-site were identified.

Monitoring system

Monitoring methods were identified to ensure that critical limits were being maintained. A number of options were given for QCPs wherever possible. It was assumed that as the brewery was to be a one-man operation, monitoring would be the sole responsibility of the brewer.

Corrective actions

Corrective actions were identified to contend with both the process and affected product following process deviation. Due to time constraints, the effect of certain corrective actions (e.g. the effect on beer colour of a specified amount of roasted barley) could not be established. It was suggested that the client determine this in the brewery by Regression Analysis during product development.

3.1.7 Establish method of verification

A method involving end-product sampling was developed to verify the effectiveness of the quality assurance plan on an ongoing basis. Auditing procedures were not thought to be appropriate on a routine basis, as the brewery was managed and operated by a single worker (N.B. however, it was recommended that external quality consultants be contracted on a more intermittent basis if at all affordable, to audit quality assurance plans). Control chart theory was incorporated into this method to indicate whether the process was operating consistently and to assist identifying any impending "out of control" situations.

Control chart theory is based on the assumption that two types of variation may exist in a manufacturing process, random (common) variation and special (assignable) variation (Groocock, 1986, p.235; Shainin & Shainin, 1988, p.24.3; Mittag, 1993, p.9; Bissell, 1994, p.101). Shewhart (1931) mentions that the former (e.g. machinery vibration, mains voltage fluctuations, unclear instructions) is inherent in the process, and that it cannot be removed without making basic changes to the process. Conversely, a special cause (e.g. faulty incoming materials, incorrect test/inspection, a change in method/procedure/operator) is more readily identified and removed, if an effective diagnostic plan is operating. A process is deemed to be "in control" if no special causes are present to influence the process.

Control charts enable manufacturers to monitor processes, measuring process performance and indicating where causes of variation exist or may exist in the future. They are based on normal distribution theory, the assumption that the range of observed

phenomena is restricted about a common mean and standard deviation. A process is deemed to be in statistical control when no special causes are active and sample data is normally distributed (i.e. are within 3 standard deviations of the population mean). This means that the process is producing a predictable quality of output. Conversely, when the quality of output does not appear to conform to a normal distribution, it is deemed to be out of control. The process is producing output of an unpredictable quality, due to the presence of special causes.

A process may be in statistical control yet may still produce output which does not meet specifications. This is due to inadequacies in the design of the process. To correctly modify the process so that product specifications fall within control limits, manufacturers must make changes to the process.

3.1.8 Construct record sheets and record keeping procedures

In addition, to the documentation already given in Section 3.1.2–3.1.7 (e.g. hazard analysis, QCP identification, the quality assurance plan), formal record sheets were developed to record monitoring, corrective action and verification data. Procedures were also established for the analysis and storage of these records.

3.2 Pilot test

The quality assurance plan was pilot-tested in a simulation of the proposed Westoz manufacturing process as described by the client (see Appendix 5 for simulation details). Due to time constraints, pilot testing was restricted, namely to QCPs associated with boiled wort's specific gravity and colour.

The pilot test was also designed to demonstrate how control charts are developed and used in the verification process. It is common for this to involve sampling of 25 consecutive batches of product, however due to time constraints, this study sampled 10 batches. Shainin and Shainin (1988) state that, while giving less accurate control limits, sampling of 10 batches in control chart construction is both adequate and often done in

practice. Raw materials were not analysed as they were taken from the same batch, thus being considered as fairly homogeneous in nature.

Samples

6 (100ml) samples from 10 batches (each group of samples is referred to as a "subgroup") of boiled wort were taken from the kettle with a beaker. The boiled wort, being fairly homogeneous in nature, was then cooled to below 35°C in an ice bucket.

Equipment

Hydrometer

Colour standard (see Appendix 6 for construction of colour standard)

400ml beakers

Data collection

1. Samples were placed in 400ml beakers and individually compared with the colour standard. Individual scores were then recorded.
2. The specific gravity of samples was then measured and recorded, with temperature corrections being made (N.B. the specific gravity of beer is influenced by temperature).

(see Appendix 7 for sample data of pilot testing).

Data analysis

$\overline{X}$ and R control charts were constructed for boiled wort colour and specific gravity using the collected data. Control lines were constructed in accordance with Shainin and Shainin (1988).

The middle line of control charts were calculated as follows

$$\text{For } \overline{X} \rightarrow \overline{\overline{X}} = \Sigma \overline{X}_i/n \ (\overline{X} = \text{subgroup mean})$$

$$\text{For R} \rightarrow \overline{R} = \Sigma R_i/n \text{ (R= subgroup range)}$$

The upper control limits were calculated as follows

$$\text{For } \overline{X} = \overline{\overline{X}} + A_2 \overline{R}$$

$$\text{For R} = D_4 \overline{R}$$

The lower control limits were calculated as follows

$$\text{For } \overline{X} = \overline{\overline{X}} - A_2 \overline{R}$$

$$\text{For R} = D_3 \overline{R}$$

N.B. 'A_2', 'D_3' and 'D_4' depend on subgroup size; these values are taken from table cited in Juran and Gryna (1988).

Subgroup means were plotted on resulting control charts. If all points were within the control limits, the process was deemed to be in statistical control. If any points fell outside the control limits, the process was not in statistical control.

SECTION 4: RESULTS AND DISCUSSION

The following sections discuss the results of both the development and pilot testing of the quality assurance plan.

4.1 The quality assurance plan

The development of the quality assurance plan is reported as a series of steps from Section 4.1.1–4.1.8.

4.1.1 The study team

The study team consisted of quality assurance and production experts from the local brewing industry in addition to prominent brewing academics based in Europe (see Table 3 for team description). The information reported in this study was derived from the comments and advice given by members of this team.

Table 3. The study team.

NAME	ORGANISATION	POSITION/DEPARTMENT
Dr Keith Thomas	***University of Sunderland, UK.***	*Brewlab*
Dip.-Ing. Hans-Jurgen Golz	***VLB Berlin, Germany***	*Quality Assurance*
Mr Peter Smith	***Brewtech, Australia***	*Quality Manager*
Mr Neil Cooke	***The Swan Brewery Co., WA***	*Brewing Development Co-ordinator*
Mr Franklin Lucarotti	***The Swan Brewery Co., WA***	*Laboratory Co-ordinator*
Mr Kenneth Gawenda	***Matilda Bay Brewing Co., WA***	*Learning Facilitator*
Mr Stephen Hollis	***The Swan Brewery Co., WA***	*Operations*
Mr George Anceschi	***Matilda Bay Brewing Co., VIC***	*Production Manager*
Mr Roy Cook	***Fremantle Brewing Co., WA***	*Manager*
Mr Gavin Gamble	***Steam Packet Brewing Co., VIC***	*Manager*
Mr Peter Yuil	***Joe White Maltings, WA***	*Production Manager*
Mr Timothy Holliday	***Mauri Integrated Foods, QLD***	*Laboratory Technician*
Ms Judy Goy	***Australian Hop Marketers, TAS***	*Document Controller*

The scope of the plan covered all processing activities from the receipt of raw materials through to the packaging of the final product.

4.1.2 Quality issues

The quality issues that were identified by focus group subjects included physical and sensory characteristics of beer. These included colour, flavour, alcohol content, carbonation, clarity and head.

Colour

Colour is the most important visual element of food (Cardello, 1996, p.37). In addition to mere aesthetic appeal, consumers use colour as an indicator of the nature of other food elements such as flavour and nutrition value. Butcher (1988) found that dark-coloured beer, despite its actual taste, is perceived to be ale-like in flavour: sweeter and heavier in taste.

Beer colour appeared to be of significant importance to focus group subjects. They tended to indicate a preference for a mid-range amber colour (Miller Genuine Draft, Emu Export Lager), while beers at either extreme (Guinness, 1857 Pilsner) were strongly rejected.

Flavour

Jellinek (1985, p.159) states that flavour is "the total impression of taste, odour, kinesthetic, temperature and pain sensations perceived through tasting". Hough, Briggs and Stevens (1971), and Meilgaard and Peppard (1986) mention that taste and odour (or "aroma") are the most important of these sensations in terms of beer flavour. Amongst all beer characteristics, flavour is considered to be the most important for consumer appeal.

Subject responses tended to support these views, with great significance being given to the flavour of individual beers. A strong preference was shown for lager-style beers (Emu Export Lager, Victoria Bitter). These beers were described as being slightly bitter, slightly hoppy in aroma and of light "body" (an attribute associated with the viscosity of beer).

Alcohol content

"Alcohol content" refers to the level of ethanol in beer. In Australia, there is evidence that people in the 18-25 year category in Australia prefer full strength, i.e. beer containing 4.2-5.5%alc/vol. (ABS Catalogue No. 4123.0:1993).

Although subjects did not appear to perceive varying levels of alcohol content amongst individual beer samples, a strong preference for full strength beer was revealed during discussions. It was thought that this preference was influenced by cultural factors.

Carbonation

Australian consumers are known to prefer beer that is highly carbonated (Gawenda, personal communication, July 01, 1997; Hollis, personal communication,July 24, 1997).

Subject responses generally supported this view, hence commenting during discussions that undercarbonated or "flat" beer was considered highly undesirable.

Clarity

Australian consumers are also known to demand beer of high clarity (Gawenda, personal communication, July 01, 1997; Hollis, personal communication,July 24, 1997). Focus group subjects conformed to this preference when they discussed the unpleasantness of visible turbidity.

Foam

Relatively low levels of beer foam, or "head", are exhibited in Australian beers. Subjects mentioned that they regard the head to be of some importance, declaring that it is used as an indicator of a beer's level of carbonation; head retention indicates the length of time that beer remains drinkable after being dispensed.

In summary, the quality issues that were addressed during the focus group included colour, flavour, alcohol content, carbonation, clarity and head. Colour and flavour were issues that received most comment and evoked the greatest hedonic response. It was thought that these factors were primary criteria used by consumers in purchasing decisions. However, it was thought that the very fact that other issues had been mentioned, indicate that they have an influence on these purchasing decisions. Consequently, it was necessary to attend to all of the identified quality issues.

In the following section, the manufacturing process utilised by Westoz was clearly identified. This was done in order to assist with the later identification of hazards to these beer attributes that exist within this process.

4.1.3 Process flow

The following section describes the manufacturing process to be performed at the Westoz plant. All of the included details were produced by the client and the researcher in unison.

4.1.3.1 Floor plan

Figure 8 illustrates the floor plan of the Westoz microbrewery.

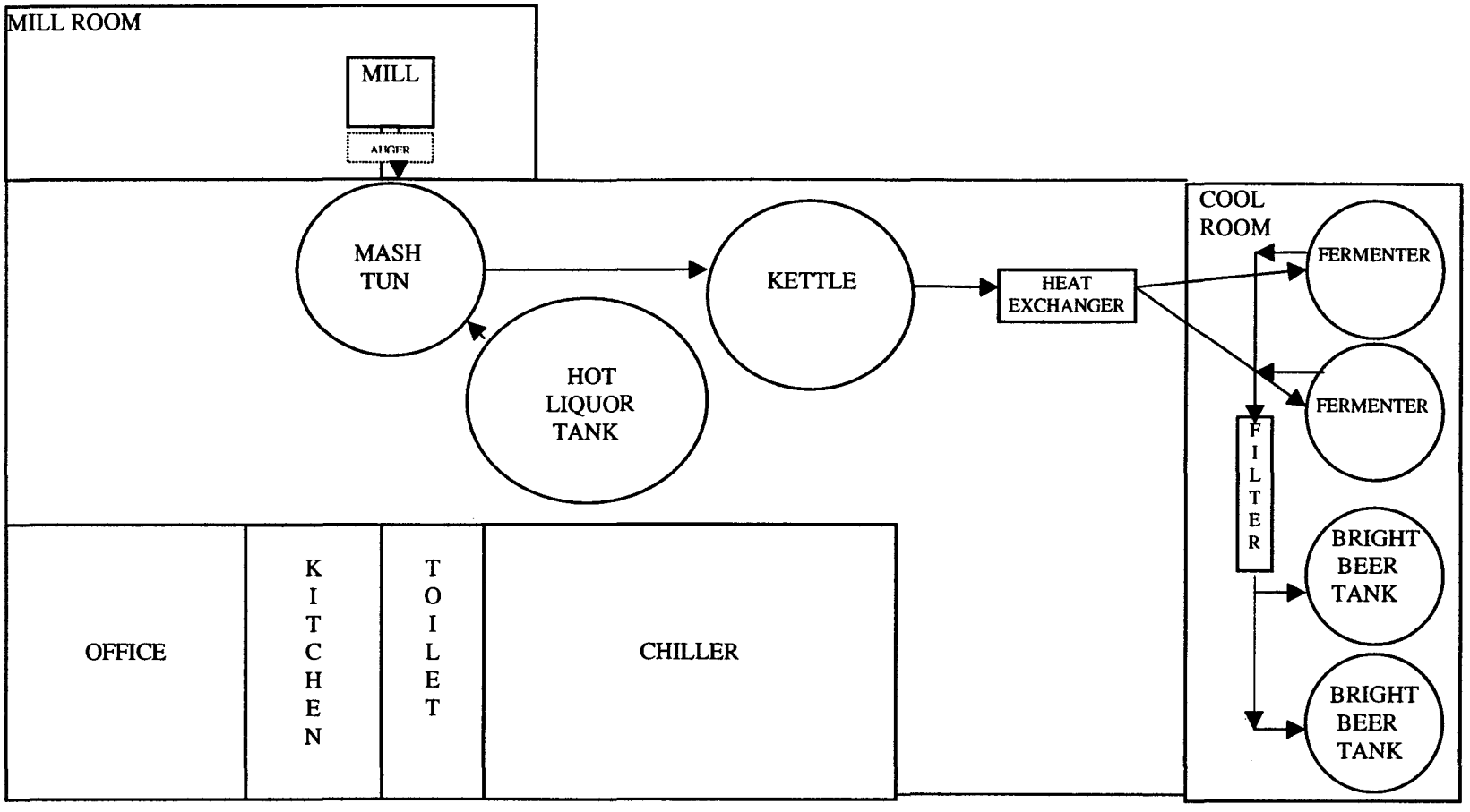

Figure 8. Westoz floor plan.

4.1.3.2 Description of plant machinery

The major equipment used at the Westoz microbrewery is described in Table 4.

Table 4. Westoz brewing equipment.

TYPE	PURPOSE	FEATURE(S)
Hot liquor tank	*Heat water for mashing, sparging and cleaning*	•cylindrical-shaped •capacity=3000L •electronic thermostat
Mill	*Crack grain*	•6-inch, 2 roll mill •processes 5kg/minute
Auger	*Transport grist to mash tun*	•archimedes screw action
Mash/lauter tun	*Mashing/sparging/lautering*	•cylindrical-shaped •capacity=1800L •false bottom with 1mm perforations and 15 drop runoff valve
Kettle	*Wort boiling*	•cylindrical-shaped •capacity=2000L •internal calandria
Heat exchanger	*Wort cooling*	•enclosed, plate heat exchanger •processes 10 litres/minute
Fermentation/maturation vessels	*Fermentation and maturation*	•cylindrical-shaped •pressurised •capacity=1600L
Filter	*Clarify beer*	•cartridge filter •processes 10litres/minute
Bright beer tanks	*Carbonation and settling*	•cylindrical-shaped •capacity=2000L •inlet for CO_2 injection •pressure regulators
Kegs	*Packaging*	•capacity=50L

Note. All vessels have attached sightglasses and thermometers, and are constructed from stainless steel.

4.1.3.3 Cleaning of plant machinery

Cleaning is a two-stage process involving the removal of soil from surfaces, followed by the elimination of microorganisms with appropriate sanitizing materials. Table 5 represents details of the cleaning regime proposed for Westoz.

Table 5. Westoz cleaning regime.

EQUIPMENT	CLEANING METHOD	REGULARITY
Hot liquor tank	Manually scrubbed with metal scourer using caustic soda. Rinsed with hot water.	every 3 months
Mill	Manually wiped clean with a clean rag.	after every use
Auger	Manually wiped clean with a clean rag.	after every use
Mash/lauter tun	Manually scrubbed with metal scourer using caustic soda. Rinsed with hot water.	after every use

Table 5. Westoz cleaning regime (cont.).

EQUIPMENT	CLEANING METHOD	REGULARITY
Kettle	Manually scrubbed with metal scourer using caustic soda. Rinsed with hot water.	after every use
Heat exchanger	Strong caustic detergent is flushed through the heat exchanger, followed by an appropriate sanitiser (e.g. hydrogen peroxide). Finally, hot water is flushed through the heat exchanger.	after every use
Fermentation/ maturation vessels	Strong caustic detergent is flushed through the fermentation/maturation vessels, followed by an appropriate sanitiser (e.g. hydrogen peroxide). Finally, hot water is flushed through the vessels.	after every use
Filter	Strong caustic detergent is flushed through the filter, followed by an appropriate sanitiser (e.g. hydrogen peroxide). Finally, hot water is flushed through the filter.	after every use
Bright beer tanks	Strong caustic detergent is flushed through the bright beer tanks, followed by an appropriate sanitiser (e.g. hydrogen peroxide). Finally, hot water is flushed through the vessels.	after every use
Kegs	Hot caustic soda is flushed through kegs, followed by a water rinse.	after every use
Piping	All piping in the system is flushed with hot caustic soda, followed by an appropriate sanitising agent. This is then followed by a water rinse.	after every use

4.1.3.4 Flow diagram

The Westoz manufacturing process is illustrated in Figure 9 and this is discussed in Table 6. The client proposed that beer would be manufactured in batches of 1000 litres. Initially, he envisaged producing one batch per week.

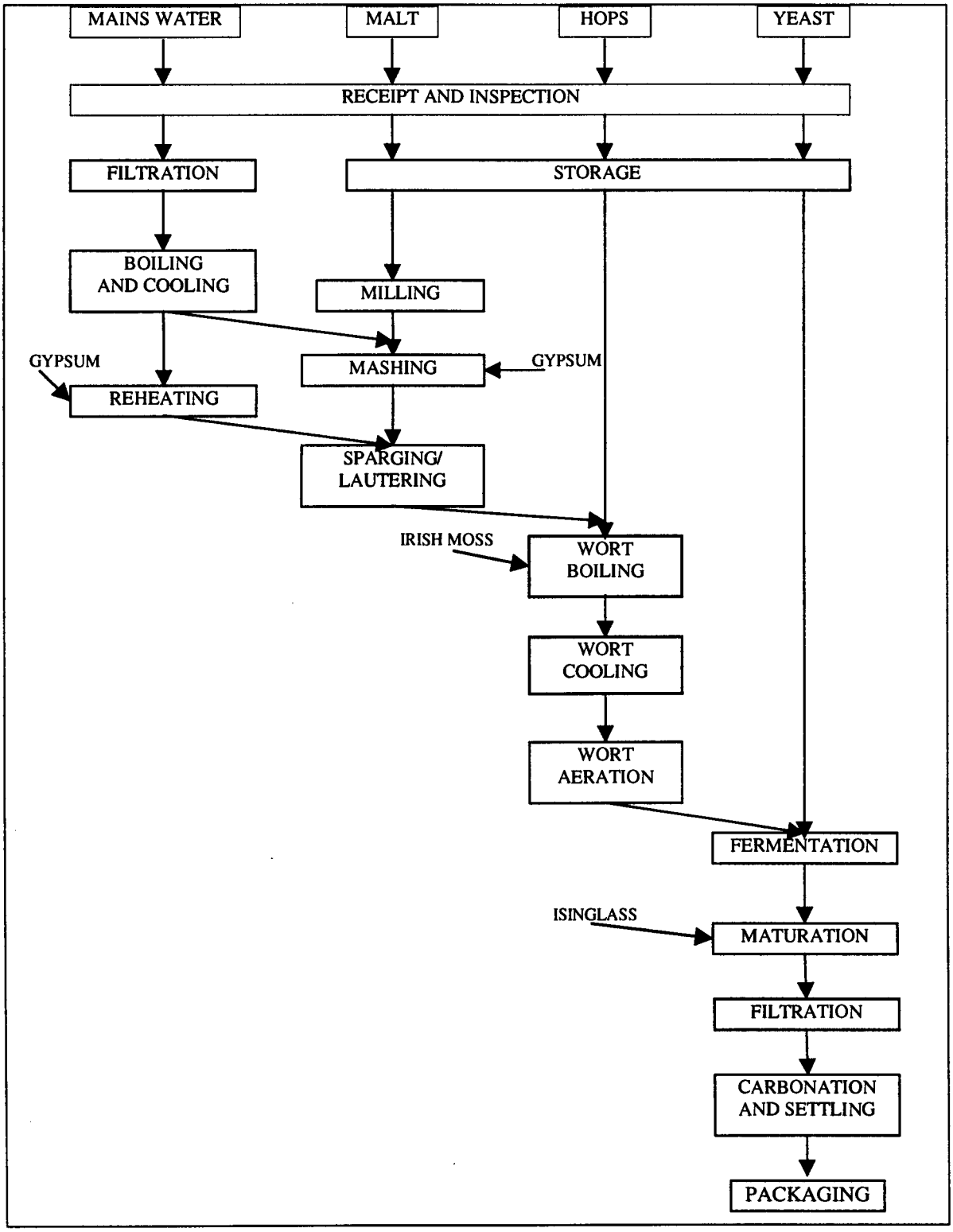

Figure 9. Westoz flow diagram.

Table 6. Description of Westoz process flow.

PROCESS STEP	DESCRIPTION
Receipt of raw materials	•malt is delivered fortnightly; hops, every 3 months; yeast, every month N.B. quantities of raw materials delivered are enough to produce 1 batch per week •malt flavour and modification assessed by sensory evaluation •hop aroma and bitterness assessed by sensory evaluation •yeast viability tested by sensory evaluation; fermentability tested by observation on addition to wort sample
Storage of raw materials	•malt is stored in sacks in the mill room for a maximum of 40 days •hops are stored in air-tight containers in the refrigerator for a maximum of 3 months. •yeast is stored in the cool room for a maximum of 30 days.
Processing of mains water	•3000L of mains water is filtered and measured into the hot liquor tank •water is then boiled for 60minutes •water is then cooled to the required strike temperature, being inspected before it is sent.
Milling	•mill gaps are set and malt sacks are weighed. •the contents of the sacks are then fed through the mill •resulting grist is continuously augered to the mash tun
Mashing	•350L of mashing liquor is sent with the grist to the mash tun •as the "mash-in" is completed, mash pH is measured using indicator paper. If necessary, it is adjusted to between 5.2-5.5 with either gypsum (calcium sulphate) or carbonate salts. •the mash is then circulated around the tun for 30 minutes, before the husks are allowed to form a filter bed on the base of the vessel
Reprocessing of water for sparging	•water in the hot liquor tank is reheated to 80°C •water pH is then measured and, if necessary, is adjusted to between 6.0-6.5
Sparging/lautering	•the mash tun's runoff valve is opened and wort allowed to flow to the kettle •650L of hot liquor is gradually pumped to the mash tun once the wort has been reduced to about 3-6cm above spent grains
Wort boiling	•the kettle is switched on as soon as sufficient wort has entered to cover its heating element •once it is brought to the boil, bittering hops are weighed and added, with the mixture being allowed to boil for 35 minutes. Irish Moss is then measured and added to the kettle •10 minutes later, aromatic hops are weighed and added •the kettle is turned off after an additional 15 minutes, and allowed to stand for a further 30 minutes to allow the hot break to settle
Wort cooling and aeration	•wort is then pumped from the kettle through the heat exchanger and onto the fermenting vessel •temperature is monitored at the fermenting vessel to ensure that the appropriate pitching temperature has been achieved •as the wort enters the fermenter, a specially designed nozzle sprays it around the vessel to encourage oxygen pick-up
Fermentation	•yeast is measured and pitched as soon as a third of the wort has entered the fermenting vessel •wort is then allowed to ferment until it has been reduced to a required specific gravity, monitored daily using a hydrometer
Maturation	•the cool room thermostat is then reduced to -1°C and the green beer is then allowed to mature for a specified period of time •24 hours into this period, isinglass is measured and added to the vessel in order to assist sedimentation of suspended material

Table 6. Description of Westoz process flow (cont.)

Filtration	•beer is then pumped from the fermentation/maturation vessels through the filter and onto bright beer tanks (N.B. the cool room thermostat is maintained at -1C)
Carbonation and settling	•carbon dioxide is injected into beer in bright beer tanks, adjusting carbonation levels as required •beer remains in tank for 24 hours to allow beer to absorb carbon dioxide and sedimentation of further chill haze (N.B. the cool room thermostat is maintained at -1C)
Packaging	•kegs are individually attached to the filling head on the side of the bright beer tank. This is done by hand. •the filling valve is then opened and beer allowed to flow to kegs under gravity •filling valve is then closed when the tank sightglass indicates that 50L has transferred •kegs are then detached from the filling head and placed into the chiller room

In the following section, the Westoz manufacturing process was analysed for factors that would be hazardous to the quality issues identified in the focus group (colour, flavour, alcohol content, carbonation, clarity and foam). This analysis was based on the preceding process flow diagram and details, and involved a review of relevant literature and consultation with study team members.

4.1.4 Hazard analysis

Each step in the Westoz manufacturing process was analysed for potential hazards. These process steps were attended to in sequential order.

4.1.4.1 Receipt of raw materials

Quality raw materials are vital to the manufacture of quality beer. Many hazards exist during the receipt of raw materials.

Malt.

A. Malt that yields low levels of extract significantly reduces the level of fermentable matter present in the wort. Consequently, the client was advised to inspect the potential extract of incoming malt.

B. Poorly modified malt has low levels of diastatic (starch digesting) activity, poor friability and excessive nitrogen content (Varnam & Sutherland, 1994, p.302; Lewis & Young, 1995, p.71). The client had proposed to inspect modification by testing the hardness of malt, however he was also advised to instead inspect its acrospire growth (N.B. this is a simple test that has been included in official methods of analysis).

C. Hardwick (1995) states that malt colour contributes over two-thirds of all melanoidins (colour pigmentation) in beer. Consequently, the use of incorrectly coloured malt has a significant effect on beer colour (Hind, 1938-1940, p223; Hough et al, 1982, p.810; Cook, personal communication, June 27, 1997; Thomas, personal communication, July 21, 1997). Therefore, the client was strongly advised to monitor the colour of incoming malt.

Hops

A. The use of hops with low alpha acid levels results in beer of both reduced bitterness and head cling (De Clerck, 1957-1958, p.535; Ashurst, 1971, p.34; Hough et al, 1982, p.422; Lewis & Young, 1995, p.129). The client had proposed to inspect alpha acid levels using sensory analysis. However, sensory analysis was judged to be an unreliable control measure and the client was advised to use a more accurate method of inspection.

B. The use of hops with low essential oil levels results in the production of beer with reduced hop aroma (De Clerck, 1957-1958, p.241; Hough, 1985, p.80; Hardwick, 1995, p.161). The client had proposed to inspect essential oil levels using sensory analysis.

Yeast

A. Yeast with a low proportion of live cells or low "viability" causes off flavours in beer and may not complete fermentation (Hough, 1985, p.122; Moll, 1991, p.347; Cooke,

personal communication, May 13, 1997). Consequently, the client was advised to inspect the viability of incoming yeast.

B. Infected yeast leads to off flavours, turbidity and occassionally, superattenuation (excessive conversion of fermentable matter) of the wort (Lewis & Young, 1995, p.202; Russell, 1995, p.191; Thomas, personal communication, July 21, 1997). The client proposed to control infection by using fresh cultures of yeast for each brew. However, he was also advised to monitor the purity of these cultures.

C. Yeast that readily flocculates lowers wort attenuation as yeast cells clump together and settle at either the top or bottom of the wort (Hind, 1938-1940, p.556; Iserentant, 1995, p.49; Lewis & Young, 1995, p.233; Goelz, personal communication, July 23, 1997). Conversely, yeast that does not readily flocculate increases turbidity (Munroe, 1995, p.335). The client was advised to inspect the flocculating behaviour of incoming cultures.

Water

A. Excessive levels of organic matter in water cause turbidity, off flavours and colour inconsistencies in beer (Moll, 1995, p.133; Goelz, personal communication, July 23, 1997). The client had proposed to filter all incoming water.

B. Changes in the mineral composition of water have a significant influence on flavour (Wainwright, 1971, p.138; MacLeod, 1977, p.59). The client was advised to monitor the mineral composition of water.

C. The use of infected production water is not only problematic in terms of product safety, it also causes off flavours and turbidity (De Clerck, 1957-1958, p.574; Moll, 1995, p.151). The client had proposed to prevent using infected water by first boiling it.

4.1.4.2 Storage of raw materials

Malt

A. Malt deteriorates over time and this is accelerated in the presence of moisture or at high temperature (Hough et al, 1981-1982, p.304; Lewis & Young, 1995, p.85). The client had proposed to keep malt in the mill room and discard malt after a maximum period in storage.

B. Malt is susceptible to infestation due to storage conditions being conducive to insect growth (Hough et al, 1981-1982, p.304; Lewis & Young, 1995, p.85). The client had proposed to maintain effective pest control.

Hops

A. Hop alpha acids diminish linearly with time, this reduction being accelerated in the presence of oxygen, moisture and ambient temperatures (De Clerck, 1957-1958, p.241; Hough, 1985, p.80; Thomas, personal communication, July 21, 1997). Essential oil levels are also reduced at high temperature (Grant, 1995, p.161; Lewis & Young, 1995, p.140; Goelz, personal communication, July 23, 1997). The client had proposed to store hops in air-tight containers in the refrigerator for a prescribed period of time.

Yeast

A. Yeast viability is reduced at both high temperature and over a period of time, as cells autolyse and die (Gilliland, 1981, p.123; Hough et al, 1981-1982, p.627; Lewis & Young, 1995, p.158). The client had proposed to minimise viability loss by storing yeast in the cool room for a prescribed period of time.

4.1.4.3 Processing of mains water

A. Unacceptable levels of organic matter remain in water if filtration is performed with excessively worn filter cartridges (Bagshaw, personal communication, July 12, 1997).

The client had proposed to replace individual cartridges after a prescribed number of uses.

B. Water that is not adequately cooled causes reduced diastatic activity during mashing (De Clerck, 1957-1958, p.585; Hough et al, 1981-1982, p.323; Lewis & Young, 1995, p.90). The client had proposed to inspect water temperature prior to it being transferred to the mash tun.

4.1.4.4 Milling

A. Incorrect mill gap settings can cause either coarse grists reducing starch available during mashing, or fine grists causing lautering problems and increases in colour and turbidity (Hough, 1985, p.56; Lewis & Young, 1995, p.85; Goelz, personal communication, July 23, 1997). The client had proposed to set appropriate mill gaps prior to milling, but was also advised that these settings be inspected at some point during processing as rolls are known to widen under vibration.

B. Incorrect grist weight causes either concentration or dilution of the wort (Papazian, 1987, p.31; Goelz, personal communication, July 31, 1997). The client proposed to feed appropriate malt quantities through to the mill.

4.1.4.5 Mashing

A. Portions of grist remain dry if mashing liquor is unevenly distributed or an insufficient volume of liquor is used during the mash-in (Moll, 1991, p.116; Lewis & Young, 1995, p.91). This reduces the level of starch that is degraded during mashing. The client had proposed to maintain an even mash-in by measuring the volume of mashing liquor added to the mash tun, but he was also advised to monitor the flow-rate of liquor during the mash-in.

B. Incorrect mash pH reduces the level of diastatic activity during mashing (N.B. high pH also causes excessive extraction of polyphenol matter) (De Clerck, 1957-1958,

p.552; Scheer, 1996, p.72; Goelz, personal communication, July 23, 1997). The client had proposed to add quantities of gypsum (calcium sulphate) to reduce the high mash pH.

C. A brief mashing period reduces the level of starch that is able to fully hydrolyse and degrade (Bates, 1993, p.243; Goelz, personal communication, July 23, 1997). The client proposed to maintain appropriate mashing duration with the aid of a clock alarm.

4.1.4.6 Reprocessing of water for sparging

A. Cool liquor reduces the dissolution of residual materials, lowering the level of extract recovered (MacLeod, 1977, p.70; Hough et al, 1981-1982, p.328). Conversely, hot liquor increases sparge pH (Hough et al, 1981, p.328; Papazian, 1987. p.30). The client had proposed to maintain appropriate liquor temperatures by controlling the heat of the hot liquor tank.

B. High liquor pH leads to the extraction of undesirable phenolic substances from the mash bed (Moll, 1991, p.126; Rehberger & Luther, 1995, p.278). The client was advised to inspect liquor pH prior to the commencement of sparging.

4.1.4.7 Sparging/lautering

A. A brief sparging period reduces the level of soluble material extracted from spent grains (Hough et al, 1981-1982, p.328). The client was advised to maintain appropriate sparging duration by setting an appropriate flow-rate of sparging liquor.

B. Rapid runoff causes the mash bed to be pulled down and to become compact (Lewis & Young, 1995, p.90). This reduces the amount of grains able to be sparged and can lead to "set mashes" where liquor cannot pass through the filter bed. Consequently, the client was advised to ensure a runoff that equalled liquor flow-rate.

C. Excessive liquor volumes cause extraction of undesirable fatty acids from spent grains and leads to the oxidation of polyphenols, colour increases and off flavours in beer. In addition, excessive liquor leads to diluted worts (Hough et al, 1981-1982, p.328; Papazian, 1987, p.30; Thomas, personal communication, July 21, 1997). The client had proposed to maintain appropriate liquor volumes.

4.1.4.8 Wort boiling

A. Low hop quantities and reduced boil durations result in lower levels of alpha acids being isomerised (Hough et al, 1981-1982, p.456; Moll, 1991, p.137; Varnam & Sutherland, 1994, p.342; Thomas, personal communication, July 21, 1997; Goelz, personal communication, July 23, 1997). The client had proposed to maintain appropriate hop additions and boil durations.

B. Prolonged boiling increases wort colour as Maillard reactions and caramelisation are allowed to continue (Hind, 1938-1940, p.223; Hough et al, 1981-1982, p.624; Hardwick, 1995, p.554; Cooke, personal communication, May 13, 1997). The client was advised that maintenance of appropriate boil duration would control wort colour.

C. Prolonged boiling also reduces the level of hop aroma that remains in wort as essential oils readily dissipate at high temperatures (De Clerck, 1957-1958, p.241; Hough, 1985, p.80; Moll, 1991, p.71; Lewis & Young, 1995, p.140). The client had proposed to introduce aromatic hops late in the boil.

D. Boiling intensity and duration has a significant impact on the concentration of wort (Cooke, personal communication, May 13, 1997). The client was advised to maintain appropriate boiling temperatures and boil duration.

E. A brief boiling period lowers protein coagulation, reducing hot break formation (Goelz, personal communication, July 23, 1997; Hollis, personal communication, July 24, 1997). Insufficient use of fining material lowers the level of hot break which

sediments during boiling. An insufficient stand also reduces the level of hot break that sediments. The client had proposed to maintain appropriate fining additions, and boil and stand duration.

4.1.4.9 Wort cooling and aeration

A. Rapid wort flow through the heat exchanger and warm coolant causes insufficient cooling of the wort (Moll, 1991, p.161; Rehberger & Luther, 1995, p.312; Bagshaw, personal communication, July 21, 1997). The client was advised to maintain appropriate wort flow rates to the heat exchanger and coolant temperatures.

B. Insufficient agitation of wort on entering the fermenting vessel results in an insufficiently aerated wort (Hough, 1985, p.91; Gamble, personal communication, July 29, 1997). The client had proposed to prevent this by using a special spraying nozzle to distribute wort in the fermenting vessel.

4.1.4.10 Fermentation

A. A number of factors cause wort to be either under or overattenuated (attenuation=conversion of fermentable matter in wort to products resulting from fermentation). Excessively cool fermentation temperature retards yeast metabolism and can halt attenuation (Bates, 1993, p.246; Varnam & Sutherland, 1994, p.322; Munroe, 1995, p.336). Extremely low quantities of yeast reduce the amount of fermentable matter metabolised (Mallett, 1992, p.25; Goelz, personal communication, July 23, 1997). In addition, a brief fermentation period does not allow yeast to fully metabolise fermentable matter present in wort (Papazian, 1987, p.30; Lewis & Young, 1995, p.63). The client had proposed to maintain an appropriate temperature by thermostat, and appropriate yeast quantity and fermentation duration.

B. Off flavours develop due to incorrect temperature, yeast quantity and fermentation duration. High temperatures accelerate fermentation and prevent the normal emission of undesirable gases that can affect beer flavour (Bates, 1993, p.246; Varnam &

Sutherland, 1994, p.322; Munroe, 1995, p.336). Excessive yeast quantities lead to yeast autolysis and the production of undesirable compounds, while insufficient quantities cause off flavours through the increased production of higher alcohols and organic acids (De Clerck, 1957-1958, p.531; Mallett, 1992, p.25; Goelz, personal communication, July 23, 1997). A short fermentation duration does not allow diacetyl to be reduced sufficiently, while prolonged fermentation causes beer to remain in contact with dead and autolysed yeast cells which cause further off flavours (Cooke, personal communication, May 13, 1997; Goelz, personal communication, July 23, 1997; Hollis, personal communication, July 23, 1997). The client was advised to prevent these off flavours by relying on the control measures indicated in Section 4.1.4.10.A.

4.1.4.11 Maturation

A. A brief maturation period prevents off flavour-causing compounds being sufficiently reduced (Goelz, personal communication, July 23, 1997). Warm temperatures also cause off flavours, as sediment rises and redisperses through beer (Mann, 1974, p.123; Goelz, personal communication, July 23, 1997). The client had proposed to maintain appropriate maturation duration and temperature.

B. Brief maturation and warm temperatures also reduce the amount of particulate matter which sediments during maturation (De Clerck, 1957-1958, p.551; Moll, 1991, p.226; Varnam & Sutherland, 1994, p.326; Lewis & Young, 1995, p.217; Cooke, personal communication, May 13, 1997). Ironically, the use of finings may also add to this turbidity (Cooke, personal communication, May 13, 1997; Goelz, personal communication, July 23, 1997). Excessive use of finings may result in some remaining in suspension, while an insufficient amount reduces expected sediment levels. The client had proposed to control maturation time and temperature using measures indicated in Section 4.1.4.11.A, while appropriate fining quantities are also to be maintained.

4.1.4.12 Filtration

A. An excessive amount of particulate matter remains in beer if filtration occurs at warm temperature, or when filter cartridges are used which are excessively worn (Moll, 1991, p.226; Varnam & Sutherland, 1994, p.326; Lewis & Young, 1995, p.217; Cooke, personal communication, May 13, 1997; Bagshaw, personal communication, July 12, 1997). The client had proposed to conduct filtration in the cool room, and to discard individual filter cartridges after a prescribed number of uses.

B. Rapid filtration causes oxidation that not only leads to the production of off flavours but also hastens the onset of permanent haze (Hough, 1985, p.141; Moll, 1991, p.344; Goelz, personal communication, July 23, 1997). The client was advised to maintain appropriate filtration rates by maintaining appropriate beer flow-rate to from the fermentation vessel to the filter.

4.1.4.13 Carbonation and settling

A. Beer becomes either undercarbonated ("flat") or overcarbonated ("gushing") if injected with incorrect levels of carbon dioxide (Gawenda, personal communication, July 1, 1997; Bagshaw, personal communication, July 12, 1997; Thomas, personal communication, July 21, 1997). The client was advised to maintain appropriate levels of CO_2 injected in the beer.

B. Warm storage temperatures hasten the onset of permanent haze. The client had proposed to maintain appropriate temperatures by thermostat.

4.1.4.14 Packaging

A. Oxygen has a deleterious effect on beer following fermentation, causing off flavours and hastening the onset of permanent haze. Rapid filling increases oxidation as beer is excessively agitated (Varnam & Sutherland, 1994, p.351; Lewis & Young, 1995, p.219). Excessive headspace in kegs exposes beer to greater volumes of oxygen (Hough, 1985, p.141; Moll, 1991, p.344). Improper and faulty keg seals also allow

oxygen to be introduced to beer (Mann, 1974, p.122; Papazian, 1987, p.29; Gawenda, personal communication, July 1, 1997). The client was advised to minimise this oxidation by maintaining appropriate filling rates and filling quantities, and by ensuring that keg seals are intact.

B. Inadequate rinsing of kegs during cleaning causes fatty acids to be introduced to the beer, as the beer comes in contact with cleaner residue (De Clerck, 1957-1958, p.535; Hough, 1985, p.139; Moll, 1991, p.342; Cooke, personal communication, May 13, 1997). This causes a significant reduction of head volume. The client had proposed to maintain an effective cleaning regime.

4.1.4.15 Hazards common to steps across the process

A. Packaged beer is a relatively poor medium for the growth of micro-organisms as it contains ethanol, few sugars, amino acids or vitamins, and is of low pH (Hough, 1985, p.102). However, some micro-organisms can survive to grow during production to have a significant effect on beer flavour and turbidity. The client had proposed to control microbiological contamination by maintaining effective cleaning procedures.

With the potential hazards identified, it was then necessary to identify which of these needed to be controlled to assure required product quality. These would be referred to as the Quality Control Points (QCPs). QCP identification was completed in the following section.

4.1.5 Quality Control Point (QCP) identification

QCP identification was assisted with the application of a decision tree by the study team. Table 7 represents the results of this exercise.

Table 7. QCPs identified in the Westoz manufacturing process.

LEGEND
Q.1=Do control measure(s) exist for the identified hazard?
Q.2=Does the process step eliminate or reduce the hazard to an acceptable level?
Q.3=Could the hazard cause beer to be produced of an unacceptable quality?
Q.4=Will a subsequent process step eliminate or reduce the hazard to an acceptable level?

Y= yes *N*= no *QCP*= Quality Control Point

PROCESS STEP	HAZARD	Q.1	Q.2	Q.3	Q.4	QCP?
1 Receipt of raw materials	*Malt*					
	•low level of extract	Y	Y			QCP
	•incorrect modification	Y	Y			QCP
	•incorrect malt colour	Y	Y			QCP
	Hops					
	•low alpha acid level	Y	Y			QCP
	•low essential oil level	Y	Y			QCP
	Yeast					
	•low viability	Y	Y			QCP
	•contamination	Y	Y			QCP
	•incorrect flocculation	Y	Y			QCP
	Water					
	•excessive organic matter	Y	N	Y	Y	Not a QCP
	•inappropriate mineral composition	Y	Y			QCP
	•contamination	Y	N	Y	Y	Not a QCP
2. Storage of raw materials	Malt					
	•moisture, high temperature ,time, infestation	Y	Y			QCP
	Hops					
	•oxygen, moisture, high temperature, time	Y	Y			QCP
	Yeast					
	•high temperature and/or time	Y	Y			QCP
3 Processing of mains water	Excessive levels of organic matter					
	•excessively worn filter cartridge	Y	Y			QCP
	Insufficiently cooled liquor	Y	Y			QCP
4.Milling	Incorrect grist fractions					
	•incorrect mill gap settings	Y	N	Y	N	QCP
	Incorrect grist weight					
	•incorrect malt sack weight	Y	N	Y	N	QCP
5. Mashing	Insufficient saccharification level					
	•dry mash portions	Y	Y			QCP
	•incorrect mash pH	Y	Y			QCP
	•insufficient mash time	Y	Y			QCP
6.Reprocessing of liquor for sparging.	Incorrect sparging liquor temperature					
	•incorrectly heated liquor	Y	Y			QCP
	Incorrect sparging liquor pH	Y	Y			QCP

Table 7. QCPs identified in the Westoz manufacturing process (cont.)

PROCESS STEP	HAZARD	Q.1	Q.2	Q.3	Q.4	QCP?
7. Wort runoff/sparging	Insufficient extract recovery					
	• rapid flow-rate	Y	Y			QCP
	•compact mash bed	Y	Y			QCP
	Extraction & oxidation of undesirable matter					
	•prolonged sparging duration	Y	Y			QCP
8. Wort boiling	Incorrect isomerisation of alpha acids					
	•insufficient hop quantity	Y	Y			QCP
	•insufficient boil duration	Y	Y			QCP
	Excessive colour increase					
	•prolonged boiling	Y	Y			QCP
	Loss of hop aroma					
	•prolonged boil duration	Y	Y			QCP
	Excessive concentration of wort					
	•incorrect boiling temperature	Y	Y			QCP
	•prolonged boiling duration	Y	Y			QCP
	Insufficient clarification level					
	•insufficient fining quantity	Y	Y			QCP
	•insufficient boil duration	Y	Y			QCP
	•insufficient wort stand duration	Y	Y			QCP
9.Wort cooling and aeration	Incorrect cooling					
	•rapid wort flow-rate	Y	Y			QCP
	•high coolant temperature	Y	Y			QCP
	Insufficient aeration					
	•insufficient agitation	Y	Y			QCP
10. Fermentation	Incorrect attenuation level					
	•low fermentation temperature	Y	Y			QCP
	•insufficient yeast quantity	Y	Y			QCP
	•insufficient fermentation time	Y	Y			QCP
	Development of off-flavours					
	•incorrect fermentation temperature	Y	Y			QCP
	•incorrect yeast quantity	Y	Y			QCP
	•incorrect fermentation time	Y	Y			QCP
11. Maturation	Development of off-flavours					
	•high maturation temperature	Y	Y			QCP
	•insufficient maturation time	Y	Y			QCP
	Insufficient clarification level					
	•high maturation temperature	Y	N	Y	Y	Not a QCP
	•incorrect fining quantity	Y	N	Y	Y	Not a QCP
	•insufficient maturation time	Y	N	Y	Y	Not a QCP

Table 7. QCPs identified in the Westoz manufacturing process (cont.)

PROCESS STEP	HAZARD	Q.1	Q.2	Q.3	Q.4	QCP?
12. Filtration	Insufficient clarification					
	•warm filtration temperature	Y	Y			QCP
	•worn filter cartridge	Y	Y			QCP
	Oxidation					
	•incorrect filtration rate	Y	N	Y	N	QCP
13. Carbonation and settling	Incorrect carbonation					
	•incorrect carbonation settings	Y	Y			QCP
	Hastening onset of permanent haze					
	•incorrect settling temperature	Y	Y			QCP
14. Packaging	Oxidation/oxygenation					
	•rapid filling rate	Y	N	Y	N	QCP
	•incorrect head-space	Y	Y			QCP
	•incorrect/improper keg seals	Y	Y			QCP
	Introduction of oils and fats					
	•improper cleaning	Y	N	Y	N	QCP
15 Hazards common to steps across the process	Microbiological infection •unsanitary brewing equipment	Y	Y			QCP

With the QCPs identified, strategies were then designed to assure that they were consistently of the correct nature for product quality. The strategies that were developed are outlined in the following section.

4.1.6 Control of QCPs

As mentioned in Section *3.1.6*, control of QCPs is a three-part procedure involving the establishment of critical limits, critical limit monitoring and corrective action procedures. These elements are presented in Table 8.

Critical limits

As mentioned in Section *3.1.6*, many critical limits are specific to individual products and the subject of further study. However, those critical limits that are common to all products are stated in Table 8.

Monitoring

Monitoring methods must be able to detect loss of control or deviation from critical limits at QCPs. As critical limits, specific to individual products, were not identified in this

study, a number of alternative methods were given wherever possible. These methods tended to vary in their level of precision. Details of these methods are presented in Table 8 and in the text. During this part of the study, it was evident that there is a significant lack of available literature on monitoring methods that can be practically applied in microbreweries.

Fortunately, the majority of monitoring methods involved simple measurements of processing parameters. These included measurements of time, temperature, quantity and flow-rate.

Corrective actions

Appropriate corrective action varies depending on the magnitude of deviation encountered during manufacturing. For instance, beer that becomes oxidated during processing may fall outside flavour specifications for that particular product, but may still be palatable. Appropriate corrective action in this instance may be to blend the beer with a previous batch, or to market it as a trial beer at the brewpub. Conversely, an oxidised beer that falls outside flavour specifications for a particular product and is also not palatable, should be disposed of. Alternative corrective actions were identified in this study wherever possible, however time constraints prevented appropriate corrective action being established for deviations of varying magnitude.

Time constraints also prevented the effect of certain individual corrective actions on quality issues from being determined. For instance, the change in beer colour when a specified amount of roasted barley is added to the grist. It is recommended that these are set in a similar manner to critical limits (i.e. by Regression Analysis).

Table 8. Controlling QCPs at Westoz.

PROCESS STEP	HAZARD	CONTROL MEASURE(S)	CRITICAL LIMIT(S)	MONITORING PROCEDURE	CORRECTIVE ACTION(S)
1. Receipt of raw materials.	*Malt* •low level of potential extract	Inspect potential extract	>80-85% of total weight	**What**: potential extract. **How**: see Notes. **When**: each batch on delivery.	Increase malt quantity or add malt extract to wort. If deviation is more serious, reject batch. Discuss matter with supplier.
	•incorrect level of modification	Inspect acrospire growth	>80% of kernels=3/4-full length	**What:** acrospire growth. **How**: see Notes **When**: each batch on delivery.	Increase malt quantity or add malt extract to wort. If deviation is more serious, reject batch. Discuss matter with supplier.
	•incorrect malt colour	Inspect malt colour	Specific (depends on particular malt type)	**What:** malt colour. **How:** see Notes. **When:** each batch on delivery.	Replace % of malt with roasted barley to darken colour or draw with beer from previous batch of same product during packaging (i.e. "blending") to lighten colour. If deviation is more serious, reject batch. Discuss matter with supplier
	Hops •low alpha acid level	Inspect alpha acid level	Specific (depends on particular hop type)	**What**: alpha acid level. **How**: see Notes. **When**: each batch on delivery.	Increase hop quantity or add hop extract to wort. If deviation is more serious, reject batch. Discuss matter with supplier.
	•low essential oil level	Inspect essential oil level	Specific (depends on particular hop type)	**What**: essential oil level: **How**: see Notes. **When**: each batch on delivery.	Increase hop quantity or add hop extract to wort. If deviation is more serious, reject batch. Discuss matter with supplier.
	Yeast •low viability	Inspect viability	>85% viable cells	**What**: yeast viability. **How**: see Notes. **When**: each batch on delivery.	Increase yeast quantity. If deviation is more serious, reject batch. Discuss matter with supplier.
	•contamination	Inspect purity	<1-2% bacteria count detection of wild yeast at magnification*500	**What**: yeast purity. **How**: see Notes. **When**: each batch on delivery.	Reject batch. Discuss matter with supplier.
	poor flocculation	Inspect flocculation	Specific (depends on yeast sample)	**What**: yeast flocculation.**How**: see Notes. **When**: each batch on delivery.	Reject batch. Discuss matter with supplier.
	Water •variable mineral composition	Inspect mineral composition	<250mg/l (chlorides) <500mg/l (sulphates) <70mg/l (calcium) <30mg/l (nitrates)	**What**: mineral composition. **How**: see Notes. **When**: once every 3 months.	Discuss matter with supplier. Monitor more regularly and/or introduce water treatment programme.

Table 8. Controlling QCPs at Westoz (cont.)

PROCESS STEP	HAZARD	CONTROL MEASURE(S)	CRITICAL LIMIT(S)	MONITORING PROCEDURE	CORRECTIVE ACTION(S)
2. Storage of raw materials	*Malt* •moisture;high temperature;time	Dehumidifier;air conditioning; clearly displayed use-by tags	<30% humidity <25°C <6 weeks	**What**: humidity;temperature;time. **How**: barometer;thermometer;use-by-date tags. **When**: daily;daily;before use.	Adjust or repair dehumidifier/air-conditioning. If passed use-by date, dispose batch and review stock control.
	•infestation	Use pest control contractor	<3 insects/day	**What**: pest presence. **How**: use insect detectors ("sticky boards") boards to monitor insect presence. **When**: daily.	Inspect sacks and dispose of sacks which are infected. Fumigate storage area. Review contract with pest control company.
	Hops •oxygen;moisture;high temperature;time	Store in air-tight containers in the refrigerator for prescribed periods of time	secured lids <4°C <12 months	**What**: container lids;refrigerator temperature; use-by tags. **How**: visual inspection ;thermometer;visual inspection. **When**: before & after every use;daily;before every use.	Re-secure or replace lids; repair refrigerator. Dispose of sacks if passed their use-by-dates and review stock control.
	Yeast •inappropriate temperature; time	Store in cool room for prescribed periods of time	5-15°C 4 weeks	**What**: cool room temperature;use-by tags. **How**: thermometer;visual inspection. **When**: daily;before every use.	Adjust or repair cool room. Dispose of sacks if past their use-by-dates and review stock control.
3. Processing of mains water	*Excessive levels of organic matter*	Prescribed number of cartridge uses	Generic value (has to be established at the brewery)	**What**: number of cartridge uses. **How**:check number of uses of current cartridge as entered on previous monitoring record MR3 (see Section 4.1.8). **When**: before every use.	Replace cartridge. Reduced prescribed number of uses before cartridge replacement.
	Insufficiently cooled liquor	Cooling time in tank	Generic value (established at brewery)	**What**: cooling time & temperature at the hot liquor tank. **How**: clock alarm & thermometer. **When**: during cooling period.	Increase cooling time.
4. Milling	*Incorrect grist fractions*	Inspect mill gap settings	Specific (depends on particular malt)	**What**: mill gap settings. **How**: visual inspection. **When**: start and midpoint of milling.	Adjust mill gap settings. Measure wort specific gravity and add malt extract as required.
	Incorrect grist size	Weigh malt sacks	=50kg	**What**: sack weight. **How**: fixed weight. **When**: every sack on delivery.	Increase/reduce malt quantity. Discuss matter with supplier.

Table 8. Controlling QCPs at Westoz (cont.)

PROCESS STEP	HAZARD	CONTROL MEASURE(S)	CRITICAL LIMIT(S)	MONITORING PROCEDURE	CORRECTIVE ACTION(S)
5. Mashing	*Low saccharification* •dry mash portions	Inspect liquor flow-rate	Generic value (established at brewery)	**What**: liquor flow-rate. **How**: either by flow meter or by calculating flow-rate by dividing the amount of liquor used by the length of time passed. **When**: at start and midpoint of mash-in.	Adjust flow-rate or repair pump. Stir mash and continue mash-in.
	•incorrect mash pH	Inspect mash pH	pH5.2-5.5	**What**: mash pH. **How**: see Notes. **When**: when mash-in has completed.	Adjust mash pH with gypsum or carbonate salts.
	•insufficient mash time	Maintain appropriate mashing duration	Generic value (established at brewery)	**What**: mash time. **How**: set clock alarm. **When**: prior to mash	Increase mash time.
6. Reprocessing of liquor for sparging	*Incorrect liquor temperature*	Thermostatic control	75-80°C	**What**: liquor temperature. **How**: thermometer. **When**: before sparging.	Cool or reheat before sparging. Adjust or repair thermostat if necessary.
	Incorrect liquor pH	Inspect liquor pH	pH6.0-6.5	**What**: liquor pH. **How**: see Notes. **When**: before sparging commences.	Add gypsum or carbonate salts to adjust liquor pH.
	•compact mash bed	Monitor runoff valve setting	=sparging liquor flow-rate	**What**: runoff flow-rate. **How**: flow meter/ runoff volume:time ratio. **When**: at start and midpoint of sparge.	Close off runoff valve until sparging liquor refloats mash bed and then, if necessary, stir mash to loosen mash bed. Reset runoff valve. Measure wort specific gravity and add malt extract as required.
7. Wort runoff/ sparging	*Insufficient extract recovery* •rapid sparge	Monitor sparging liquor flow-rate	Generic value (established at brewery)	**What**: liquor flow-rate. **How**: flow meter/calculate by dividing liquor volume indicated on sightglass by time passed.**When**: at start and midpoint of sparge.	Adjust flow-rate or repair pump. Measure wort specific gravity and add malt extract as required.
	Extraction & oxidation of undesirable matter	Monitor sparge duration	650L of sparging liquor	**What**: liquor volume. **How**: sightglass. **When**: towards designated end-time for sparge.	Inspect specific gravity of wort, and flavour and colour of final beer. Add malt extract to the wort as required. Blend with previous batch if necessary. If product specifications cannot be achieved either market it as a "trial beer" (i.e. production of a beer that is being tested on the market) or dispose batch.

Table 8. Controlling QCPs at Westoz (cont.)

PROCESS STEP	HAZARD	CONTROL MEASURE(S)	CRITICAL LIMIT(S)	MONITORING PROCEDURE	CORRECTIVE ACTION(S)
8. Wort boiling	*Low hop isomerisation* •low hop quantity	Inspect hop quantity	Specific (depends on particular product being manufactured)	**What**: hop quantity. **How**: fixed weight measurement. **When**: before addition.	Add hops as required.
	Excessive colour increase	Monitor boil time	*(Governed by critical limit required for acceptable wort concentration)*	**What**: boil time. **How**: set clock alarm. **When**: prior to boil.	Inspect wort colour and blend with previous batch if required. If product specifications cannot be achieved either market it as a "trial beer" (i.e. production of a beer that is being tested on the market) or dispose batch.
	Loss of hop aroma	Late addition of aromatic hops	last 15mins of boil	**What**: time of addition. **How**: set clock alarm. **When**: prior to boil.	Add hop extract to wort if required.
	Excessive wort concentration	Monitor boiling temperature & time	Generic (established at brewery)	**What**: temperature & time **How**: thermometer & clock alarm. **When**: during boil	Dilute with sterile water following boil.
	Low wort clarity •low fining use	Maintain appropriate fining quantity	to fining supplier's directions	**What** fining quantity. **How**: fixed weight measurement. **When**: before addition.	Maintain appropriate fining quantity.
	•short boil time	Maintain appropriate boil duration	*(Governed by critical limit required for acceptable wort concentration)*	**What**: boil time. **How**: clock alarm. **When**: prior to boil.	Increase boil time. Repair clock alarm. Adjust replacement time of filter cartridge.
	•short wort stand	Monitor stand time	=30minutes	**What**: stand time. **How**: set clock alarm. **When**: prior to stand.	Increase stand time. Repair clock alarm. Adjust replacement time of filter cartridge.
9. Wort cooling and aeration	*High wort temperature* •rapid wort flow-rate	Monitor flow rate	Generic (established at brewery)	**What**: wort flow-rate. **How**: flow-meter/wort volume:time ratio. **When**: at start and midpoint of filtration.	Adjust flow-rate. Lower cool-room temperature and/or delay pitching.
	•high coolant temperature	Monitor coolant temperature	Generic (established at brewery)	**What**: coolant temperature. **How**: thermometer. **When**: at start and midpoint filtration.	Adjust flow-rate. Lower cool-room temperature and/or delay pitching.

Table 8. Controlling QCPs at Westoz (cont.)

PROCESS STEP	HAZARD	CONTROL MEASURE(S)	CRITICAL LIMIT(S)	MONITORING PROCEDURE	CORRECTIVE ACTION(S)
10. Fermentation	*Insufficient attenuation* •low fermentation temperature	Fermentation temperature controlled by thermostat.	thermostat set to yeast supplier's directions	**What**: cool room temperature. **How**: thermometer. **When**: twice daily.	Adjust and/or repair thermostat. Increase fermentation duration.
	•insufficient yeast quantity	Inspect yeast quantity	Yeast supplier's directions	**What**: yeast quantity. **How**: fixed weight measurement. **When**: before addition.	If insufficient amount used either add more and/or agitate wort.
	•short fermentation time	Monitor fermentation time	Specific (depends on particular product being manufactured	**What**: specific gravity. **How**: see Notes. **When**: daily.	Maintain appropriate fermentation time. If overattenuated, blend batches. If product specifications cannot be achieved either market it as a "trial beer" (i.e. production of a beer that is being tested on the market) or dispose batch.
	Off-flavours develop •incorrect fermentation temperature	Fermentation temperature controlled by thermostat.	thermostat set to yeast supplier's directions	**What**: cool room temperature. **How**: thermometer. **When**: twice daily.	Adjust or repair cool room thermostat if faulty. Inspect final beer flavour and either blend batches if necessary. If product specifications cannot be achieved either market it as a "trial beer" (i.e. production of a beer that is being tested on the market) or dispose batch.
	•incorrect yeast quantity	Inspect yeast quantity	Yeast supplier's directions	**What**: yeast quantity. **How**: fixed weight measurement. **When**: before addition.	Inspect final beer flavour, and blend batches if necessary. If product specifications cannot be achieved either market it as a "trial beer" (i.e. production of a beer that is being tested on the market) or dispose batch.
	•incorrect fermentation time	Monitor fermentation time	*(Governed by critical limit required for sufficient attentuation)*	**What**: fermentation time. **How**: set clock alarm. **When**: prior to fermentation.	If fermentation is prolonged, inspect final beer flavour and either blend batches if necessary. If product specifications cannot be achieved either market it as a "trial beer" (i.e. production of a beer that is being tested on the market) or dispose batch.
11. Maturation	*Off-flavours develop* •high maturation temperature	Maturation temperature controlled by thermostat	-1–0°C	**What**: cool room temperature. **How**: thermometer. **When**: twice daily.	Inspect final beer flavour, and blend batches if necessary. If product specifications cannot be achieved either market it as a "trial beer" (i.e. production of a beer that is being tested on the market) or dispose batch.
	•short maturation duration	Monitor time	Specific (depends on particular product being manufactured)	**What**: maturation time. **How**: set clock alarm. **When**: prior to maturation.	Inspect final beer flavour, and blend batches if necessary. If product specifications cannot be achieved either market it as a "trial beer" (i.e. production of a beer that is being tested on the market) or dispose batch.

Table 8. Controlling QCPs at Westoz (cont.)

PROCESS STEP	HAZARD	CONTROL MEASURE(S)	CRITICAL LIMIT(S)	MONITORING PROCEDURE	CORRECTIVE ACTION(S)
12. Filtration	*Insufficient clarification* •warm filtration temperature	Filtration temperature controlled by thermostat	-1–0°C	**What**: cool room temperature. **How**: thermometer. **When**: prior to filtration.	Adjust and/or repair thermostat. Increase settling time in bright beer tank.
	•wom filter cartridge	Replace cartridge after a prescribed number of uses	Generic (established at brewery)	**What**: number of cartridge uses. **How**: check number of uses of current cartridge as entered on previous monitoring record MR3 (see Section 4.1.8). **When**: before every use.	Replace cartridge. Reduced prescribed number of uses before cartridge replacement.
	Oxidation	Monitor filtration rate	<10l/min.	**What**: filtration rate. **How**: flow meter/volume of beer:time ratio. **When**: at start and midpoint of filtration.	Adjust flow-rate. Inspect final beer flavour, blend batch or market as a different product at the brewpub. If unpalatable, dispose batch.
	Hastening onset of permanent haze.	Filtration temp. controlled by thermostat	-1–0°C	**What**: cool room temperature. **How**: thermometer. **When**: daily.	Adjust and/or repair cool room thermostat. Priority to sell affected beer as soon as possible at the brewpub.
13. Carbonation and settling	*Incorrect level of carbonation*	Monitor CO_2 injection levels	Specific (depends on particular product being manufactured)	**What**: CO_2 levels. **How**: either by CO_2 Volume meter or calculating by reduced weight of gas cylinder (See Notes). **When**: constantly during carbonation.	Increase carbonation or release tank pressure.
14. Packaging	*Oxidation* •rapid filling rate	Monitor filling rate	25-30l/min.	**What**: filling rate. **How**: flow meter/beer volume:time ratio. **When**: at start of filling.	Adjust filling valve/filling rate. Inspect flavour of affected kegs. Dispose affected kegs if necessary.
	•excessive head-space	Monitor filling quantity	=50L	**What**: filling quantity. **How**: sightglass. **When**: constantly during filling.	Maintain appropriate filling rates. Siphon keg if necessary.
	•faulty keg seals	Monitor keg pressure	Specific (depends on particular product being manufactured)	**What**: keg pressure. **How**: electronic pressure sensor. **When**: after filling and 24hrs later.	Discard contents of affected kegs. Repair or replace affected kegs.
	Introduction of oils and fatty acids	Effective cleaning	strict compliance with cleaning procedures	**What**: cleaning procedures. **How**: work to a checklist. **When**: every cleaning.	Re-clean.
General	*Microbiological infection*	Effective cleaning of brewery equipment	strict compliance with cleaning procedures	**What**: cleaning procedures. **How**: work to a checklist. **When**: every cleaning.	Re-clean.

The following notes describe in detail the analytical procedures included in the proposed control of QCPs as stated in Table 8.

Notes

1. Receipt and inspection of raw materials

- **Malt**

A. Sampling.

5 (100g) samples taken from 10% of sacks of delivered batches. These are made into a composite sample.

N.B. individual sacks are selected at random; samples taken from different points of sacks using either a sampling spear (trier) or by hand.

B. Analyses

Acrospire growth (as cited in De Clerck 1957-1958)

1. 50 corns are boiled in a small beaker with a 2% solution of copper sulphate for 10 minutes until the husks have become translucent.

2. The corns are then classified into the following categories of acrospire length and counted:

0 up to and including 1/4 of corn length
1/4 up to and including 1/2 of corn length
1/2 up to and including 3/4 of corn length
3/4 up to and including full length of corn
Over corn length

3. Results are stated as percentages for each category.

4. The mean acrospire length is then calculated.

This test is highly subjective and it is preferred that the evaluation of acrospire length is made in conjunction with standards such as those represented in Figure 10.

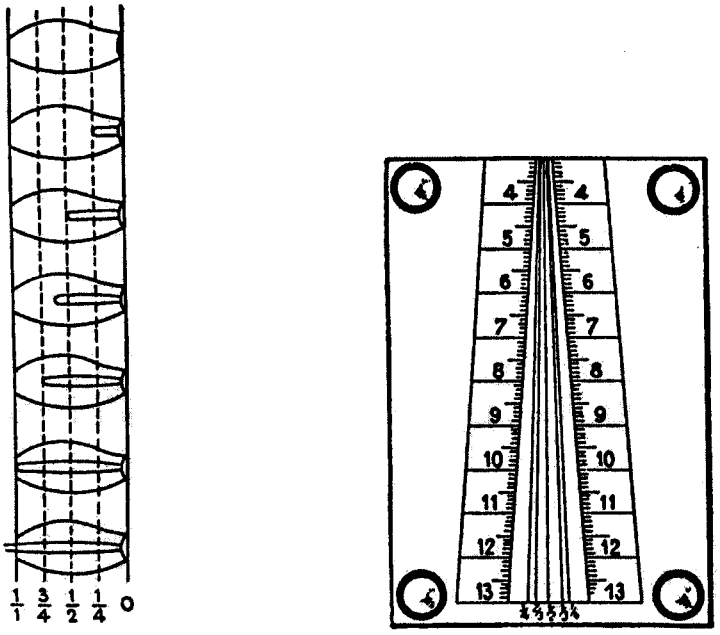

Figure 10. Standards for measuring acrospire growth.
Source: De Clerck, 1957-1958, p.327.

Extract and colour

A trial wort is normally used to analyse malt extract and colour. The following details are associated with the production of a wort recommended by the European Brewery Convention (EBC) (1987).

Method

a) Mill grain to achieve fine grist of 50.0g ± 0.01g (Note. EBC(1987) recommends use of the Buhler-Miag DLFU disc mill, set to "fine").
b) Heat 200ml distilled water to 45°C-46°C.
c) Add distilled water to grist in beaker, stirring continuously.
d) Immediately place beaker into a water bath set to a temperature that ensures mash temperature of 45°C, and start timer.

e) Fit a stirrer and stir the contents of the beaker through the mashing period.

f) Hold the mash at 45°C for exactly 30 minutes.

g) Raise the temperature of the mash by approximately 1°C per minute, so that a mash temperature of 70°C is achieved exactly 25 minutes after the commencement of heating.

h) During this period of heating, 100ml of distilled water is heated to 70°C.

i) At the end of 25 minutes, add 100ml of preheated water to beaker containing mash.

j) Hold the mash at 70°C for exactly 60 minutes.

k) At the end of the mashing period (a total of 115 minutes) cool mash to 20°C in 10-15 minutes. Cooling may be achieved in the water bath by running cold water through the bath, or alternatively by removing the beaker and stirrer from the bath and placing the beaker into iced water.

l) Adjust the weight of the contents of beaker to 45.0g ± 0.01g, by adding distilled water.

m) Stir the mash thoroughly and filter into a 500ml conical flask, returning the first 100ml filtrate to the funnel.

n) Use the filtrate to determine colour and extract.

for colour: EBC (1987) recommends that colour assessments are made with the Lovibond Comparitor, while ASBC (1992) endorses measurement by spectrophotometer. Alternatively, brewers may construct their own colour standards.

for extract: Official methods of assessing extract involve pycnometers. Alternatively, microbrewers relinquish some accuracy for economy and use hydrometers.

- **Hops**

A. Sampling.

5 (5g) samples are taken from 10% of bags in each batch. These are made into a composite sample.

N.B. bags are selected at random. Samples are taken from various points of the bag(s) using either a sampling spear (trier) or by hand.

B. Analyses.

Alpha acid content and essential oil content

Hop analysis is a highly sophisticated activity. Alpha acid content analysis of hops is carried out either with lead acetate, spectrophotometry or polarimetry, while essential oils are normally assessed by steam distillation. Harrison, Apsey, Badger and Moon (1987) mentions that these methods are impractical for most small brewers.

Generally, microbrewers must rely on supplier information and/or external consultants (i.e. professional consultant or universities) to make hop determinations. However, it is advised that the microbrewer performs routine sensory evaluation procedures to detect gross differences in hop quality. This normally involves hops being rubbed into the palm of the hand and assessed for both taste and aroma. Standards involving hop extracts may be developed to assist these determinations. However, due to the volatility of alpha acids and essential oils, these must be continually renewed.

- ***Yeast***

Viability and purity

Microscopic examination remains a practical method of assessing yeast purity and viability in microbreweries.

Preparations for examinations can be made by adding distilled/sterile water to a yeast sample to make a smooth paste, with more water being added by stirring in about 20 times the original volume of dried yeast.

Viability test

Apply a drop of this preparation to a microscope slide and apply a cover glass slip. By pressing the slip down gently under filter paper, any surplus fluid can be removed (N.B. a

platinum wire loop, about 3mm diameter, fused into a glass rod is a suitable means of applying the drop).

Add a loopful of methylene blue to the slide with the loopful of the aforementioned yeast preparation. Dead cells stain blue whereas living cells remain colourless.

The sample is viewed under a microscope and the proportion of unstained (viable) cells is estimated. This estimation is best aided by some pictorial reference.

Purity test

If yeast cells are clumped together or if there are any amorphous particles, then a slide needs to be prepared to examine for bacteria and wild yeast. This is prepared from a sample of the yeast preparation to which a few drops of 10% sodium hydroxide is added (sodium hydroxide causes the yeast cells to spread out evenly and also dissolves small protein particles which might be mistaken for bacteria). The sample should be shaken after adding sodium hydroxide and the preparation examined without delay, as bacteria are sometimes slowly attracted to the underside of yeast cells, where they may escape detection.

The preparation is examined under a microscope (magnification*500). The brewer can then analyse it for abnormal cell shape and size, thus indicating the presence of foreign micro-organisms. Papazian (1990) states that this examination is greatly assisted by the use of a pictorial reference guide illustrating common micro-organisms encountered in brewing (see Figure 11 for a guide depicting bacteria commonly encountered in brewing).

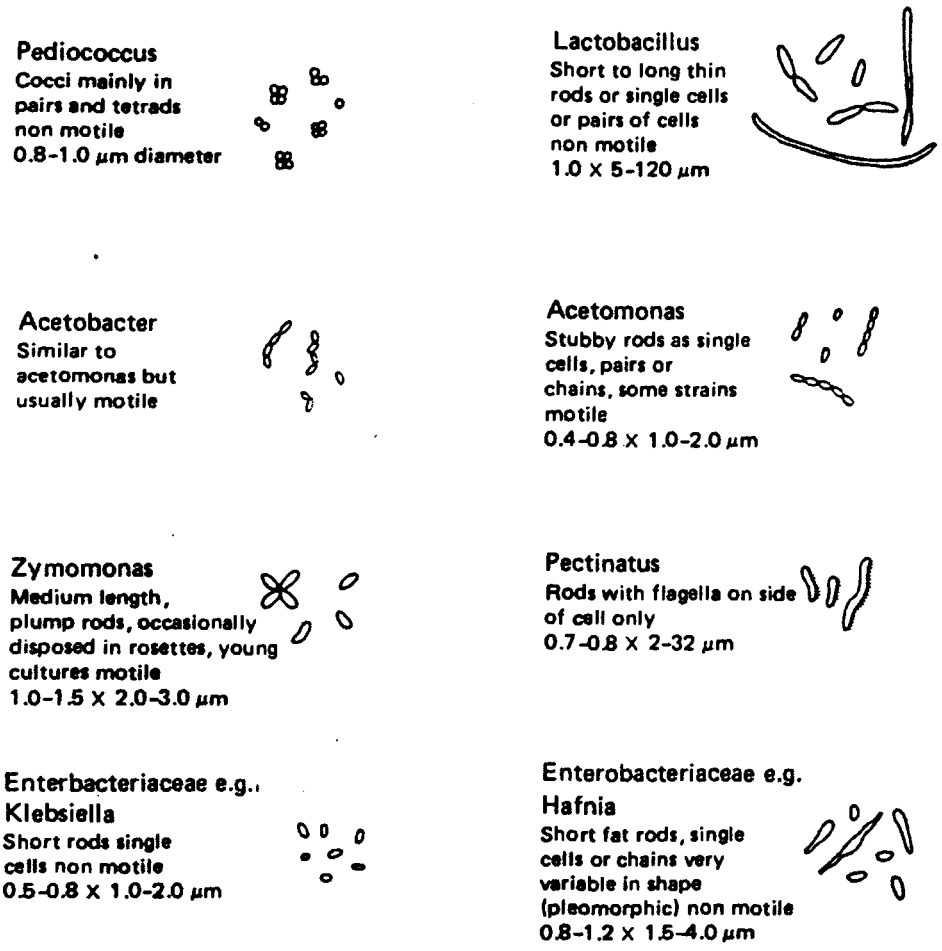

Figure 11. Guide to bacteria commonly encountered in brewing.
Source: Hough, 1985, p.108.

Flocculation

Russell (1995) states that no method has been standardised for assessing the flocculation behaviour of yeast. One simple method of assessing flocculating behaviour is mentioned in Jeffrey (1956), namely the Burns Test.

0.5g of yeast is dropped into a 15ml centrifuge tube (N.B. this tube has a mark at 10ml, and graduates below that in steps of 1/10ml). Yeast is mixed to a paste with a few drops of distilled water, by means of a thin glass rod. It is then diluted to the 10ml mark with distilled water. 1ml of acetate buffer (pH 4.6) is then added, with the whole mixture

being shaken well and allowed to stand for exactly 10 minutes. The volume of the sediment is then observed.

5. Mashing

Mash pH

A. Sampling

Samples within the same batch of mash are assumed to be fairly homogeneous due to the mixing that occurs during mashing. 5 (100ml) samples are transferred to beakers via the mash tun's sampling tap. Muslin or filter paper is used to separate grains from the liquid. This filtrate is then used in pH determinations.

B. Analysis

It is recommended that pH is measured by pH meter, although some small brewers use indicator paper in these determinations.

6. Reprocessing of liquor for sparging

Sparging liquor pH

A. Sampling

Samples within the same batch are assumed to be fairly homogeneous. 5 (100ml) samples are transferred to beakers via the hot liquor tank's sampling tap.

B. Analysis

The pH of sparging liquor is measured in the same way as mentioned in Note 5.B (*Mash pH*).

10. Fermentation

Fermenting wort's specific gravity

A. Sampling

Samples within the same batch are assumed to be fairly homogeneous due to agitation caused by yeast cell action during fermentation. 5 (150ml) samples are transferred to

beakers via the fermenting vessel's sampling tap. Muslin or filter paper is used to separate grains from the liquid. This filtrate is used for wort specific gravity determinations.

B. Analysis

It is recommended that pycnometers are used for these determinations, although hydrometers, while less accurate, are often considered to be adequate.

13. Carbonation and settling

Level of CO_2 injected

During CO_2 injection, keep CO_2 cylinder on a scale. The weight reduction of the cylinder during injection tells the volume of CO_2 injected by weight. Assuming the volume of beer in the bright beer tank and knowing that 410g of CO_2 per barrel gives 1 volume per weight, it is easy to calculate how many grams of gas to let into the product in order to give required volumes of gas in solution.

4.1.7 Verification procedures

Ongoing verification involves a method of end-product sampling. Resulting data is analysed by control chart, this indicating the effectiveness of the process with implementation of the quality assurance plan. In order for this method of verification to be effective, the process must first be under statistical control. Details of how statistical control is achieved and verification performed are now given.

Step 1 Record unusual circumstances during batch production

Individual logs are kept of all unusual circumstances during the production of 25 batches of a particular product. These unusual circumstances include such things as the use of new raw material, delays, machine breakdowns etc. This assists with the identification of special causes.

Step 2 Sampling

It is assumed that samples within a batch are fairly homogeneous due to significant mixing throughout the process. After 24 hours in storage, 6 kegs from each batch are chosen from a newly manufactured product batch. These kegs are selected using random numbers. One beer sample is drawn from each of these kegs.

Step 3 Measurement

Measurements are taken of sample colour, flavour, alcohol content, clarity and head (N.B. carbonation is measured previously by keg with pressure sensor).

Head

Head is assessed from the time it is drawn from the keg, since it is affected over a period of time. As the head volume is pre-determined by carbonation levels and method of dispense, head stability or retention is the variable, which is the main focus. Analysts measure the time it takes for head to disappear. The De Clerck and Dedycker method (as cited in De Clerck, 1957-1958) involves simple measurement of head retention, particularly as seen by the consumer.

Beer is first brought to a temperature of 12°C and then 300ml poured into a glass. Excess foam is cut away with a clean glass rod. The foam is allowed to collapse for about 30 seconds and a microscope (magnification*20) is focussed on the surface of the head. When bubbles can be seen distinctly, a stopwatch is started. The microscope is lowered by a centimetre and the head observed again; when the bubbles appear clearly, the watch is stopped. This gives the time of collapse of head in seconds per centimetre. (N.B. It is critical that standard methods of sample dispense are maintained in this test as the pouring action will have a significant influence on results).

Flavour

Flavour is assessed soon after samples are collected as it too is affected over a period of time. Sensory analysis remains the most effective and popular method of assessing

flavour within the brewing industry. Expert panels are used throughout the industry, being trained to identify certain flavours at various thresholds in beer. The ASBC (1992) and the EBC (1987) have developed official standards that cover descriptors of these flavours.

The microbrewer can take formal sensory analysis training or they may devise a personal testing method. Either way, use of a standard is recommended as sensory analysis is influenced by evaluator's condition and biases. As beer flavour changes over time, it is difficult to maintain a rigid standard. EBC (1987) and ASBC (1992) descriptor solutions can be used to develop a standard. These solutions are added at varying intensities to the beer. Untreated samples are then compared with these control samples.

Alcohol Content

There is a direct relationship between the level of extract spent during fermentation and the ethanol content of final beer. The level of extract used during fermentation is obtained by determining the difference between the original extract of the wort and the residual extract of the final beer. Reference is then made to Balling or Plato tables. Alternatively, alcohol content can be measured by refractometer.

Clarity

Beer turbidity is measured in large breweries by nephelometer or hazemeter. These instruments are calibrated to standard Formazin Turbidity Units. The microbrewer can evaluate beer clarity effectively by visual inspection when performed in conjunction with a pictorial standard depicting varying levels of turbidity in beer.

Colour

Colour can be measured by visual comparison, this measurement being given more reliability with the use of a standard (i.e. the EBC-endorsed Lovibond Colour Comparitor or one developed by the microbrewer). Colour can also be measured by objective methods involving spectrophotometry or tristumulus colourimetry.

Step 4 Construct control chart

$\overline{X}$ and R control charts are then constructed for each characteristic (i.e. colour, flavour, alcohol content, carbonation, clarity, and head), from the data collected in Step 3 (see Section 3.2 for control chart construction).

Step5 Chart points.

Subgroup mean and range values should then be plotted on respective control charts. If all points are within control limits, the process is in statistical control. If any points fall outside the control limits, the process is not in statistical control. Special causes of this excessive variation should then be identified and eliminated, with examination of the log being a starting point. Step 1-5 should be repeated in iterative fashion after each special cause is removed to ensure that no others remain.

Step 6 Ongoing verification

Once under control, control charts are used on an ongoing basis to verify that the manufacturing process is meeting specification and remaining under statistical control. Steps 1-3 are performed with each batch, with resulting data being plotted on respective control charts. If batch data falls within control limits, the process has remained under control. If data fall outside of control limits, the process is out of control, indicating the introduction of a special cause(s). These have then to be identified through review of both log and QCP monitoring records, and eliminated.

Control charts can also be useful in identifying impending deviation from control limits. This is done by analysing charts for certain patterns that tend to indicate the existence of special causes. Bissel (1994) gives examples of these patterns.

4.1.8 Records and record-keeping

The following record sheets were constructed for registering monitoring and verification data. They are generic in nature, allowing use during production of different products.

List of records

- MR1A Receipt of raw materials [malt]
- MR1B Receipt of raw materials [hops]
- MR1C Receipt of raw materials [yeast]
- MR1D Receipt of raw materials [water]
- MR2A Storage of raw materials [mill room]
- MR2B Storage of raw materials [cool room]
- MR2C Storage of raw materials [hop storage]
- MR3 Batch production
- MR4 Cleaning regime
- VR Verification record

MR1A-MR1C were formatted to account for two deliveries of each of the respective materials, while MR1D recorded water analysis for the year.

MR2A-MR2C were formatted to record storage data per fortnight.

MR3 was formatted to record production data per batch.

MR4 is a record used during every cleaning session. It is also recommended that supplementary cleaning records are devised to ensure the correct application of particular cleaning methods (e.g. correct preparation of cleaners, problems areas in vessels that should be concentrated on).

VR is a record used to register verification data for individual batches. Subgroup mean and range values should be entered onto established control charts.

It was recommended that records are kept together in a ring binder for a period of 12 months. They should then be destroyed by incineration or shredder.

MONITORING RECORD 1A: RECEIPT OF RAW MATERIALS [MALT]

CRITICAL LIMITS
Potential extract= >80-85% of total weight Acrospire growth= >80% of kernels= ¾-full length
Colour= *depends on particular malt type*

BATCH NUMBER	HAZARD	CONTROL MEASURE	ACTUAL READING	CORRECTIVE ACTION
	Low level of potential extract	Inspect potential extract		
	Incorrect level of modification	Inspect acrospire growth		
	Incorrect malt colour	Inspect malt colour		
	Low level of potential extract	Inspect potential extract		
	Incorrect level of modification	Inspect acrospire growth		
	Incorrect malt colour	Inspect malt colour		
	Low level of potential extract	Inspect potential extract		
	Incorrect level of modification	Inspect acrospire growth		
	Incorrect malt colour	Inspect malt colour		
	Low level of potential extract	Inspect potential extract		
	Incorrect level of modification	Inspect acrospire growth		
	Incorrect malt colour	Inspect malt colour		

MONITORING RECORD 1B: RECEIPT OF RAW MATERIALS [HOPS]

CRITICAL LIMITS
Alpha acid level= *depends on particular malt type*
Essential oils level= *depends on particular malt type*

BATCH NUMBER	HAZARD	CONTROL MEASURE	ACTUAL READING	CORRECTIVE ACTION
	Low alpha acid level	Inspect alpha acid level		
	Low essential oil level	Inspect essential oil level		
	Low alpha acid level	Inspect alpha acid level		
	Low essential oil level	Inspect essential oil level		
	Low alpha acid level	Inspect alpha acid level		
	Low essential oil level	Inspect essential oil level		
	Low alpha acid level	Inspect alpha acid level		
	Low essential oil level	Inspect essential oil level		
	Low alpha acid level	Inspect alpha acid level		
	Low essential oil level	Inspect essential oil level		
	Low alpha acid level	Inspect alpha acid level		
	Low essential oil level	Inspect essential oil level		

MONITORING RECORD 1C: RECEIPT OF RAW MATERIALS [YEAST]

CRITICAL LIMITS
Viability= >85% viability Contamination= <2% of cells being bacteria; detection of wild yeast under magnification *500 Flocculation= depends on particular yeast sample

BATCH NUMBER	HAZARD	CONTROL MEASURE	ACTUAL READING	CORRECTIVE ACTION
	Low viability	Inspect viability		
	Contamination	Inspect purity		
	Poor flocculation	Inspect flocculation		
	Low viability	Inspect viability		
	Contamination	Inspect purity		
	Poor flocculation	Inspect flocculation		
	Low viability	Inspect viability		
	Contamination	Inspect purity		
	Poor flocculation	Inspect flocculation		
	Low viability	Inspect viability		
	Contamination	Inspect purity		
	Poor flocculation	Inspect flocculation		
	Low viability	Inspect viability		
	Contamination	Inspect purity		
	Poor flocculation	Inspect flocculation		

MONITORING RECORD 1D: RECEIPT OF RAW MATERIALS [MAINS WATER]

CRITICAL LIMITS
Mineral composition= <250mg/l (chlorides) <500mg/l (sulphates) <70mg/l (calcium)
<30mg/l (nitrates)

DATE	HAZARD	CONTROL MEASURE	ACTUAL READING	CORRECTIVE ACTION
	Significant variation in mineral composition	Inspect mineral composition		
	Significant variation in mineral composition	Inspect mineral composition		
	Significant variation in mineral composition	Inspect mineral composition		
	Significant variation in mineral composition	Inspect mineral composition		

MONITORING RECORD 2A: STORAGE OF RAW MATERIALS [MILL ROOM]

CRITICAL LIMITS

Humidity= <30% Temperature= <25°C Time in storage (malt)= <6 weeks

Insector detector reading= <3 insects in trap per day

DATE	HUMIDITY	TEMPERATURE	TIME IN STORAGE (MALT)	INSECT DETECTOR READING	CORRECTIVE ACTION
/ /98					
/ /98					
/ /98					
/ /98					
/ /98					
/ /98					
/ /98					
/ /98					
/ /98					
/ /98					
/ /98					
/ /98					
/ /98					
/ /98					
/ /98					

MONITORING RECORD 2B: STORAGE OF RAW MATERIALS [COOL ROOM]

CRITICAL LIMITS

Temperature= 5-15°C Time in storage (yeast)= <4 weeks

DATE	TEMPERATURE	TIME IN STORAGE (YEAST)	CORRECTIVE ACTION
/ /98			
/ /98			
/ /98			
/ /98			
/ /98			
/ /98			
/ /98			
/ /98			
/ /98			
/ /98			
/ /98			
/ /98			
/ /98			
/ /98			

MONITORING RECORD 2C : STORAGE OF RAW MATERIALS [HOP STORAGE]

CRITICAL LIMITS

Refrigerator temperature= <4°C Time in storage (hops)= <12 months Is the lid secured?= yes

DATE	TEMPERATURE	TIME IN STORAGE (HOPS)	IS THE LID SECURED?	CORRECTIVE ACTION
/ /98				
/ /98				
/ /98				
/ /98				
/ /98				
/ /98				
/ /98				
/ /98				
/ /98				
/ /98				
/ /98				
/ /98				
/ /98				
/ /98				

MONITORING RECORD 3: BATCH PRODUCTION

PRODUCT NAME:
START DATE:

BATCH NUMBER:
COMPLETION DATE:

PROCESS STEP	HAZARD	CONTROL MEASURE	CRITICAL LIMIT	ACTUAL READING	CORRECTIVE ACTION
Processing of mains water	*Excessive levels of organic matter*	Prescribed no. of cartridge uses	*tba*		
	Insufficiently cooled liquor	Cooling time in tank	*tba*		
Milling	*Incorrect grist fractions*	Inspect mill gap settings	*tba*	Start= Midpoint=	
	Incorrect grist size	Weigh malt sacks	=50kg/sack	Average sack weight=	
Mashing	*Low saccharification* •dry mash portions	Maintain liquor flow-rate	*tba*	Start= Midpoint=	
	•incorrect mash pH	Inspect mash pH	pH5.2-5.5		
	•insufficient mash time	Maintain appropriate mashing duration	*tba*		
Reprocessing of liquor for sparging	*Incorrect liquor temperature*	Thermostatic control	*tba*		
	Incorrect liquor pH	Inspect liquor pH	pH6.0-6.5		
	•compact mash bed	Monitor runoff valve setting	*tba*	Start= Midpoint=	

MONITORING RECORD 3: BATCH PRODUCTION

PRODUCT NAME: BATCH NUMBER:

START DATE: COMPLETION DATE:

PROCESS STEP	HAZARD	CONTROL MEASURE	CRITICAL LIMIT	ACTUAL READING	CORRECTIVE ACTION
Wort runoff/ sparging	*Insufficient extract recovery* •rapid sparge	Monitor sparging liquor flow-rate	*tba*	Start= Midpoint=	
	Extraction & oxidation of undesirable matter	Monitor sparge duration	*tba*		
Wort boiling	*Low hop isomerisation* •low hop quantity	Inspect hop quantity	*tba*		
	Excessive colour increase	Monitor boil time	*tba*		
	Loss of hop aroma	Late addition of aromatic hops	last 15mins of boil		
	Excessive wort concentration	Monitor boiling temperature (& time)	*tba*	*Time of boil is recorded in [excessive colour increase]*	
	Low wort clarity •low fining use	Maintain appropriate fining quantity	to fining supplier's directions		
	•short boil time	Maintain appropriate boil duration	*tba*	*Time of boil is recorded in [excessive colour increase]*	
	•short wort stand	Monitor stand time	=30minutes		

MONITORING RECORD 3: BATCH PRODUCTION

PRODUCT NAME: BATCH NUMBER:

START DATE: COMPLETION DATE:

PROCESS STEP	HAZARD	CONTROL MEASURE	CRITICAL LIMIT	ACTUAL READING	CORRECTIVE ACTION
Wort cooling and aeration	*High wort temperature* •rapid wort flow-rate	Monitor flow rate	*tba*	Start= Midpoint=	
	•high coolant temp.	Monitor coolant temperature	*tba*	Start= Midpoint=	
Fermentation	*Insufficient attenuation* •low fermentation temperature	Fermentation temperature controlled by thermostat.	*tba*	DAY ONE 1st= 2nd= DAY TWO 1st= 2nd= DAY THREE 1st= 2nd= DAY FOUR 1st= 2nd= DAY FIVE 1st= 2nd= DAY SIX 1st= 2nd= DAY SEVEN 1st= 2nd=	

MONITORING RECORD 3: BATCH PRODUCTION

PRODUCT NAME: BATCH NUMBER:

START DATE: COMPLETION DATE:

Fermentation (cont.)	•insufficient yeast quantity	Maintain appropriate yeast quantity	*tba*		
	•short fermentation time	Monitor fermentation time	*tba*	DAY ONE= DAY TWO= DAY THREE= DAY FOUR= DAY FIVE= DAY SIX= DAY SEVEN=	
	Off-flavours develop •incorrect fermentation temperature	Fermentation temperature controlled by thermostat.	*tba*	*Time of boil is recorded in [insufficient attenuation]]*	
	•incorrect yeast quantity	Measure yeast quantity	*tba*		
	•incorrect fermentation time	Monitor fermentation time	*tba*		
Maturation	*Off-flavours develop* •high maturation temperature	Maturation temp. controlled by thermostat	-1–0°C	DAY ONE 1st= 2nd= DAY TWO 1st= 2nd= DAY THREE 1st= 2nd= DAY FOUR 1st= 2nd=	

MONITORING RECORD 3: BATCH PRODUCTION

PRODUCT NAME: BATCH NUMBER:

START DATE: COMPLETION DATE:

Maturation (cont.)	*Off-flavours develop* •high maturation temperature	Maturation temp. controlled by thermostat	-1–0°C	DAY FIVE 1st= 2nd= DAY SIX 1st= 2nd= DAY SEVEN 1st= 2nd=	
	•short maturation duration	Monitor time	*tba*		
Filtration	*Insufficient clarification* •warm filtration temperature	Filtration temp. controlled by thermostat	-1–0°C		
	•worn filter cartridge	Replace cartridge after a prescribed number of uses	*tba*		
	Oxidation	Monitor filtration rate	<10l/min.	Start= Midpoint=	
	Hastening onset of permanent haze.	Filtration temp. controlled by thermostat	-1–0°C		
Carbonation and settling	*Incorrect level of carbonation*	Monitor CO_2 injection levels	*tba*		

MONITORING RECORD 3: BATCH PRODUCTION

PRODUCT NAME: BATCH NUMBER:

START DATE: COMPLETION DATE:

Packaging	*Oxidation* •rapid filling rate	Monitor filling rate	25-30l/min.		
	•excessive head-space	Monitor filling quantity	=50L		
	•faulty keg seals	Monitor keg pressure	*tba*	After filling/24 hrs later 1st keg= / 2nd keg= / 3rd keg= / 4th keg= / 5th keg= / 6th keg= / 7th keg= / 8th keg= / 9th keg= / 10th keg= / 12th keg= / 13th keg= / 14th keg= / 15th keg= / 16th keg= / 17th keg= / 18th keg= / 19th keg= /	
	Introduction of oils and fatty acids	Effective cleaning	strict compliance with cleaning procedures		

Note. *tba*= to be arranged for particular brewery parameters and specific product being manufactured.

MONITORING RECORD 4: CLEANING REGIME

REGULARITY

All equipment is to be cleaned after every use, except for the hot liquor tank, which is cleaned once every 3 months.

DATE	EQUIPMENT	CLEANING METHOD	CHECK OFF
	Hot liquor tank	Manually scrubbed with metal scourer using caustic soda. Rinsed with hot water.	
	Mill	Manually wiped clean with a clean rag.	
	Auger	Manually wiped clean with a clean rag.	
	Mash/lauter tun	Manually scrubbed with metal scourer using caustic soda. Rinsed with hot water.	
	Kettle	Manually scrubbed with metal scourer using caustic soda. Rinsed with hot water.	
	Heat exchanger	Strong caustic detergent is flushed through the heat exchanger, followed by an appropriate sanitiser (e.g. hydrogen peroxide). Finally, hot water is flushed through the heat exchanger.	
	Fermentation/ maturation vessels	Strong caustic detergent is flushed through the fermentation/maturation vessels, followed by an appropriate sanitiser (e.g. hydrogen peroxide). Finally, hot water is flushed through the vessels.	
	Filter	Strong caustic detergent is flushed through the filter, followed by an appropriate sanitiser (e.g. hydrogen peroxide). Finally, hot water is flushed through the filter.	
	Bright beer tanks	Strong caustic detergent is flushed through the bright beer tanks, followed by an appropriate sanitiser (e.g. hydrogen peroxide). Finally, hot water is flushed through the vessels.	
	Kegs	Hot caustic soda is flushed through kegs, followed by a water rinse.	
	Piping	All piping in the system is flushed with hot caustic soda, followed by an appropriate sanitising agent. This is then followed by a water rinse.	

VERIFICATION RECORD

PRODUCT NAME: BATCH NUMBER:

DATE OF VERIFICATION:

HEAD	FLAVOUR	ALCOHOL CONTENT	CLARITY	COLOUR
1st keg=	1st keg=	1st keg=	1st keg=	1st keg=
2nd keg=	2nd keg=	2nd keg=	2nd keg=	2nd keg=
3rd keg=	3rd keg=	3rd keg=	3rd keg=	3rd keg=
4th keg=	4th keg=	4th keg=	4th keg=	4th keg=
5th keg=	5th keg=	5th keg=	5th keg=	5th keg=
6th keg=	6th keg=	6th keg=	6th keg=	6th keg=
$\overline{X}$ = R=	$\overline{X}$ = R=	$\overline{X}$ = R=	$\overline{X}$ = R=	$\overline{X}$ = R=

4.2 Pilot test results

In this section, the results of the pilot test are presented in such a way so as to demonstrate how sample data and control charts can be used in the verification of the quality assurance plan.

$\overline{X}$ (mean) and R (range) values for specific gravity (SG) of boiled wort produced during pilot testing are presented in Table 9 (see Appendix 7 for complete sample data).

Table 9. $\overline{X}$ and R values: boiled wort's specific gravity.

BATCH NO.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
SPECIFIC GRAVITY	1050	1051	1048	1049	1047	1047	1049	1047	1051	1049
RANGE	1	1	0	2	1	1	2	1	1	2

Using the formula given in Section 3.2, $\overline{X}$ and R control charts were constructed from this data with subsequent control chart parameters being

Central line ($\overline{\overline{X}}$)= (1050 + 1051 + 1048 + 1049 + 1047 + 1047 + 1049 + 1047 +1051 +1049) ÷ 10 = 1048.8

Upper control limit (UCL) for $\overline{X}$ = 1048.8 + (0.483*1.2) = 1049.38

Lower control limit for $\overline{X}$ (LCL) = 1048.8 – (0.483*1.2) =1048.22

Central line $\overline{R}$ = (1 + 1 + 0 + 2 + 1 + 1 + 2 + 1 + 1 + 2) ÷10 =1.2

Upper control limit (UCL) for R= 2.004 * 1.2=2.4048

Lower control limit (LCL) for R=0* 1.2=0

Since the precision of the hydrometer was to the nearest 1.0 units of specific gravity, control limits had to be set to the nearest 1.0 SG. Therefore, the process was deemed to be out of control if any subgroup mean value was either below 1048 or equal to or above 1050. These control limits are not as accurate as desired, yet they do allow detection of process deviation at a fairly early stage.

The resulting $\overline{X}$ and R charts are illustrated in Figures 12 and 13, respectively. In Figure 14, it is evident that only Batches 3, 4, 7 and 10 fell within the required control limits.

The log taken during production points to a number of possible causes

- inability of monitoring methods to detect a widening of mill gaps during milling
- inability of monitoring methods to accurately measure mash pH
- variable sparge times due to a faulty runoff tap
- inconsistent heat temperatures due to variability of heating element

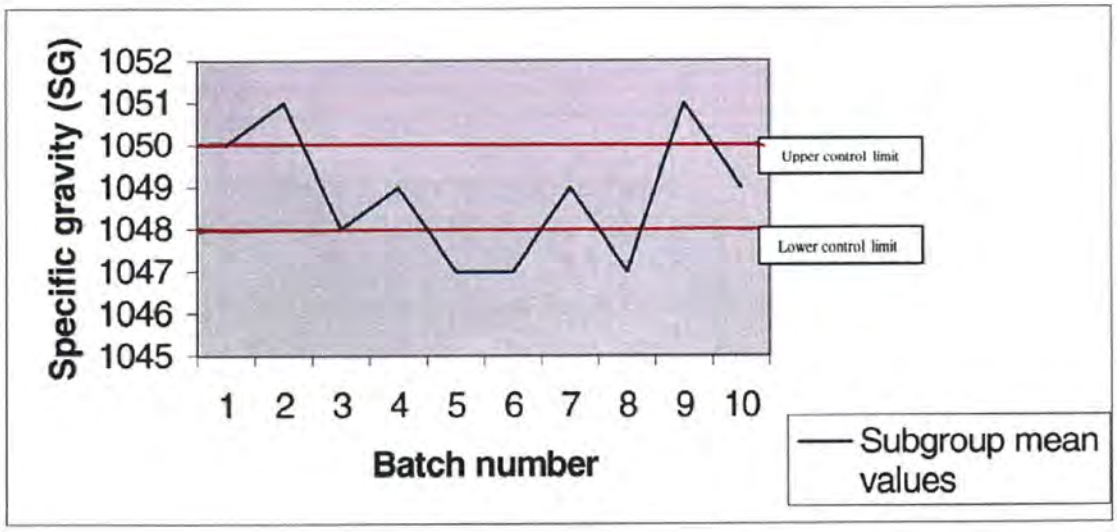

Figure 12. $\overline{X}$ -chart: specific gravity of boiled wort.

Shainin and Shainin (1988) state that this lack of control is typical of industrial processes when they are first analysed. As expected, Figure 13 illustrates that subgroup ranges were within required control limits. This indicates the uniformity of the process, or the homogeneity of samples within a given batch.

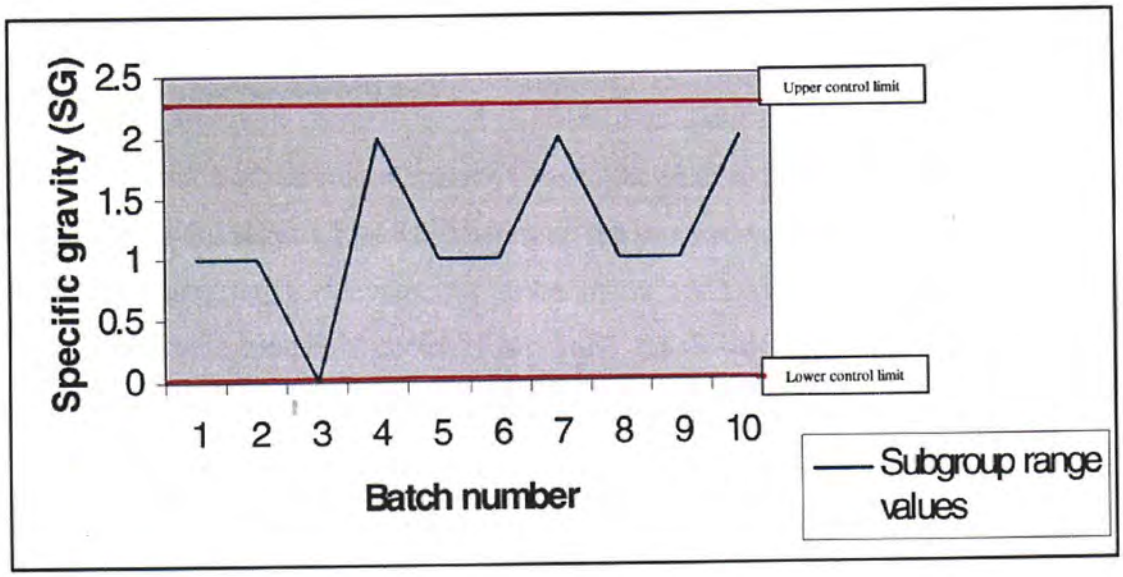

Figure 13. R-chart: specific gravity of boiled wort.

$\overline{X}$ and R values for the colour of boiled wort produced during pilot testing are presented in Table 10.

Table 10. $\overline{X}$ and R values: Boiled Wort Colour.

BATCH NO.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
SPECIFIC GRAVITY	16	16	16	16	16	16	16	16	16	16
RANGE	0	0	0	1	1	0	0	1	1	0

Again, using the formula given in Section 3.2, $\overline{X}$ and R control charts were constructed from this data with subsequent control chart parameters being

Central line ($\overline{\overline{X}}$)=(16 + 16 + 16 + 16 + 16 + 16 + 16 + 16 + 16 + 16) ÷ 10 =16

Upper control limit for $\overline{X}$ = 16 + (0.483∗0.4) =16.19

Lower control limit for $\overline{X}$ = 16 – (0.483∗0.4) =15.80

Central line $\overline{R}$ = (0 + 0 + 0 + 1 + 1 + 0 + 0 + 1 + 1 + 0) ÷10 =0.4

Upper control limit for R= 2.004 * 0.4=1 (rounded to nearest CU)

Lower control limit for R=0* 0.4=0

Since the precision of the colour standard was to the nearest 1.0 colour unit, control limits had to be set to the nearest 1.0 CU. Therefore, the process was deemed to be out of control if any subgroup mean value was either below 15CU or equal to or above 16CU. These control limits are not as accurate as desired, yet they do allow detection of process deviation at a fairly early stage. The resulting $\overline{X}$ and R charts are illustrated in Figures 14 and 15, respectively.

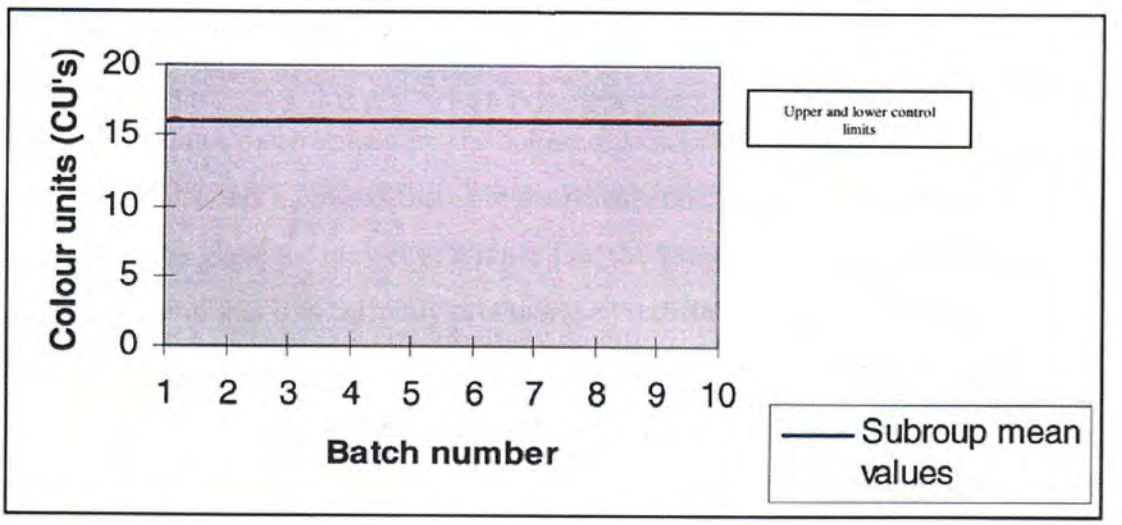

Figure 14. $\overline{X}$ -chart: colour of boiled wort.

Note. In Figure 14, upper and lower control limits were both calculated as 16CU's. This effectively means that for the process to be considered "under control", the average or mean beer colour value of each subgroup had to equal 16 CU's. In the pilot test, all mean values did equal 16 CU's.

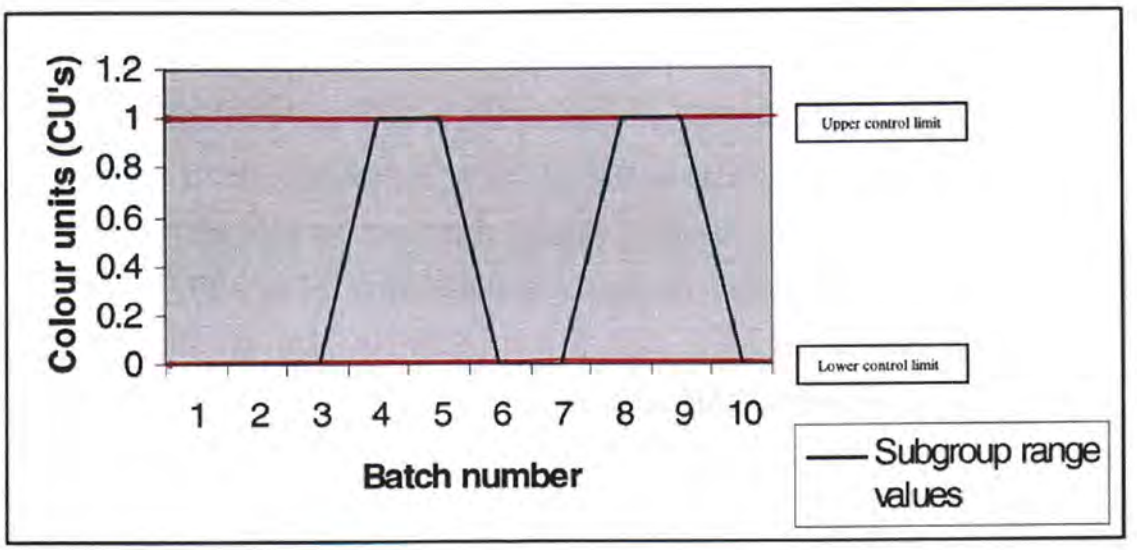

Figure 15. R-chart: colour of boiled wort.

Figure 14 illustrates mean values for the colour of successive batches. In contrast to Figure 12, it illustrates a process that is in statistical control. All colour data is normally distributed. This gives the brewer assurance that the simulated process contains no special causes and that it is currently producing a predictable quality of output. Consequently, the brewer is in a position to detect when a special cause for colour is introduced to the process, indicating the instance to apply corrective action. Again, the homogeneity of samples taken from a given batch was indicated by range values falling within control limits in Figure 15.

Two important points were noted during pilot testing that were deemed relevant to the quality assurance plan. Firstly, it became evident that a more effective method of measuring mill gaps was needed. The suggested methods were not capable of detecting the widening of mill gaps during processing. Subsequently, it was suggested that this could be done by hand-held micrometer. Secondly, it was found that universal indicator paper did not give pH measurements of sufficient accuracy. Consequently, there was some doubt whether critical limits for mash and sparging liquor pH had been attained. The client was recommended to use a hand-held pH meter in these determinations.

SECTION 5: CONCLUSION

The development and maintenance of a quality assurance system to a standard such as ISO 9000, is beyond the economic and labour constraints under which a small company such as Westoz is forced to operate. With HACCP becoming a prerequisite for doing business in the food industry, the stress of quality assurance on small companies has gone to the extreme. This has led to the recent development of a number of alternative standards, specifically designed for the needs of these companies. In many instances, these are integrated systems that involve the use of the HACCP concept to attend to both safety and wider quality issues, simultaneously.

The main purpose of this study was to develop an open structured quality assurance plan for the manufacture of lager-style products at one of the client's microbreweries. It was intended that this would become the template for establishing specific quality assurance systems for individual products. A major concern of the client was that a quality assurance plan could be designed that was both effective and within the constraints of the brewery. In order to achieve these goals, the HACCP concept was applied during plan development.

Features of plan development included the following

- quality issues identified through focus group research involving members of one of Westoz's niche markets (i.e. West Australian females aged 18-25 years); these issues were found to include colour, flavour, alcohol content, carbonation, clarity and head. The control of these beer attributes became the goal of the plan.

- Westoz's manufacturing process analysed to identify existing hazards to these attributes, and also control measures capable of either preventing these hazards from occurring or reducing their effects on product quality to acceptable levels. It was subsequently found that the quality assurance regime previously proposed by the client was incapable of attending to identified quality issues. A number of identified hazards had not been attended to, and certain of the proposed control measures were

unreliable due to suspect methodology. In addition, no formal method of process management had been specified. Finally, these hazards were reduced to Quality Control Points (QCPs), which were deemed to be essential for product quality. Hence, this was to ensure that resources were not spent on extraneous considerations.

- provision made for the effective control of QCPs. This involved establishing critical limits, identifying monitoring methods, and specifying corrective actions. Critical limits were required to provide criteria for determining whether adequate control was being applied. A differentiation was made between critical limits common to all products and those particular to individual products. Monitoring procedures tended to involve observing variables associated with ensuring adequate application of control measures, although analysis of product at certain QCPs was deemed necessary. Objective measurements were predominantly used in these instances, although it was thought that the brewer would occasionally have to rely on more subjective methodologies. In these instances, it was recommended that determinations be made in conjunction with some form of standard. Corrective actions were then identified to restore the manufacturing process and affected product following process deviation.

- a method of process management devised to ensure ongoing effectiveness of the quality assurance plan. This involved establishing verification and record-keeping procedures. Verification involved incorporation of control chart theory for the purposes of detecting process deviation and circumstances that lead to deviation. This was based on end-product sampling. Record sheets were designed to note monitoring data, corrective actions and verification data. It was decided that they should be kept for a period of 12 months.

The plan was partially tested, primarily to determine the adequacy of certain monitoring methods, but also to demonstrate the implementation of verification methods. In particular, this involved the control of wort colour and specific gravity being performed in a simulation of the client's brewing process. It was subsequently found that two of the

monitoring methods required adjustment, namely the measurement of mill gap width, and mash and sparging liquor pH. It was recommended that mill gap width be measured by micrometer, and the pH values of both mash and sparging liquor pH by pH meter.

The present study formulates a quality assurance plan that will be of significant value to the client. It is both systematic and practical in approach in assuring beer quality issues other than safety at the microbrewery. In addition, by incorporating the HACCP concept, it allows the eventual development of a single system that attends to both safety and wider food quality issues. Therefore, it is an initial step toward certification to standards such as SQF 2000. Ultimately, the benefit of this study to the client is increased market competitiveness through improved product quality.

Conversely, the significance of this study to the wider microbrewery community is somewhat limited as the plan was developed for one particular brewing system. However, it was thought that many of the identified QCPs and associated control provisions would be also relevant to other microbreweries.

Recommendations

The following are recommendations for the implementation and maintenance of the quality assurance plan at Westoz.

1. Quantitative studies must be conducted to ensure that identified quality issues are truly representative of the concerns of targeted consumers.
2. The flow diagram must be verified once the brewery is operational. If it is accurate, implementation of the plan may continue. However, if it is not accurate, the plan must be re-assessed to determine whether it is still able to achieve control.
3. Certain critical limits must be established for individual products at the plant. This is best achieved during product development by regression or other scientific methodologies.

4. The effect of various corrective actions on product attributes has also to be determined. Again, this is best determined during product development by regression or other scientific methodologies.
5. In order for effective ongoing verification of the process, the process has first got to be brought under statistical control. This will be gained over a period of time where all special causes of variation are removed.
6. The effectiveness of this HACCP plan relies on the quality of brewery equipment and personnel. It is vital that equipment is regularly maintained and calibrated, and personnel given adequate training to ensure that they are able to effectively perform quality assurance duties.
7. This plan is not effective if it is partially implemented. It must be implemented as a whole, if quality assurance is to be achieved.
8. A major problem encountered during the study was the lack of literature detailing practical methods of analysis for microbreweries. There is a real need for not only methods to be identified but also to be standardised if this sector of the market is to establish itself and grow.

Limitations of the study

The quality assurance plan was based on a proposed process. The Westoz process may differ to this once the plant is operational. If this eventuates, the plan will have to be re-assessed to determine whether it remains effective.

Only limited testing of analytical methods was possible due to time constraints. There is a need for testing to be completed to ensure the reliability and validity of various methods.

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APPENDICES

APPENDIX 1: ISO 9002:1994

Quality systems — Model for quality assurance in production, installation and servicing

1 Scope

This International Standard specifies quality system requirements for use where a supplier's capability to supply conforming product to an established design needs to be demonstrated.

The requirements specified are aimed primarily at achieving customer satisfaction by preventing nonconformity at all stages from production through to servicing.

This International Standard is applicable in situations when

a) the specified requirements for product are stated in terms of an established design or specification, and

b) confidence in product conformance can be attained by adequate demonstration of a supplier's capabilities in production, installation and servicing.

NOTE 1 For informative references, see annex A.

2 Normative reference

The following standard contains provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the edition indicated was valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent edition of the standard indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 8402:1994, *Quality management and quality assurance — Vocabulary.*

3 Definitions

For the purposes of this International Standard, the definitions given in ISO 8402 and the following definitions apply.

3.1 product: Result of activities or processes.

NOTES

2 A product may include service, hardware, processed materials, software or a combination thereof.

3 A product can be tangible (e.g. assemblies or processed materials) or intangible (e.g. knowledge or concepts), or a combination thereof.

4 For the purposes of this International Standard, the term "product" applies to the intended product offering only and not to unintended "by-products" affecting the environment. This differs from the definition given in ISO 8402.

3.2 tender: Offer made by a supplier in response to an invitation to satisfy a contract award to provide product.

3.3 contract: Agreed requirements between a supplier and customer transmitted by any means.

4 Quality system requirements

4.1 Management responsibility

4.1.1 Quality policy

The supplier's management with executive responsibility shall define and document its policy for quality, including objectives for quality and its commitment to quality. The quality policy shall be relevant to the supplier's organizational goals and the expectations and needs of its customers. The supplier shall ensure

that this policy is understood, implemented and maintained at all levels of the organization.

4.1.2 Organization

4.1.2.1 Responsibility and authority

The responsibility, authority and the interrelation of personnel who manage, perform and verify work affecting quality shall be defined and documented, particularly for personnel who need the organizational freedom and authority to:

a) initiate action to prevent the occurrence of any nonconformities relating to the product, process and quality system;

b) identify and record any problems relating to the product, process and quality system;

c) initiate, recommend or provide solutions through designated channels;

d) verify the implementation of solutions;

e) control further processing, delivery or installation of nonconforming product until the deficiency or unsatisfactory condition has been corrected.

4.1.2.2 Resources

The supplier shall identify resource requirements and provide adequate resources, including the assignment of trained personnel (see 4.18), for management, performance of work and verification activities including internal quality audits.

4.1.2.3 Management representative

The supplier's management with executive responsibility shall appoint a member of the supplier's own management who, irrespective of other responsibilities, shall have defined authority for

a) ensuring that a quality system is established, implemented and maintained in accordance with this International Standard, and

b) reporting on the performance of the quality system to the supplier's management for review and as a basis for improvement of the quality system.

NOTE 5 The responsibility of a management representative may also include liaison with external parties on matters relating to the supplier's quality system.

4.1.3 Management review

The supplier's management with executive responsibility shall review the quality system at defined intervals sufficient to ensure its continuing suitability and effectiveness in satisfying the requirements of this International Standard and the supplier's stated quality policy and objectives (see 4.1.1). Records of such reviews shall be maintained (see 4.16).

4.2 Quality system

4.2.1 General

The supplier shall establish, document and maintain a quality system as a means of ensuring that product conforms to specified requirements. The supplier shall prepare a quality manual covering the requirements of this International Standard. The quality manual shall include or make reference to the quality system procedures and outline the structure of the documentation used in the quality system.

NOTE 6 Guidance on quality manuals is given in ISO 10013.

4.2.2 Quality system procedures

The supplier shall

a) prepare documented procedures consistent with the requirements of this International Standard and the supplier's stated quality policy, and

b) effectively implement the quality system and its documented procedures.

For the purposes of this International Standard, the range and detail of the procedures that form part of the quality system shall be dependent upon the complexity of the work, the methods used, and the skills and training needed by personnel involved in carrying out the activity.

NOTE 7 Documented procedures may make reference to work instructions that define how an activity is performed.

4.2.3 Quality planning

The supplier shall define and document how the requirements for quality will be met. Quality planning shall be consistent with all other requirements of a supplier's quality system and shall be documented in a format to suit the supplier's method of operation. The supplier shall give consideration to the following activities, as appropriate, in meeting the specified requirements for products, projects or contracts:

a) the preparation of quality plans;

b) the identification and acquisition of any controls, processes, equipment (including inspection and test equipment), fixtures, resources and skills that may be needed to achieve the required quality;

c) ensuring the compatibility of the production process, installation, servicing, inspection and test procedures and the applicable documentation;

d) the updating, as necessary, of quality control, inspection and testing techniques, including the development of new instrumentation;

e) the identification of any measurement requirement involving capability that exceeds the known state of the art, in sufficient time for the needed capability to be developed;

f) the identification of suitable verification at appropriate stages in the realization of product;

g) the clarification of standards of acceptability for all features and requirements, including those which contain a subjective element;

h) the identification and preparation of quality records (see 4.16).

NOTE 8 The quality plans referred to [see 4.2.3 a)] may be in the form of a reference to the appropriate documented procedures that form an integral part of the supplier's quality system.

4.3 Contract review

4.3.1 General

The supplier shall establish and maintain documented procedures for contract review and for the coordination of these activities.

4.3.2 Review

Before submission of a tender, or the acceptance of a contract or order (statement of requirement), the tender, contract or order shall be reviewed by the supplier to ensure that:

a) the requirements are adequately defined and documented; where no written statement of requirement is available for an order received by verbal means, the supplier shall ensure that the order requirements are agreed before their acceptance;

b) any differences between the contract or order requirements and those in the tender are resolved;

c) the supplier has the capability to meet the contract or order requirements.

4.3.3 Amendment to a contract

The supplier shall identify how an amendment to a contract is made and correctly transferred to the functions concerned within the supplier's organization.

4.3.4 Records

Records of contract reviews shall be maintained (see 4.16).

NOTE 9 Channels for communication and interfaces with the customer's organization in these contract matters should be established.

4.4 Design control

The scope of this International Standard does not include quality-system requirements for design control. This subclause is included to align the clause numbering with ISO 9001.

4.5 Document and data control

4.5.1 General

The supplier shall establish and maintain documented procedures to control all documents and data that relate to the requirements of this International Standard including, to the extent applicable, documents of external origin such as standards and customer drawings.

NOTE 10 Documents and data can be in the form of any type of media, such as hard copy or electronic media.

4.5.2 Document and data approval and issue

The documents and data shall be reviewed and approved for adequacy by authorized personnel prior to issue. A master list or equivalent document control procedure identifying the current revision status of documents shall be established and be readily available to preclude the use of invalid and/or obsolete documents.

This control shall ensure that:

a) the pertinent issues of appropriate documents are available at all locations where operations essen-

tial to the effective functioning of the quality system are performed;

b) invalid and/or obsolete documents are promptly removed from all points of issue or use, or otherwise assured against unintended use;

c) any obsolete documents retained for legal and/or knowledge-preservation purposes are suitably identified.

4.5.3 Document and data changes

Changes to documents and data shall be reviewed and approved by the same functions/organizations that performed the original review and approval, unless specifically designated otherwise. The designated functions/organizations shall have access to pertinent background information upon which to base their review and approval.

Where practicable, the nature of the change shall be identified in the document or the appropriate attachments.

4.6 Purchasing

4.6.1 General

The supplier shall establish and maintain documented procedures to ensure that purchased product (see 3.1) conforms to specified requirements.

4.6.2 Evaluation of subcontractors

The supplier shall:

a) evaluate and select subcontractors on the basis of their ability to meet subcontract requirements including the quality system and any specific quality assurance requirements;

b) define the type and extent of control exercised by the supplier over subcontractors. This shall be dependent upon the type of product, the impact of subcontracted product on the quality of final product and, where applicable, on the quality audit reports and/or quality records of the previously demonstrated capability and performance of subcontractors;

c) establish and maintain quality records of acceptable subcontractors (see 4.16).

4.6.3 Purchasing data

Purchasing documents shall contain data clearly describing the product ordered, including where applicable:

a) the type, class, grade or other precise identification;

b) the title or other positive identification, and applicable issues of specifications, drawings, process requirements, inspection instructions and other relevant technical data, including requirements for approval or qualification of product, procedures, process equipment and personnel;

c) the title, number and issue of the quality system standard to be applied.

The supplier shall review and approve purchasing documents for adequacy of the specified requirements prior to release.

4.6.4 Verification of purchased product

4.6.4.1 Supplier verification at subcontractor's premises

Where the supplier proposes to verify purchased product at the subcontractor's premises, the supplier shall specify verification arrangements and the method of product release in the purchasing documents.

4.6.4.2 Customer verification of subcontracted product

Where specified in the contract, the supplier's customer or the customer's representative shall be afforded the right to verify at the subcontractor's premises and the supplier's premises that subcontracted product conforms to specified requirements. Such verification shall not be used by the supplier as evidence of effective control of quality by the subcontractor.

Verification by the customer shall not absolve the supplier of the responsibility to provide acceptable product, nor shall it preclude subsequent rejection by the customer.

4.7 Control of customer-supplied product

The supplier shall establish and maintain documented procedures for the control of verification, storage and maintenance of customer-supplied product provided for incorporation into the supplies or for related activities. Any such product that is lost, damaged or is

otherwise unsuitable for use shall be recorded and reported to the customer (see 4.16).

Verification by the supplier does not absolve the customer of the responsibility to provide acceptable product.

4.8 Product identification and traceability

Where appropriate, the supplier shall establish and maintain documented procedures for identifying the product by suitable means from receipt and during all stages of production, delivery and installation.

Where and to the extent that traceability is a specified requirement, the supplier shall establish and maintain documented procedures for unique identification of individual product or batches. This identification shall be recorded (see 4.16).

4.9 Process control

The supplier shall identify and plan the production, installation and servicing processes which directly affect quality and shall ensure that these processes are carried out under controlled conditions. Controlled conditions shall include the following:

a) documented procedures defining the manner of production, installation and servicing, where the absence of such procedures could adversely affect quality;

b) use of suitable production, installation and servicing equipment, and a suitable working environment;

c) compliance with reference standards/codes, quality plans and/or documented procedures;

d) monitoring and control of suitable process parameters and product characteristics;

e) the approval of processes and equipment, as appropriate;

f) criteria for workmanship, which shall be stipulated in the clearest practical manner (e.g. written standards, representative samples or illustrations);

g) suitable maintenance of equipment to ensure continuing process capability.

Where the results of processes cannot be fully verified by subsequent inspection and testing of the product and where, for example, processing deficiencies may become apparent only after the product is in use, the processes shall be carried out by qualified operators and/or shall require continuous monitoring and control of process parameters to ensure that the specified requirements are met.

The requirements for any qualification of process operations, including associated equipment and personnel (see 4.18), shall be specified.

NOTE 11 Such processes requiring pre-qualification of their process capability are frequently referred to as special processes.

Records shall be maintained for qualified processes, equipment and personnel, as appropriate (see 4.16).

4.10 Inspection and testing

4.10.1 General

The supplier shall establish and maintain documented procedures for inspection and testing activities in order to verify that the specified requirements for the product are met. The required inspection and testing, and the records to be established, shall be detailed in the quality plan or documented procedures.

4.10.2 Receiving inspection and testing

4.10.2.1 The supplier shall ensure that incoming product is not used or processed (except in the circumstances described in 4.10.2.3) until it has been inspected or otherwise verified as conforming to specified requirements. Verification of conformance to the specified requirements shall be in accordance with the quality plan and/or documented procedures.

4.10.2.2 In determining the amount and nature of receiving inspection, consideration shall be given to the amount of control exercised at the subcontractor's premises and the recorded evidence of conformance provided.

4.10.2.3 Where incoming product is released for urgent production purposes prior to verification, it shall be positively identified and recorded (see 4.16) in order to permit immediate recall and replacement in the event of nonconformity to specified requirements.

4.10.3 In-process inspection and testing

The supplier shall:

a) inspect and test the product as required by the quality plan and/or documented procedures;

b) hold product until the required inspection and tests have been completed or necessary reports have been received and verified, except when

product is released under positive-recall procedures (see 4.10.2.3). Release under positive-recall procedures shall not preclude the activities outlined in 4.10.3 a).

4.10.4 Final inspection and testing

The supplier shall carry out all final inspection and testing in accordance with the quality plan and/or documented procedures to complete the evidence of conformance of the finished product to the specified requirements.

The quality plan and/or documented procedures for final inspection and testing shall require that all specified inspection and tests, including those specified either on receipt of product or in-process, have been carried out and that the results meet specified requirements.

No product shall be dispatched until all the activities specified in the quality plan and/or documented procedures have been satisfactorily completed and the associated data and documentation are available and authorized.

4.10.5 Inspection and test records

The supplier shall establish and maintain records which provide evidence that the product has been inspected and/or tested. These records shall show clearly whether the product has passed or failed the inspections and/or tests according to defined acceptance criteria. Where the product fails to pass any inspection and/or test, the procedures for control of nonconforming product shall apply (see 4.13).

Records shall identify the inspection authority responsible for the release of product (see 4.16).

4.11 Control of inspection, measuring and test equipment

4.11.1 General

The supplier shall establish and maintain documented procedures to control, calibrate and maintain inspection, measuring and test equipment (including test software) used by the supplier to demonstrate the conformance of product to the specified requirements. Inspection, measuring and test equipment shall be used in a manner which ensures that the measurement uncertainty is known and is consistent with the required measurement capability.

Where test software or comparative references such as test hardware are used as suitable forms of inspection, they shall be checked to prove that they are capable of verifying the acceptability of product, prior to release for use during production, installation or servicing, and shall be rechecked at prescribed intervals. The supplier shall establish the extent and frequency of such checks and shall maintain records as evidence of control (see 4.16).

Where the availability of technical data pertaining to the inspection, measuring and test equipment is a specified requirement, such data shall be made available, when required by the customer or customer's representative, for verification that the inspection, measuring and test equipment is functionally adequate.

NOTE 12 For the purposes of this International Standard, the term "measuring equipment" includes measurement devices.

4.11.2 Control procedure

The supplier shall:

a) determine the measurements to be made and the accuracy required, and select the appropriate inspection, measuring and test equipment that is capable of the necessary accuracy and precision;

b) identify all inspection, measuring and test equipment that can affect product quality, and calibrate and adjust them at prescribed intervals, or prior to use, against certified equipment having a known valid relationship to internationally or nationally recognized standards. Where no such standards exist, the basis used for calibration shall be documented;

c) define the process employed for the calibration of inspection, measuring and test equipment, including details of equipment type, unique identification, location, frequency of checks, check method, acceptance criteria and the action to be taken when results are unsatisfactory;

d) identify inspection, measuring and test equipment with a suitable indicator or approved identification record to show the calibration status;

e) maintain calibration records for inspection, measuring and test equipment (see 4.16);

f) assess and document the validity of previous inspection and test results when inspection, measuring or test equipment is found to be out of calibration;

g) ensure that the environmental conditions are suitable for the calibrations, inspections, measurements and tests being carried out;

h) ensure that the handling, preservation and storage of inspection, measuring and test equipment is such that the accuracy and fitness for use are maintained;

i) safeguard inspection, measuring and test facilities, including both test hardware and test software, from adjustments which would invalidate the calibration setting.

NOTE 13 The metrological confirmation system for measuring equipment given in ISO 10012 may be used for guidance.

4.12 Inspection and test status

The inspection and test status of product shall be identified by suitable means, which indicate the conformance or nonconformance of product with regard to inspection and tests performed. The identification of inspection and test status shall be maintained, as defined in the quality plan and/or documented procedures, throughout production, installation and servicing of the product to ensure that only product that has passed the required inspections and tests [or released under an authorized concession (see 4.13.2)] is dispatched, used or installed.

4.13 Control of nonconforming product

4.13.1 General

The supplier shall establish and maintain documented procedures to ensure that product that does not conform to specified requirements is prevented from unintended use or installation. This control shall provide for identification, documentation, evaluation, segregation (when practical), disposition of nonconforming product, and for notification to the functions concerned.

4.13.2 Review and disposition of nonconforming product

The responsibility for review and authority for the disposition of nonconforming product shall be defined.

Nonconforming product shall be reviewed in accordance with documented procedures. It may be

a) reworked to meet the specified requirements,

b) accepted with or without repair by concession,

c) regraded for alternative applications, or

d) rejected or scrapped.

Where required by the contract, the proposed use or repair of product [see 4.13.2 b)] which does not conform to specified requirements shall be reported for concession to the customer or customer's representative. The description of the nonconformity that has been accepted, and of repairs, shall be recorded to denote the actual condition (see 4.16).

Repaired and/or reworked product shall be reinspected in accordance with the quality plan and/or documented procedures.

4.14 Corrective and preventive action

4.14.1 General

The supplier shall establish and maintain documented procedures for implementing corrective and preventive action.

Any corrective or preventive action taken to eliminate the causes of actual or potential nonconformities shall be to a degree appropriate to the magnitude of problems and commensurate with the risks encountered.

The supplier shall implement and record any changes to the documented procedures resulting from corrective and preventive action.

4.14.2 Corrective action

The procedures for corrective action shall include:

a) the effective handling of customer complaints and reports of product nonconformities;

b) investigation of the cause of nonconformities relating to product, process and quality system, and recording the results of the investigation (see 4.16);

c) determination of the corrective action needed to eliminate the cause of nonconformities;

d) application of controls to ensure that corrective action is taken and that it is effective.

4.14.3 Preventive action

The procedures for preventive action shall include:

a) the use of appropriate sources of information such as processes and work operations which af-

fect product quality, concessions, audit results, quality records, service reports and customer complaints to detect, analyse and eliminate potential causes of nonconformities;

b) determination of the steps needed to deal with any problems requiring preventive action;

c) initiation of preventive action and application of controls to ensure that it is effective;

d) ensuring that relevant information on actions taken is submitted for management review (see 4.1.3).

4.15 Handling, storage, packaging, preservation and delivery

4.15.1 General

The supplier shall establish and maintain documented procedures for handling, storage, packaging, preservation and delivery of product.

4.15.2 Handling

The supplier shall provide methods of handling product that prevent damage or deterioration.

4.15.3 Storage

The supplier shall use designated storage areas or stock rooms to prevent damage or deterioration of product, pending use or delivery. Appropriate methods for authorizing receipt to and dispatch from such areas shall be stipulated.

In order to detect deterioration, the condition of product in stock shall be assessed at appropriate intervals.

4.15.4 Packaging

The supplier shall control packing, packaging and marking processes (including materials used) to the extent necessary to ensure conformance to specified requirements.

4.15.5 Preservation

The supplier shall apply appropriate methods for preservation and segregation of product when the product is under the supplier's control.

4.15.6 Delivery

The supplier shall arrange for the protection of the quality of product after final inspection and test. Where contractually specified, this protection shall be extended to include delivery to destination.

4.16 Control of quality records

The supplier shall establish and maintain documented procedures for identification, collection, indexing, access, filing, storage, maintenance and disposition of quality records.

Quality records shall be maintained to demonstrate conformance to specified requirements and the effective operation of the quality system. Pertinent quality records from the subcontractor shall be an element of these data.

All quality records shall be legible and shall be stored and retained in such a way that they are readily retrievable in facilities that provide a suitable environment to prevent damage or deterioration and to prevent loss. Retention times of quality records shall be established and recorded. Where agreed contractually, quality records shall be made available for evaluation by the customer or the customer's representative for an agreed period.

NOTE 14 Records may be in the form of any type of media, such as hard copy or electronic media.

4.17 Internal quality audits

The supplier shall establish and maintain documented procedures for planning and implementing internal quality audits to verify whether quality activities and related results comply with planned arrangements and to determine the effectiveness of the quality system.

Internal quality audits shall be scheduled on the basis of the status and importance of the activity to be audited and shall be carried out by personnel independent of those having direct responsibility for the activity being audited.

The results of the audits shall be recorded (see 4.16) and brought to the attention of the personnel having responsibility in the area audited. The management personnel responsible for the area shall take timely corrective action on deficiencies found during the audit.

Follow-up audit activities shall verify and record the implementation and effectiveness of the corrective action taken (see 4.16).

NOTES

15 The results of internal quality audits form an integral part of the input to management review activities (see 4.1.3).

16 Guidance on quality system audits is given in ISO 10011.

4.18 Training

The supplier shall establish and maintain documented procedures for identifying training needs and provide for the training of all personnel performing activities affecting quality. Personnel performing specific assigned tasks shall be qualified on the basis of appropriate education, training and/or experience, as required. Appropriate records of training shall be maintained (see 4.16).

4.19 Servicing

Where servicing is a specified requirement, the supplier shall establish and maintain documented procedures for performing, verifying and reporting that the servicing meets the specified requirements.

4.20 Statistical techniques

4.20.1 Identification of need

The supplier shall identify the need for statistical techniques required for establishing, controlling and verifying process capability and product characteristics.

4.20.2 Procedures

The supplier shall establish and maintain documented procedures to implement and control the application of the statistical techniques identified in 4.20.1.

APPENDIX 2: *Codex Guidelines for HACCP:1997*

HAZARD ANALYSIS AND CRITICAL CONTROL POINT (HACCP) SYSTEM AND GUIDELINES FOR ITS APPLICATION

Annex to CAC/RCP 1-1969, Rev. 3 (1997)

PREAMBLE

The first section of this document sets out the principles of the Hazard Analysis and Critical Control Point (HACCP) system adopted by the Codex Alimentarius Commission. The second section provides general guidance for the application of the system while recognizing that the details of application may vary depending on the circumstances of the food operation.[1]

The HACCP system, which is science based and systematic, identifies specific hazards and measures for their control to ensure the safety of food. HACCP is a tool to assess hazards and establish control systems that focus on prevention rather than relying mainly on end-product testing. Any HACCP system is capable of accommodating change, such as advances in equipment design, processing procedures or technological developments.

HACCP can be applied throughout the food chain from primary production to final consumption and its implementation should be guided by scientific evidence of risks to human health. As well as enhancing food safety, implementation of HACCP can provide other significant benefits. In addition, the application of HACCP systems can aid inspection by regulatory authorities and promote international trade by increasing confidence in food safety.

The successful application of HACCP requires the full commitment and involvement of management and the work force. It also requires a multidisciplinary approach; this multidisciplinary approach should include, when appropriate, expertise in agronomy, veterinary health, production, microbiology, medicine, public health, food technology, environmental health, chemistry and engineering, according to the particular study. The application of HACCP is compatible with the implementation of quality management systems, such as the ISO 9000 series, and is the system of choice in the management of food safety within such systems.

While the application of HACCP to food safety was considered here, the concept can be applied to other aspects of food quality.

DEFINITIONS

Control (verb): To take all necessary actions to ensure and maintain compliance with criteria established in the HACCP plan.

Control (noun): The state wherein correct procedures are being followed and criteria are being met.

Control measure: Any action and activity that can be used to prevent or eliminate a food safety hazard or reduce it to an acceptable level.

Corrective action: Any action to be taken when the results of monitoring at the CCP indicate a loss of control.

Critical Control Point (CCP): A step at which control can be applied and is essential to prevent or eliminate a food safety hazard or reduce it to an acceptable level.

Critical limit: A criterion which separates acceptability from unacceptability.

Deviation: Failure to meet a critical limit.

Flow diagram: A systematic representation of the sequence of steps or operations used in the production or manufacture of a particular food item.

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[1] The Principles of the HACCP System set the basis for the requirements for the application of HACCP, while the Guidelines for the Application provide general guidance for practical application.

HACCP: A system which identifies, evaluates, and controls hazards which are significant for food safety.

HACCP plan: A document prepared in accordance with the principles of HACCP to ensure control of hazards which are significant for food safety in the segment of the food chain under consideration.

Hazard: A biological, chemical or physical agent in, or condition of, food with the potential to cause an adverse health effect.

Hazard analysis: The process of collecting and evaluating information on hazards and conditions leading to their presence to decide which are significant for food safety and therefore should be addressed in the HACCP plan.

Monitor: The act of conducting a planned sequence of observations or measurements of control parameters to assess whether a CCP is under control.

Step: A point, procedure, operation or stage in the food chain including raw materials, from primary production to final consumption.

Validation: Obtaining evidence that the elements of the HACCP plan are effective.

Verification: The application of methods, procedures, tests and other evaluations, in addition to monitoring to determine compliance with the HACCP plan.

PRINCIPLES OF THE HACCP SYSTEM

The HACCP system consists of the following seven principles:

PRINCIPLE 1

Conduct a hazard analysis.

PRINCIPLE 2

Determine the Critical Control Points (CCPs).

PRINCIPLE 3

Establish critical limit(s).

PRINCIPLE 4

Establish a system to monitor control of the CCP.

PRINCIPLE 5

Establish the corrective action to be taken when monitoring indicates that a particular CCP is not under control.

PRINCIPLE 6

Establish procedures for verification to confirm that the HACCP system is working effectively.

PRINCIPLE 7

Establish documentation concerning all procedures and records appropriate to these principles and their application.

GUIDELINES FOR THE APPLICATION OF THE HACCP SYSTEM

Prior to application of HACCP to any sector of the food chain, that sector should be operating according to the Codex General Principles of Food Hygiene, the appropriate Codex Codes of Practice, and appropriate food safety legislation. Management commitment is necessary for implementation of an effective HACCP system. During hazard identification, evaluation, and subsequent operations in designing and applying HACCP systems, consideration must be given to the impact of raw materials, ingredients, food manufacturing practices, role of manufacturing processes to control hazards, likely end-use of the product, categories of consumers of concern, and epidemiological evidence relative to food safety.

The intent of the HACCP system is to focus control at CCPs. Redesign of the operation should be considered if a hazard which must be controlled is identified but no CCPs are found.

HACCP should be applied to each specific operation separately. CCPs identified in any given example in any Codex Code of Hygienic Practice might not be the only ones identified for a specific application or might be of a different nature.

The HACCP application should be reviewed and necessary changes made when any modification is made in the product, process, or any step.

It is important when applying HACCP to be flexible where appropriate, given the context of the application taking into account the nature and the size of the operation.

Application

The application of HACCP principles consists of the following tasks as identified in the Logic Sequence for Application of HACCP (Diagram 1).

1. Assemble HACCP team

The food operation should assure that the appropriate product specific knowledge and expertise is available for the development of an effective HACCP plan. Optimally, this may be accomplished by assembling a multidisciplinary team. Where such expertise is not available on site, expert advice should be obtained from other sources. The scope of the HACCP plan should be identified. The scope should describe which segment of the food chain is involved and the general classes of hazards to be addressed (e.g. does it cover all classes of hazards or only selected classes).

2. Describe product

A full description of the product should be drawn up, including relevant safety information such as: composition, physical/chemical structure (including A_w, pH, etc.), microcidal/static treatments (heat-treatment, freezing, brining, smoking, etc.), packaging, durability and storage conditions and method of distribution.

3. Identify intended use

The intended use should be based on the expected uses of the product by the end user or consumer. In specific cases, vulnerable groups of the population, e.g. institutional feeding, may have to be considered.

4. Construct flow diagram

The flow diagram should be constructed by the HACCP team. The flow diagram should cover all steps in the operation. When applying HACCP to a given operation, consideration should be given to steps preceding and following the specified operation.

5. On-site confirmation of flow diagram

The HACCP team should confirm the processing operation against the flow diagram during all stages and hours of operation and amend the flow diagram where appropriate.

6. *List all potential hazards associated with each step, conduct a hazard analysis, and consider any measures to control identified hazards*

(SEE PRINCIPLE 1)

The HACCP team should list all of the hazards that may be reasonably expected to occur at each step from primary production, processing, manufacture, and distribution until the point of consumption.

The HACCP team should next conduct a hazard analysis to identify for the HACCP plan which hazards are of such a nature that their elimination or reduction to acceptable levels is essential to the production of a safe food.

In conducting the hazard analysis, wherever possible the following should be included:

- the likely occurrence of hazards and severity of their adverse health effects;
- the qualitative and/or quantitative evaluation of the presence of hazards;
- survival or multiplication of microorganisms of concern;
- production or persistence in foods of toxins, chemicals or physical agents; and,
- conditions leading to the above.

The HACCP team must then consider what control measures, if any, exist which can be applied for each hazard.

More than one control measure may be required to control a specific hazard(s) and more than one hazard may be controlled by a specified control measure.

7. *Determine Critical Control Points*

(SEE PRINCIPLE 2)[2]

There may be more than one CCP at which control is applied to address the same hazard. The determination of a CCP in the HACCP system can be facilitated by the application of a decision tree (e.g. Diagram 2), which indicates a logic reasoning approach. Application of a decision tree should be flexible, given whether the operation is for production, slaughter, processing, storage, distribution or other. It should be used for guidance when determining CCPs. This example of a decision tree may not be applicable to all situations. Other approaches may be used. Training in the application of the decision tree is recommended.

If a hazard has been identified at a step where control is necessary for safety, and no control measure exists at that step, or any other, then the product or process should be modified at that step, or at any earlier or later stage, to include a control measure.

8. *Establish critical limits for each CCP*

(SEE PRINCIPLE 3)

Critical limits must be specified and validated if possible for each Critical Control Point. In some cases more than one critical limit will be elaborated at a particular step. Criteria often used include measurements of temperature, time, moisture level, pH, A_w, available chlorine, and sensory parameters such as visual appearance and texture.

9. *Establish a monitoring system for each CCP*

(SEE PRINCIPLE 4)

Monitoring is the scheduled measurement or observation of a CCP relative to its critical limits. The monitoring procedures must be able to detect loss of control at the CCP. Further, monitoring should ideally provide this information in time to make adjustments to ensure control of the process to prevent violating the critical limits. Where possible, process adjustments should be made when monitoring results indicate a trend towards loss of control at a CCP. The adjustments should be taken before a deviation occurs. Data derived from monitoring must be evaluated by a designated person with knowledge and authority to carry out corrective actions when indicated. If monitoring is not continuous, then the amount or frequency of monitoring must be sufficient to guarantee the CCP is in control. Most

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[2] Since the publication of the decision tree by Codex, its use has been implemented many times for training purposes. In many instances, while this tree has been useful to explain the logic and depth of understanding needed to determine CCPs, it is not specific to all food operations, e.g. slaughter, and therefore it should be used in conjunction with professional judgement, and modified in some cases.

monitoring procedures for CCPs will need to be done rapidly because they relate to on-line processes and there will not be time for lengthy analytical testing. Physical and chemical measurements are often preferred to microbiological testing because they may be done rapidly and can often indicate the microbiological control of the product. All records and documents associated with monitoring CCPs must be signed by the person(s) doing the monitoring and by a responsible reviewing official(s) of the company.

10. Establish corrective actions

(SEE PRINCIPLE 5)

Specific corrective actions must be developed for each CCP in the HACCP system in order to deal with deviations when they occur.

The actions must ensure that the CCP has been brought under control. Actions taken must also include proper disposition of the affected product. Deviation and product disposition procedures must be documented in the HACCP record keeping.

11. Establish verification procedures

(SEE PRINCIPLE 6)

Establish procedures for verification. Verification and auditing methods, procedures and tests, including random sampling and analysis, can be used to determine if the HACCP system is working correctly. The frequency of verification should be sufficient to confirm that the HACCP system is working effectively. Examples of verification activities include:

- Review of the HACCP system and its records;
- Review of deviations and product dispositions;
- Confirmation that CCPs are kept under control.

Where possible, validation activities should include actions to confirm the efficacy of all elements of the HACCP plan.

12. Establish Documentation and Record Keeping

(SEE PRINCIPLE 7)

Efficient and accurate record keeping is essential to the application of a HACCP system. HACCP procedures should be documented. Documentation and record keeping should be appropriate to the nature and size of the operation.

Documentation examples are:

- Hazard analysis;
- CCP determination;
- Critical limit determination.

Record examples are:

- CCP monitoring activities;
- Deviations and associated corrective actions;
- Modifications to the HACCP system.

An example of a HACCP worksheet is attached as Diagram 3.

Training

Training of personnel in industry, government and academia in HACCP principles and applications, and increasing awareness of consumers are essential elements for the effective implementation of HACCP. As an aid in developing specific training to support a HACCP plan, working instructions and procedures should be developed which define the tasks of the operating personnel to be stationed at each Critical Control Point.

Cooperation between primary producer, industry, trade groups, consumer organizations, and responsible authorities is of vital importance. Opportunities should be provided for the joint training of industry and control authorities to encourage and maintain a continuous dialogue and create a climate of understanding in the practical application of HACCP.

APPENDIX 3: SQF 2000:1997

1. Scope

The SQF 2000™ Quality Code: 1997 specifies quality system requirements for use by primary producers, food manufacturers or food distributors to provide objective evidence of their ability to supply food, beverages, fibre or services which are safe and which meet customer and legislative requirements.

The Code is designed to achieve product safety and customer satisfaction. It relies on the supplier and the customer defining the product and identifying and documenting critical quality and safety criteria.

By applying the principles of Hazard Analysis and Critical Control Point (HACCP) and prerequisite programs such as Good Manufacturing Practice (GMP) and Good Hygiene Practice (GHP), the risks to product safety and poor quality are identified. Strategies are then put in place to minimise and manage these risks.

2. References

The Code makes reference to the current edition of the CODEX Alimentarius Commission Guidelines for the Application of the Hazard Analysis and Critical Control Point (HACCP) System. It also makes reference to the International Organisation for Standardisation (ISO) 9000 series of Quality Standards.

3. Definitions

For the purpose of this Code, the definitions outlined in ISO 8402: 1994 Quality Management and Quality Assurance - Vocabulary apply, together with the following additional definitions:

3.1 Business: an organisation involved either in the production, manufacture, processing, transport, storage, distribution or sale of food, beverages, packaging or fibre.

3.2 HACCP: Hazard Analysis and Critical Control Point. A system which identifies, evaluates and controls hazards which are significant for food safety. (As defined in the current edition of the CODEX Alimentarius Commission Guidelines).

HACCP is recognised as a risk management system. For the purpose of this Code HACCP can be applied to other aspects of food quality and production.

3.3 HACCP Method: The application of HACCP principles in the logical sequence of the twelve steps as defined in the current edition of the CODEX Alimentarius Commission Guidelines.

3.4 HACCP Plan: As defined in the current edition of the CODEX Alimentarius Commission Guidelines.

The HACCP plan includes product specifications, a description of the product and its intended use, a process flow diagram, the HACCP audit table, details of verification activities and support documentation (including hazard analysis) to justify the selection of hazards and the validation data of critical limits.

3.5 Recognised HACCP Training: Training in HACCP Principles and application that is in accordance with the current edition of the CODEX Alimentarius Commission Guidelines. Such training must be approved in writing by *AGWEST* Trade & Development, Agriculture Western Australia or its nominated agent.

3.6 Skilled HACCP Practitioner: An individual, licenced by *AGWEST* Trade & Development or its nominated agent, who is responsible for developing, validating and verifying HACCP plans. They must have completed a recognised HACCP Training course and achieved a demonstrated level of proficiency. They will have experience and a sound technical knowledge of the commodity and the process under HACCP study.

4. Quality System Requirements

4.1 Commitment

4.1.1 Quality Policy

The owner or most senior person must define the business commitment to quality in a policy statement which is relevant to the business goals and customer needs and expectations. It must be documented and understood by all members of the business (derived from ISO 9002:1994, 4.1.1).

The pressures of business often cloud the intentions, awareness and commitment to quality publicly expressed by business operators. It is often wrongly

assumed that because everyone in the organisation knows about quality and that they are 'all for it', quality products will automatically be produced. In most instances this seldom happens. That is why the business's attitude to quality, and to its customers, must be clearly expressed and displayed as a reminder for all to see and understand.

4.1.2 Organisation

The organisational reporting structure must be described to detail those who have functional responsibility for food safety and quality and their interrelationship (derived from ISO 9002:1994, 4.1.2).

The owner or the person in charge of a business has over-all responsibility for its profitability and for the safety and quality of the goods it produces. The reporting structure in the form of an organisation chart showing the functional responsibilities of all individuals working in the business is required. A brief description of their responsibilities and authorities is beneficial to an efficient and effective quality management system. This can be in the form of written job descriptions or it can be included on the organisation chart.

4.1.3 Training

Appropriate training must be provided for personnel carrying out the tasks at the critical steps identified by the hazard analysis. Instructions must be available setting out how these tasks are to be performed. A training register describing who has been trained in relevant areas is to be maintained (derived from ISO9002:1994, 4.18).

The key to quality is to ensure operators are adequately trained in the job they are to complete. This is particularly so in regard to tasks that have a direct impact on food safety. Competency levels should be maintained by appropriate further training. In addition to maintaining a training register certificates (or official copies) issued by recognised external training organisation proving a person's competence level should also be made available for audit purposes.

4.2 Suppliers

4.2.1 Purchasing

The business must have documented specifications for all goods purchased which affect product safety and quality. The specification must define raw material in terms of its critical safety and quality parameters (derived from ISO 9002:1994, 4.6.1).

Many businesses do not sufficiently communicate to suppliers the safety and quality requirements of their raw material purchases, including packaging. Quality problems frequently start with a sub-standard raw material, sourced from an unreliable supplier, without clear specification.

4.2.2 Raw Material Inspection

The business must provide documented evidence to show that specified raw materials have been inspected before use or that they have originated from a supplier with a demonstrated good supply record (derived from ISO 9002:1994, 4.10.2-5).

Use of poor quality raw materials can increase production costs. Simple checks can identify defective raw material before use and enable a quality profile of suppliers to be established. This helps to reduce costly rejections and rework. The maintenance of a list of approved suppliers is recommended.

4.3 Control of Production

4.3.1 Process Control

To produce safe food and meet customer requirements the HACCP method must be applied to all stages of the process and that HACCP plans are developed, validated and verified by Skilled HACCP Practitioners. Finished product specifications must be provided (derived from ISO 9002:1994, 4.9).

The HACCP method was developed for the food industry as a risk management system emphasising prevention as a means of controlling hazards. Its original focus was on food safety but this has now been expanded to include, as required, other quality related factors which impact on business profitability.

To ensure the integrity of the quality management system the business must ensure that HACCP plans are prepared by skilled HACCP practitioners who are experienced and competently trained in the HACCP method.

HACCP can also be used to build quality into the production process. Through inspections during production, faults are identified early and corrective measures implemented to maintain quality and improve yields. Appropriate prerequisite programs, including GMP and GHP, are necessary to support the HACCP plan.

4.3.2 Corrective Action

The business must have a procedure for identifying and documenting the cause and resolution of significant problems affecting food quality and safety. Appropriate action must then be taken to reduce the likelihood of the problem occurring again (derived from ISO 9002:1994, 4.14.1-2).

Mistakes happen and if not rectified, they can occur again. Problem identification and definition provides an opportunity to take corrective action to reduce the likelihood of them recurring. Corrective action makes good business sense because the elimination of a mistake nearly always produces a cost saving.

4.3.3 Handling, Storage, Packing and Delivery

The practices to ensure raw materials, work in progress and finished goods are handled, stored, packed and delivered must be documented. They must be carried out in such a way that minimises the risk of damage, mix-ups or improper use (derived from ISO9002:1994, 4.15).

The effort put into specifying appropriate raw materials and producing a safe, quality product can be undone by careless handling, storage and delivery practices. All raw materials, particularly chemicals, cleaning compounds and additives should be stored appropriately to avoid a contamination risk or threat to the integrity of the finished product.

Ensuring the finished product is stored under the right conditions and that it is handled, packed and delivered in the appropriate manner will lead to satisfied customers.

4.3.4 Food Safety

The business must ensure that, at the time of delivery to the customer, the food supplied will comply with all food regulatory requirements specified in the appropriate legislation of the country in which the food is to be consumed.

Responsible operators are aware of customers' concerns about the use of chemicals and drugs in food production and manufacturing. To build consumer confidence medicines, chemicals, preservatives processing aids, or food additives should be used responsibly as recommended by the manufacturer or, if required, with professional advice. Heavy metals and other contaminants should not exceed regulatory or customer requirements.

4.4 Inspection and Testing

4.4.1 Inspection, Measuring and Test Equipment

All measuring, test and inspection equipment used for monitoring activities outlined in the HACCP plan or to demonstrate compliance with customer requirements must be routinely calibrated to recognised standards or to an accuracy appropriate to their use. Records of calibration must be maintained (derived from ISO 9002:1994, 4.11.1).

Many food production systems require the use of thermometers, scales, syringes, refractometers and other equipment to verify controls which are important to food safety and quality. Over time such devices lose accuracy and need recalibration. Simple calibration checks can prevent costly problems from occurring. A schedule of calibration requirements should be included in the HACCP plan or maintained as a separate log.

4.4.2 Inspection and Test Status

Product and raw material which does not meet specifications must be isolated and identified. Sub-standard product or materials must be handled and disposed of in such a manner that there is no risk to the integrity of acceptable product (derived from ISO 9002:1994, 4.12).

Substantial effort can be wasted if sub-standard product is allowed to mix with quality product. Proper isolation (and if possible identification) of reject product helps to reduce the incidence of sub-standard product being released onto the market and the subsequent expense of product recalls and a tarnished business reputation.

4.4.3 Internal Audits

The business must schedule and carry out internal audits to verify that activities comply with documented requirements and to determine the effectiveness of the quality system and the HACCP plan. Action must be taken to correct any deficiencies found (derived from ISO 9002:1994, 4.17).

Internal audits are necessary to check what ought to happen is happening. This is a very powerful tool to measure the effectiveness of the quality system. It identifies areas of poor performance where corrective action needs to be taken.

4.5 Document Control and Quality Records

4.5.1 Document Control

A list of current documents and amendments to documents shall be maintained to identify the current document in use. HACCP plans must be reviewed annually or when changes occur and the reviews must be documented. Changes to HACCP plans must be developed, validated and verified by Skilled HACCP Practitioners (derived from ISO 9002:1994, 4.5.2).

Mistakes can be made if it is not clear which of many documents is the most up to date in describing how work should be done. HACCP plans must be reviewed annually or when changes occur and the reviews must be documented.

Where changes are introduced to the process such as a new raw material, equipment or procedures, the effect of these changes to the HACCP plan will need to be reviewed by the HACCP Team.

4.5.2 Quality Records

Legible quality records must be maintained to demonstrate that essential production processes, inspections or tests identified in the HACCP plan have been completed. Quality records must be stored to prevent their damage and deterioration. Records must be retained for a minimum of twelve months (derived from ISO 9002:1994, 4.16).

Records provide the proof to auditors and clients that what you say you are doing has in fact been done. Records should be clear, concise and easy to use. They are retained to ensure that a thorough investigation can be conducted into any food safety and quality related problems that may occur. Under the Trade Practices Act a food business has liability for its product for up to ten years.

4.6 Product Identification and Traceability

4.6.1 General

Finished product must be clearly identified. It must be traceable so that product recalls can be readily facilitated if required. Records of product identification and product destination must be maintained (derived from ISO 9002: 1994, 4.8 and ISO 9004:1994, 19).

The food business should make every attempt to reduce the chance of faulty or defective product reaching the customer. The demand for fresh food which contains little or no additive is placing increasing demands on the food industry. The risks to food safety are increased and while food suppliers make every effort to ensure their product is safe problems can occur.

By identifying product when it is harvested, processed and despatched, faulty product can be quickly traced. An effective recall procedure should also be in place to minimise consumer health risks and damage to business reputation.

APPENDIX 4: Regression

The following passage is a description of regression given in Mendenhall and Sincich (1995) (re: Mendenhall, W., & Sincich, T. [1995]. Statistics for engineering and the sciences, 4th ed. New Jersey: Prentice Hall).

One of the most important applications of statistics involves estimating the mean value of a response variable y or predicting some future value of y based on knowledge of a set of related independent* variables, $x_1, x_2, \ldots, x_k$.

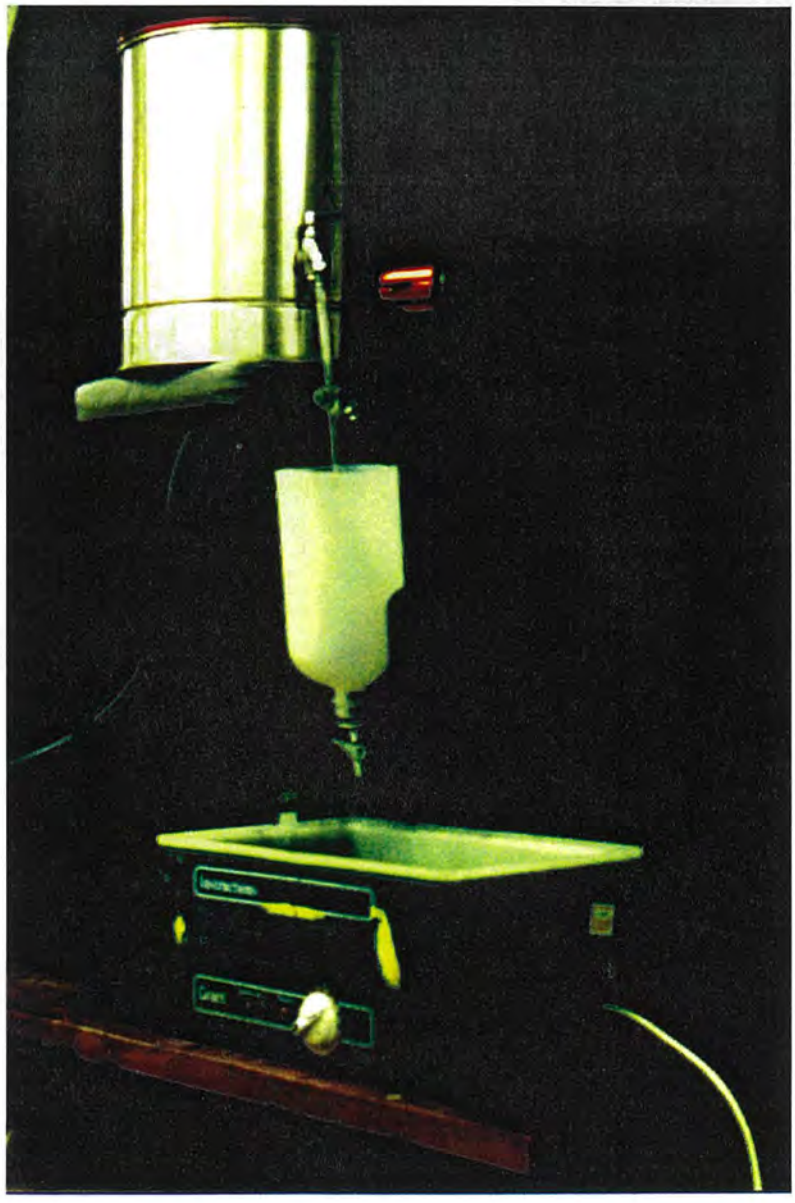
For example, the manager of a data-processing center might want to relate the waiting time y (the dependent variable) between the time a job is submitted to a computer and the time it is completed to such variables as the number and sizes of the jobs already awaiting execution and the size of the job being submitted (the independent variables). The objective would be to develop a prediction equation (or model) that expresses y as a function of the independent variables. This would enable the manager to predict y for specific values of the independent variables and, ultimately, to use knowledge derived from a study of the prediction equation to institute policies to control the waiting time.

As another example, an engineer might want to relate the rate of malfunction y of a mechanical assembler to such variables as its speed of operation and the assembler operator. The objective would be to develop a prediction equation relating the dependent variable y to the independent variables and to use the prediction equation to predict the value of the rate of malfunction y for various combinations of speed of operation and operator.

The models used to relate a dependent variable y to the independent variables $x_1, x_2, \ldots, x_k$, are called regression models or linear statistical models because they express the mean value of y for given values of $x_1, x_2, \ldots, x_k$, as a linear function of a set of unknown parameters.

APPENDIX 5: Simulation of Westoz brewing process

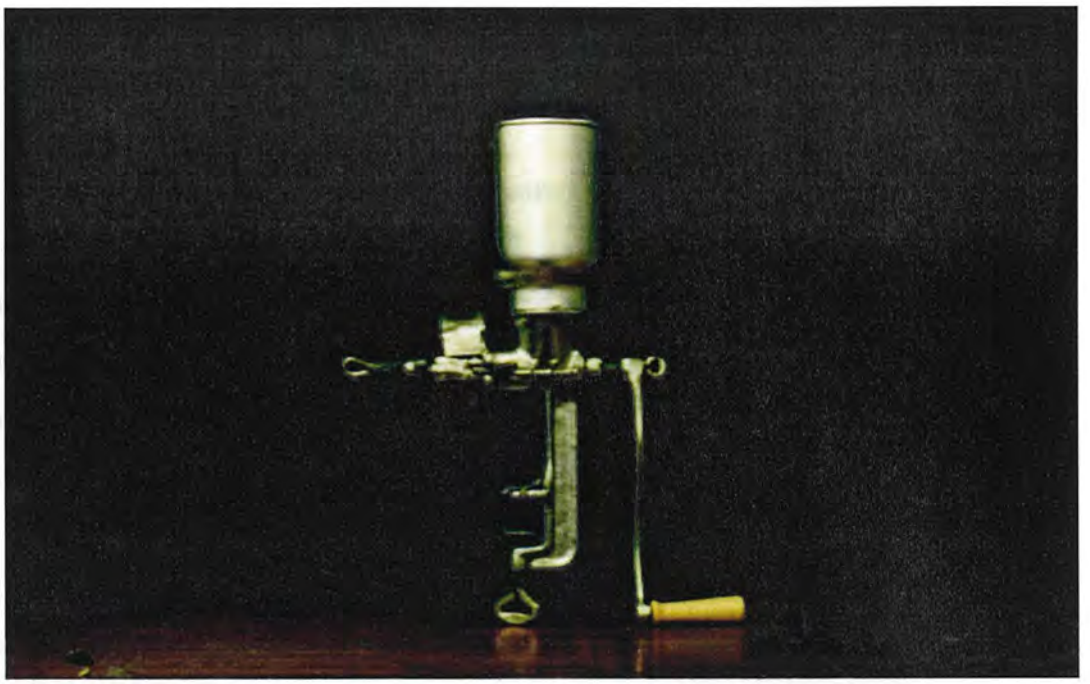
The following text details the simulation created of the Westoz brewing process.



Sparging and lautering system.

This illustration depicts the sparging and lautering system used in the simulation. Sparging water was heated in the hot water urn and gradually added to the sparging/lautering vessel via plastic tubing and glass tap. The sparging/lautering vessel was constructed by cutting the base from a plastic bottle, putting a rubber bung in the

mouth of the bottle, and inserting a plastic tap into this bung. Muslin lined the bottle in order to avoid blockage of the outlet, which allowed clarified wort to flow to the beaker immersed in the water bath.



Grain mill.

Materials

500g of grist (2-row Sterling malt)

2.5L of water

Gypsum (as required)

1/4 tsp of finings (Irish Moss)

Brewing equipment

Water bath

Hot water urn (thermostatically controlled)

Stainless steel pot

2L plastic bottle

Muslin

Rubber bung

Plastic tap

13mm plastic tubing

Glass tap

5L glass beaker

Additional monitoring materials and equipment

Hydrometer

Colour standard (see Appendix 6 for colour standard used in this simulation)

Universal indicator paper

Thermometers

Electronic scales

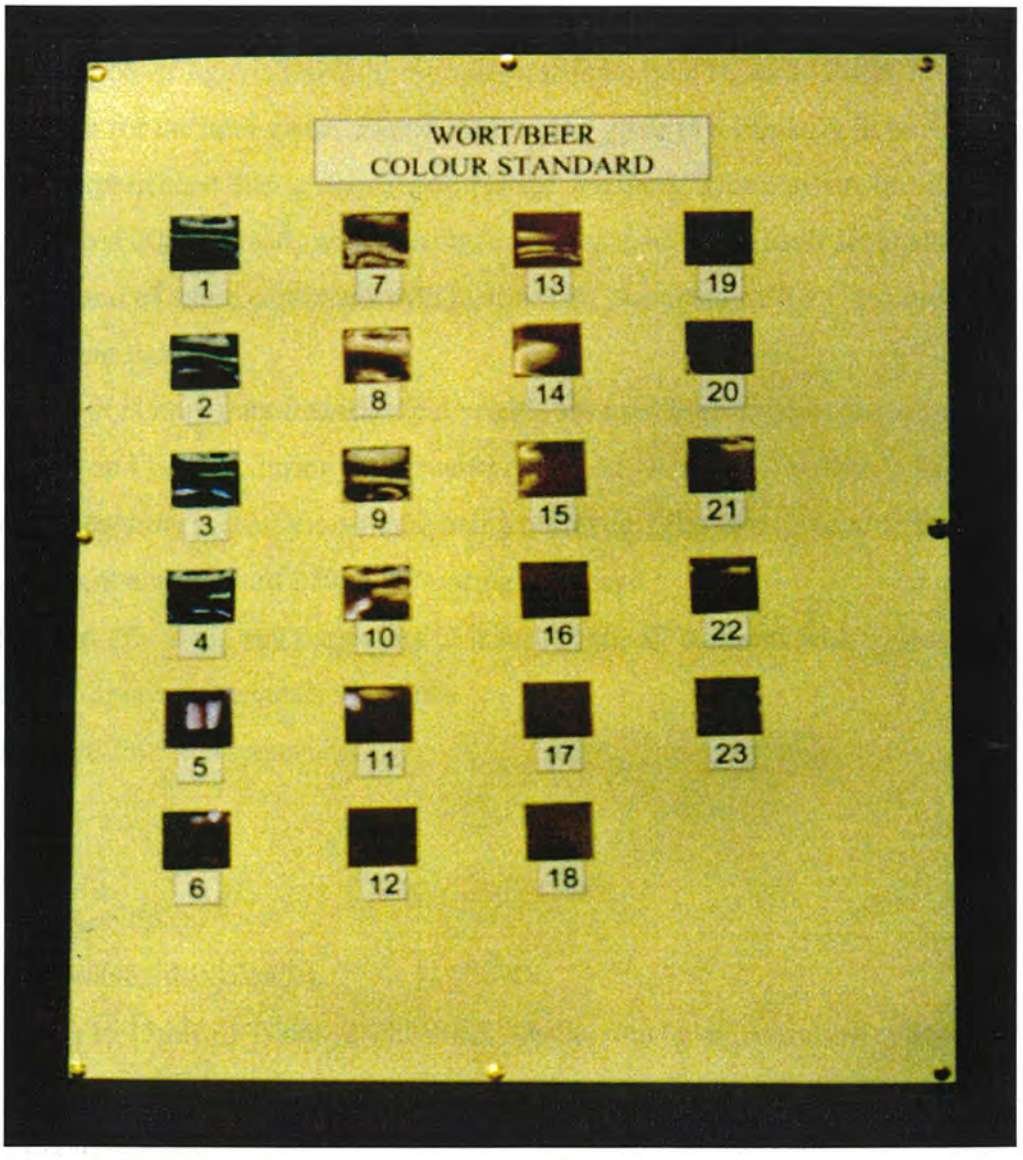
Procedure

1. The stainless steel pot is placed into the water bath, and the bath is heated to 80°C. This temperature is monitored by thermometer.
2. Water is added to the urn, and the urn is heated to 75°C. This temperature is monitored by thermometer.
3. 500g of grist and 1.25L of the 75°C water is measured and mixed into the pot, preventing dry portions of mash.
4. Mash pH is measured with indicator paper, with the pH being adjusted down with gypsum if necessary.
5. Mashing continues for 40 minutes.
6. While mashing occurs, water in the urn is reheated to 78°C and its pH adjusted with gypsum if necessary.
7. Once mashing has completed, the mash is transferred into the sparging vessel.
8. Both sparging liquor and wort runoff taps are opened allowing a simultaneous transfer of liquor and wort under gravity. The wort is collected in a 5L beaker that is standing in the water bath, now heated to 90°C.

9. Sparging continues for 45 minutes. The level of liquor above the mash bed is continuously monitored to ensure that it is remaining constant.
10. Once the beaker has taken 2.75L of wort, the wort is then transferred to another stainless steel pot where it is boiled for 45 minutes.
11. Finings are added to the kettle after 25 minutes of boiling.
12. The wort is then tranferred back to the beaker, which is subsequently placed in a sink of iced water and cooled below 35°C.

APPENDIX 6: Development of a colour standard

Details of the development of a colour standard are now given. This standard was based on that developed by Fix (as cited in G.S.Kuyat (1994). Dr Fix's beer colour article. Homebrew Digest, 1328. Available WWW: http://hbd.org/hbd/archive/1328.html).



The Westoz beer colour standard.

Materials

1. Tooheys Old Black Ale
2. Distilled water--Coloured tap water can affect the standard from between 1-20 percent.
3. Blender--Dissolved CO_2 in the beer affects its colour. The commercial beer used, Tooheys Old Black Ale, is degassed. This is done in a blender. A lot of foam is created, but once it recedes and the beer falls clear, it is ready for testing.
4. Light source--If light is too dim, everything looks the same. In addition, it is important for the later visual comparison to take place in a similarly lit environment to that experienced during construction of the standard. This consists of a 75watt bulb placed 20cm directly above the holding vessel, which is itself set against a background of white cardboard with matt finish. Surrounding light is sourced from fluorescent lighting.
5. Vessels--It is important that identical vessels are used during the construction of the standard and later on during the visual comparison. According to Beer's Law, colour looks deeper the greater the volume being observed. The vessels used in this experiment are standard 250ml measuring cylinders.
6. Glass rod--To avoid any possibility of layering, stir all dilutions with a glass rod.
7. Camera (aperture 4, shutter speed 60)
8. 100 speed Film (24 exposures)

Procedure

1. Clean everything.
2. De-gas standard in blender.
3. Measure in 15mls of Tooheys Old Black Ale into the large measuring cylinder. Photograph.
4. Pour contents of cylinder and mix in 20mls of distilled water.
5. Return preparation to measuring cylinder and photograph.
6. Repeat Steps 4 and 5 until 23 photographs have been taken.

7. Dilutions are allocated a number ("Colour Unit (CU)"), with the photograph of the undiluted Tooheys Old Black Ale being 1 and that of the final dilution being 23.

N.B. Method of use.

Each sample is placed into a vessel and compared with the standard until the closest match is found. The sample is given the 'score' of the match. It is important that standard conditions are present when comparisons are made. In particular, this requires the same light source and vessels, and degassing of the sample.

APPENDIX 7: Sample data from pilot testing

BATCH NUMBER	SAMPLE NUMBER	SPECIFIC GRAVITY	COLOUR (CUs)
1	1	1051	16
	2	1051	16
	3	1050	16
	4	1050	16
	5	1050	16
	6	1050	16
2	1	1051	16
	2	1051	16
	3	1051	16
	4	1050	16
	5	1050	16
	6	1050	16
3	1	1048	16
	2	1048	16
	3	1048	16
	4	1048	16
	5	1048	16
	6	1048	16
4	1	1048	15
	2	1049	15
	3	1049	16
	4	1049	16
	5	1049	16
	6	1050	16
5	1	1048	16
	2	1047	16
	3	1047	16
	4	1047	16
	5	1047	16
	6	1047	15

BATCH NUMBER	SAMPLE NUMBER	SPECIFIC GRAVITY	COLOUR (CUs)
6	1	1047	16
	2	1047	16
	3	1047	16
	4	1047	16
	5	1048	16
	6	1048	16
7	1	1049	16
	2	1049	16
	3	1049	16
	4	1049	16
	5	1049	16
	6	1048	16
8	1	1046	15
	2	1046	15
	3	1046	16
	4	1047	16
	5	1047	16
	6	1047	16
9	1	1050	16
	2	1051	16
	3	1051	16
	4	1051	16
	5	1051	16
	6	1051	15
10	1	1048	16
	2	1049	16
	3	1049	16
	4	1049	16
	5	1050	16
	6	1049	16