CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION AND BACKGROUND

South African Breweries (SAB) is the biggest producer of malted barley beer in South Africa with subsequent large amounts of water used in the process. An investigation by Binnie and Partners (1986), with respect to the water consumption for SAB breweries in South Africa, yielded the results shown in Table 2.1. For these breweries the volume of water used per volume of beer produced (excluding malting plants) ranges from 5,5 – 8,8 m^3 water/m^3 beer.

Table 2.1 The ratio of water used (excluding malting) per beer product produced for different breweries in South Africa.

Brewery	Average beer production per month in m^3	Average water intake per month in m^3	Water used per beer product in m^3/m^3
A	17 100	102 500	6,0
B	9 000	79 100	8,8
C	18 200	129 000	7,1
D	14 000	77 000	5,5
E	2 000	13 700	6,8
F	16 000	100 800	6,3
G	8 300	61 700	7,4
H	5 200	34 700	6,7

Since environmental legislation is becoming more stringent, it will become necessary for brewing industries to manage the consumption of water in breweries and therefore the reduction of effluent. This may be accomplished by developing environmental management tools to monitor water usage and developing recycling techniques to optimise the usage of water. With limited or no information/benchmarks available in the literature pertaining to water consumption in breweries, a detailed investigation into the brewing process needs to be undertaken to determine why:

- brewing industries consume such high volumes of water, and
- why there is significant differences in the water to beer ratio for breweries producing approximately the same volumes of beer.

2.2 BEER COMPOSITION AND PRODUCTION

Hulse (2000) gives two definitions for beer, namely

- it is a liquid extract of malted barley which has been flavoured with hops and fermented with yeast, and/or
- beer is a carbonated, weakly alcoholic beverage which is prepared from malt, hops, water and yeast.

The essential elements of a beer are, *inter alia*, the aroma, taste, colour, foam and alcohol content. Beers differ in these characteristics due to the type of ingredients used (for example, sorghum or barley) and/or different operating parameters. In South Africa, the majority of breweries use malted barley and this document will thus concentrate on the water use within the malted barley production process. A generalisation by Wainwright (1998) of beer production is shown in Figure 2.1.

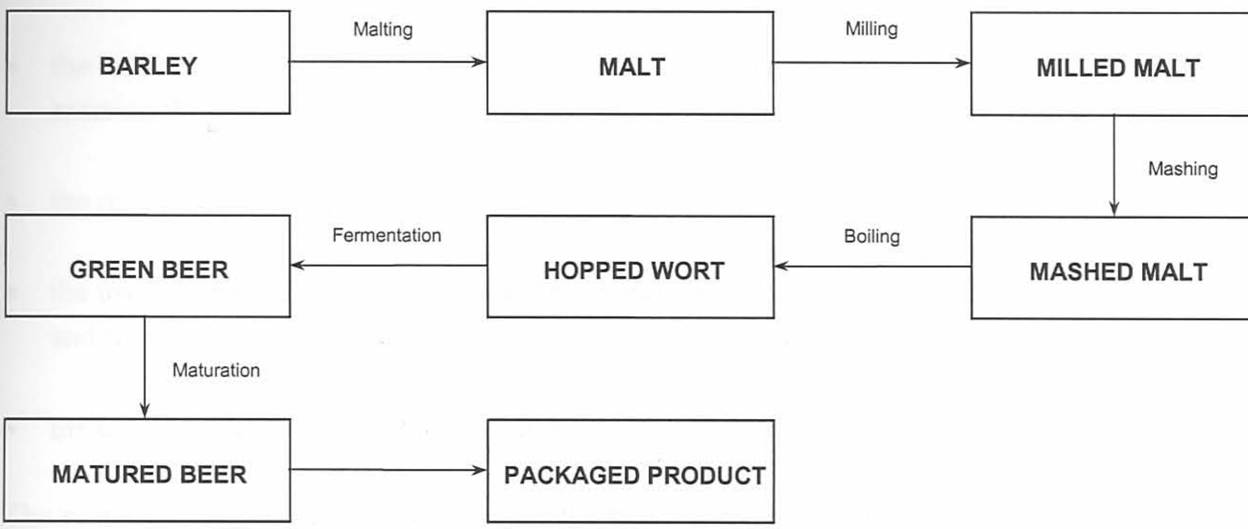

Figure 2.1 Basic overview for the production of beer.

This simplified process diagram is typical for most breweries and the process starts off with the malting of barley. Malting is the process whereby barley kernels (also termed grains or corns) are germinated for a limited period of time and then dried. The malted barley kernels, which are termed malt, are then milled to expose the endosperm (which is the part of the barley kernel which contains most of the food reserves/starch). The milled malt is then mashed in a vessel called the mash tun. Mashing is the process whereby the starch is extracted from the malt, with the addition of water, to produce sweet wort. The enzymes developed during the malting process are released during mashing and convert the exposed starch to fermentable sugars. Malted barley converted into a product with the correct amount of fermentable sugars, nitrogen compounds and other essential components, is termed wort. In order to remove volatile compounds from the wort and to add the bitter flavour characteristic of a beer, the wort is boiled with hops in a vessel termed the wort kettle. This hopped wort is then fermented with yeast in fermentation vessels where the sugars are converted to alcohol and CO_2 and the subsequent product is termed green beer. The green beer is transferred to storage vessels for at least a week to mature the beer. Thereafter the beer is filtered and forwarded to the packaging production line.

2.3 PRODUCTION OF MALTED BARLEY BEER

A typical malted barley beer brewing process is presented in Figure 2.2 by the Pollution Research Group (1987). Malted barley breweries are divided into four hypothetical areas, namely malting, brewhouse, cellars (fermentation and filtration) and packaging. A similar brewing process is employed by SA Breweries at their Rosslyn plant with a few exceptions, as depicted in Figure 2.3. These include, *inter alia*,

- the removal of the maize cooker, where maize was added to the brewing process,
- the addition of a buffering vessel, called the underback, where the wort is placed before entering the wort kettle,
- the removal of the hop strainer (all waste is removed in the whirlpool) and the wort filter,
- the use of separate vessels for fermentation and primary storage prior to the maturation phase, and finally
- the use of a filter prior to the maturation phase.

The remainder of this chapter will discuss the brewing processes utilised in the four hypothetical areas, as practised at the SAB Rosslyn plant.

2.3.1 Malting

The first stage of malting is termed steeping (see Figure 2.3). During steeping barley kernels are soaked in water until they contain 42 – 44 % moisture required for embryo growth (the embryos are contained within the barley kernels) and adequately supplied with oxygen (Kunze, 1999). Water uptake by the barley kernels depends on, *inter alia,* the steeping time, steeping temperature and barley kernel size.

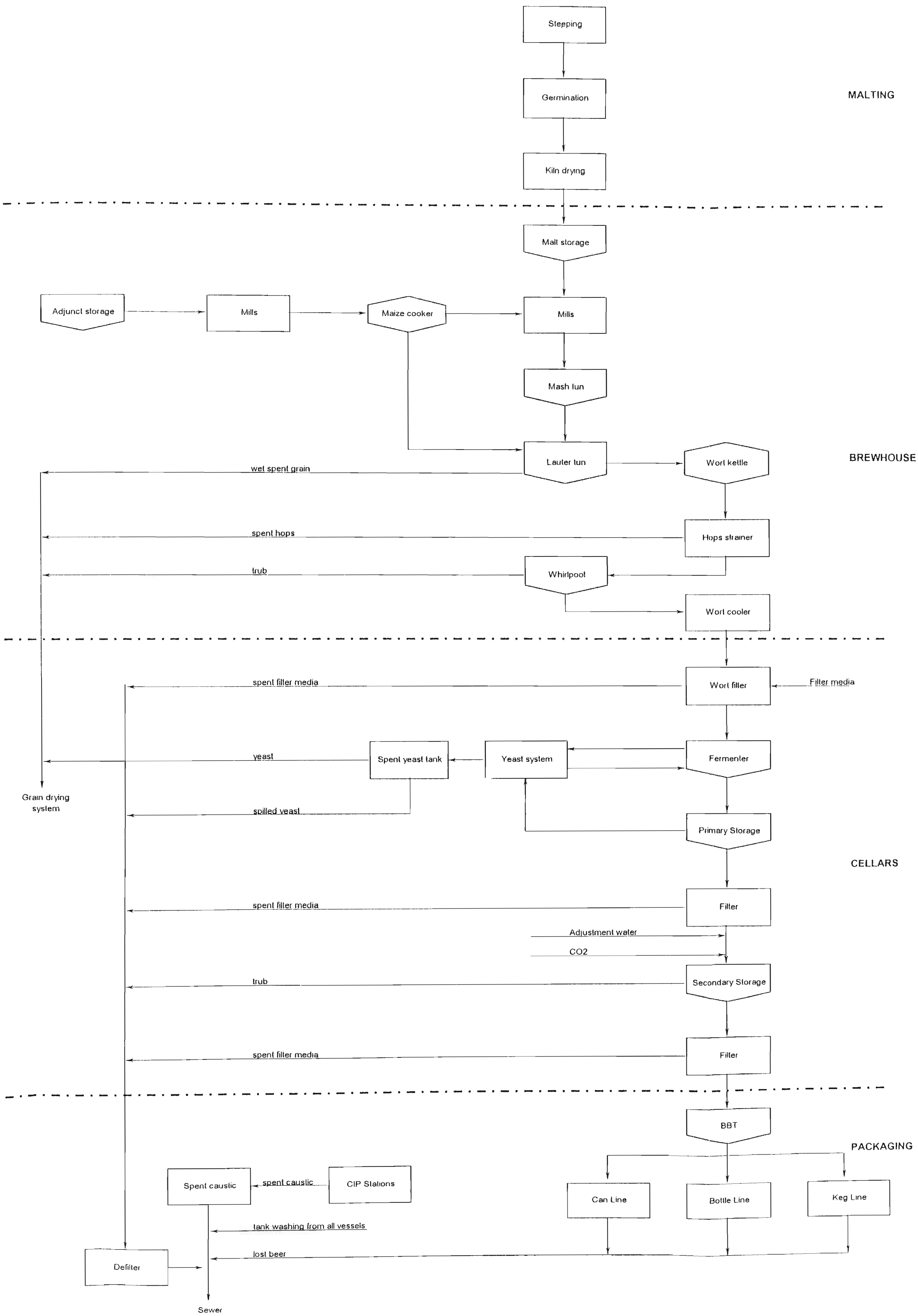

Figure 2.2 A typical process flow diagram of a barley brewery

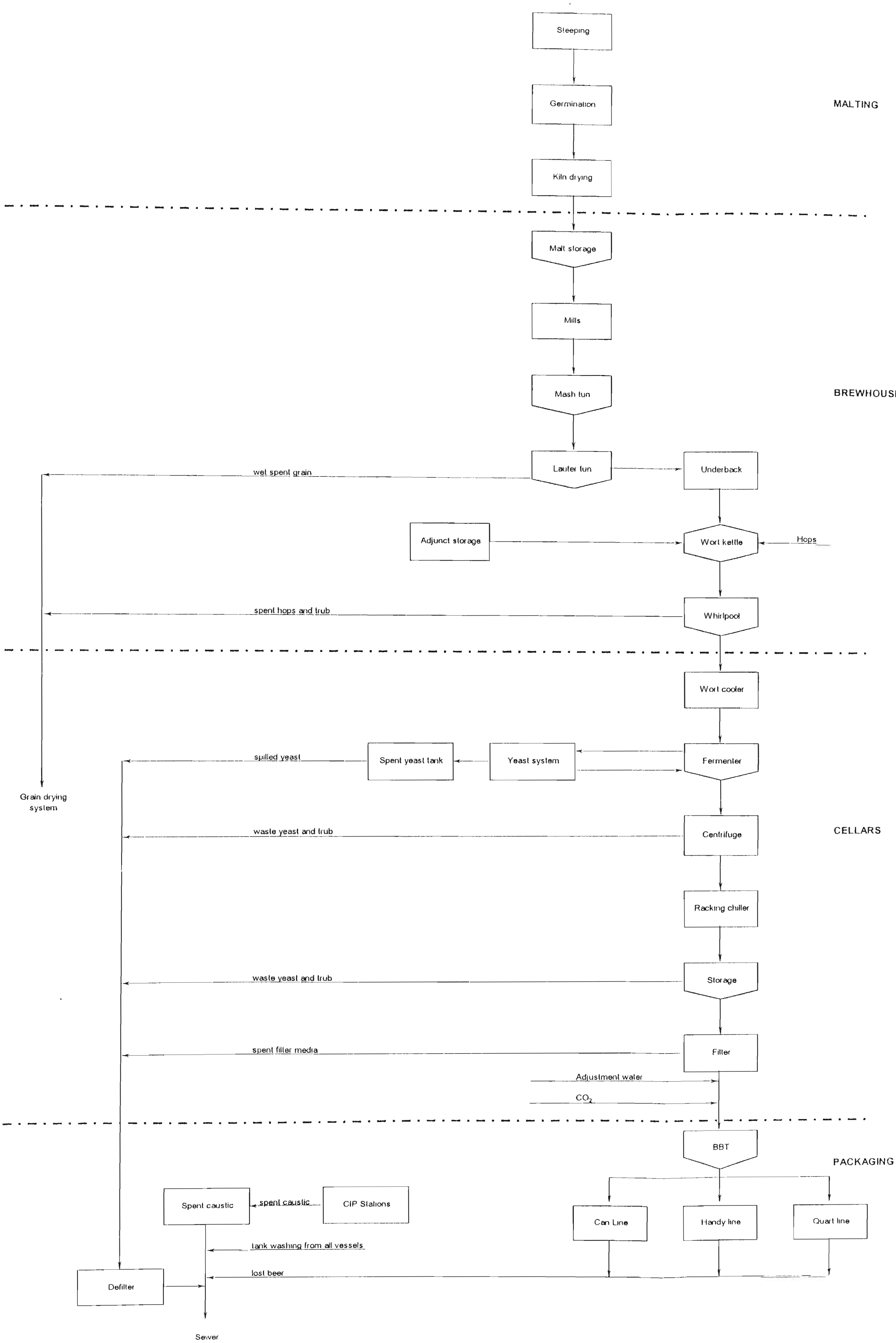

Figure 2.3 The flow diagram for Soputh African Breweries Rosslyn plant to be used in the analysis

At the start of the malting process the endosperm contents are in a stable high molecular weight form. These substances must be degraded to products of smaller molecules before they can be transported with water. This degradation is performed by enzymes which are formed during germination. During germination a new barley plant is produced from the kernel resulting in the formation of rootlets and a small shoot, which grows under the husk. (The husk consists of two overlapping leaf-like layers which were a part of the flower in which the seed was formed. It also forms the outer layer of the kernel and acts as a relatively waterproof and insect-proof protective barrier.)

As the barley kernels germinate, they produce enzymes which start to degrade the starch (in the kernel) into smaller carbohydrates, including some sugars (Wainwright, 1998). The next stage of malting is kiln drying. Here the germinated kernels, termed malt or malted barley, are dried to stop the modification of the enzymes and to produce a kilned malt which is dry enough to store for months. This kilned malt is responsible for much of the flavour, colour and foam of beer (Wainwright, 1998). South African Breweries purchases modified barley kernels, or malt, from external contracting companies, for example, Caledon Maltsers. At SAB's Rosslyn plant the malted barley is housed in storage silos from where it is transferred to the mills in the brewhouse. (As the malting process takes place outside of the SAB's brewing activities, its water use will not be considered in this thesis. However, typically 5 m^3 of water is used to produce 1 ton of malted barley and according to Binnie and Partners (1986), 3,4 m^3 of this volume exits the process as effluent, mostly due to the steeping process.)

2.3.2 Brewhouse

The brewhouse area at the brewery consists of the mills, mash tun, lauter tun, underback, wort kettle, whirlpool and relevent storage vessels (for the addition of hops and syrup). The malted barley is milled to expose the endosperm, thereby optimising the extraction of soluble substances (for example, starch and proteins) from the malt. To prevent too much fragmentation of the husk, some breweries treat the malt with water before milling in a process known as steep conditioning. (The Rosslyn brewery does not perform steep conditioning.) During milling the husk must be kept intact while the endosperm is crushed into smaller pieces. The husk is kept intact to ensure that during the separation of the spent grains from the wort in the lauter tun, the filter bed (formed from the kernel husks) in the lauter tun does not become to tightly packed with fine particles. The milled malt, now termed grist, exits the milling chamber, is mixed with water at a specified liquor to grist ratio, and is transferred to the mashing vessel (mash tun). The mixture of grist and water is termed mash. The liquor to grist ratio is dependent on the process and ranges from about 1:1 to 5:1 (volume:weight).

The process of mashing refers to the conversion of barley malt or mash, in the presence of enzymes, to a fermentable extract suitable for yeast growth and beer production. According to

Wainwright (1998), the enzymes present in the mash convert starch to sugars and proteins to free alpha amino nitrogen (FAN). This enzyme activity is temperature and pH specific making it possible to control the conversion of starch and proteins (Wainwright, 1998). The product from the mash tun is transferred to the lauter tun.

In the lauter tun, prior to the transfer of the mash, water is added in a process called underletting. This water is added to cover the false bottom of the lauter tun to ensure the even distribution of mash in the vessel and therefore facilitates the separation process. The main aim of the lautering process is to separate the husk fraction (or spent grain) from the mash liquor while collecting as much extract (fermentable sugars) as possible. The spent grain, which is removed from the mash liquor, is released to storage bins and sold to farmers as animal feed (Wainwright, 1998). After the bulk of the mash liquor has been extracted in the lauter tun, water is sprayed over the bed to recover any remaining liquor. This process is called sparging.

The mash liquor recovered in the lauter tun is temporarily stored in a vessel called the underback, before being sent to the wort kettle. The underback is a buffering facility to optimise the brew cycle time. During the transfer from the underback to the wort kettle, syrup or caramel adjunct is added to the mash liquor. (Adjuncts are substances which provide fermentable sugars in addition to those from the malt.) In the wort kettle, this mixture (termed sweet wort) is boiled with hops or hops products. The product from the wort kettle is called wort. (Wort is the mixture resulting from the mashing process and contains partially degraded starch, sugars, enzymes, proteins and water.) The main reasons for wort boiling include (Wainwright, 1998):

- wort sterilisation,
- coagulation and consequent precipitation of proteins,
- the removal of the volatile components,
- extraction of the hop bitter compounds,
- evaporation of water to obtain the correct extract concentration (gravity),
- achieving the correct colour, and
- the addition of the liquid adjuncts.

The hops added during wort boiling contain extractable compounds which, according to Wainwright (1998):

- suppress the growth of micro-organisms,
- impart a characteristic flavour and hops aroma,
- stabilise the foam compounds, and
- assist in clarifying the wort via precipitation with the coagulated proteins.

Boiling of the wort normally takes between one and two hours during which time approximately 5 – 15 % of the volume of product entering the wort kettle is evaporated (Wainwright, 1998). After the wort has been boiled, it contains suspended particles derived from waste hops (and proteins) and spent hops material, called trub. The boiled wort is transferred to a vessel named the whirlpool for the separation of the trub from the wort. In the whirlpool the hot wort swirls around while the suspended solids sink towards the bottom of the vessel. The suspended solids are stored in a trub tank, mixed with the spent grain and sold to farmers as animal feed (Pollution Research Group, 1987).

2.3.3 Cellars

The first area of cellars is called wort cooling where the wort leaving the whirlpool is cooled from approximately 95°C to between 9 and 10°C. The cooling, which facilitates the removal and enhanced settling of the trub, is accomplished in plate heat exchangers (Wainwright, 1998). The incoming cooling water, produced in the chilled liquor plant, exits the wort coolers for use as high temperature process water throughout the brewery. The cooled wort is transferred to the fermentation vessels.

Prior to entering the fermentation vessels, aeration of the wort occurs and a batch of yeast is added (or pitched). Aeration is necessary for the yeast to synthesise unsaturated fatty acids and sterols (which are vital cell components for the internal membranes of the yeast cells) while the yeast is an essential requirement for the fermentation process (Hulse, 2000).

During fermentation organic material is broken down into simpler compounds through the action of micro-organisms (yeast). In the brewery context, fermentation is where yeast metabolises wort sugars and other nutrients in order to multiply and also produce alcohol and carbon dioxide as major products (Wainwright, 1998). The growth requirements for the yeast cells are (Hulse, 2000):

- carbon sources - for energy which is obtained from fermentable sugars,
- nitrogen sources - for growth and enzyme synthesis,
- oxygen - for the production of lipids for membrane synthesis,
- vitamins - acting as growth factors,
- inorganic ions - required for yeast metabolism,
- water and
- yeast foods.

Fermentation can continue for 2 to 16 days depending on the time required to develop the characteristics of the beer (flavour compounds and alcohol percentage unique to the beer). During the fermentation process, yeast, CO_2 (continuously) and trub (not removed in the whirlpool) are removed from the vessel. At the end of the fermentation process, the product is called green or immature beer. Most of the yeast is removed and the green beer proceeds to storage or maturation (Wainwright, 1998).

The transfer of green beer to storage vessels for maturation is referred to as racking. To minimise the uptake of oxygen, the vessel and pipes are filled with deaerated water or carbon dioxide prior to being filled with the beer (Jones, 2000). (Deaerated water is produced in the deaeration water plant where water is flashed at a temperature above its boiling point, cooled and carbonated.) At the Rosslyn plant, the racking process includes centrifugal separation, chilling and carbonation steps. The main aim of centrifugation is to remove the yeast from the fermented beer before transferring to the storage vessel. Centrifugation accelerates the separation and settling of particles. Chilling reduces the temperature of the green beer to between - 1,5 to - 2,0°C, which is the optimal storage temperature for the beer. (The storage tanks at the Rosslyn plant, unlike other breweries, do not contain jackets or coils for lowering the temperature of the beer but utilise racking chillers.) During the carbonation phase, CO_2 is introduced into the beer to achieve the correct concentration in the beer and ensure that the quality of the beer is attained.

In addition to the above, green beer flavours are removed during storage by enzymatic reduction of the yeast. Remaining suspended matter, which causes the haze in beer, is also removed. The subsequent solid material, which settles out of the storage tanks, is drained. The beer remains in the storage tanks for up to 30 days.

To ensure that all yeast and chill haze (protein residues) are removed from the beer before packaging, the beer undergoes a filtration step. During filtration, the smaller particles still residing in the beer is separated from the beer. At the Rosslyn plant, kieselguhr filter aids are added to the beer inside candle filters to form a suitable filter bed. The spent filter aids are washed out of the filter during backwashing and discharged to the drains.

Since the Rosslyn plant makes and ferments worts with a relatively high initial extract content, the beer is blended with deaerated carbonated water to the correct alcohol content. After the filtration phase, deaerated carbonated water is added to the beer at a ratio of 0,44 m^3 per cubic meter of high gravity beer. The practice of brewing beer with a high initial extract content has been adopted to optimise equipment utilisation. (Brewing in smaller vessels also reduces the volumes of water and energy required and subsequently less effluents are produced.)

2.3.4 Packaging

After the high gravity beer has been adjusted with deaerated carbonated water, the beer is stored in bright beer tanks (BBT) until a line is planned to package the beer into relevant containers for distribution and consumption. The lines package the beer into 750 ml returnable bottles (called "quarts"), 340 ml non-returnable bottles (called "handys"), 340 ml or 450 ml cans and kegs, and on occasions into plastic bottles for sporting events. (At the Rosslyn plant facilities are not available to package the beer into kegs.)

Each unit process on a packaging line utilises water for, *inter alia*, cleaning or heat transfer. Simplified flow diagrams of the packaging line for returnable bottles and non returnable containers (cans and handys), depicted in Figure 2.4 and Figure 2.5 respectively, show that very few differences exist between the two packaging lines.

2.3.4.1 Packaging activities on the returnable bottle line

At the Rosslyn plant there are three returnable bottle lines. As shown in Figure 2.4, a returnable bottle line includes storage in the bright beer tanks, unpacking of empty returnable bottles, removal of existing crowns on returned bottles, bottle and crate washing, filling, pasteurisation, labelling, and packing into crates and on pallets.

Depalletiser, decrater and crate washer
Bottles are returned in crates (cases) stacked on pallets and the pallets disassembled into individual crates by a machine called the depalletiser. Depalletisers have gripper arms to hold a complete layer of 8 to 10 crates which place them onto a slow moving, wide conveyor. The crates are then orientated into a single file and any crowns (bottle lids), still remaining on the returned bottles, are removed by the decrowner. Decraters are then used to lift the bottles out of the crates onto a transfer conveyor, leading to the bottle washer, while the crates are moved via a different conveyer to the crate washer. In the crate washer, consisting of several compartments, the crates move on a conveyor and through a tunnel, where they are treated with high pressure jets. Detergents are used in specific compartments of the crate washer to facilitate the cleaning process. Dirt from the crates is separated from the water or detergent by straining, to allow for liquid reuse (ICBD, 2000).

Bottle washer
Dirty bottles are conveyed to the bottle washer consisting, like the crate washer, of several compartments. Bottle washers hold dirty bottles inside pockets on a continuous carrier chain in which they remain until they are discharged, clean at the end of a cycle. The continuous carrier chain, carrying the bottles, bends in a set pattern to ensure that the bottles undergo a series of jet cycles, *inter alia*, inversion, draining, steeping and rinsing until they are clean (ICBD, 2000).

A typical sequence of events inside the washer is as follows:
- bottle loading,
- pre-soaking and rinsing,
- immersion and
- rinsing.

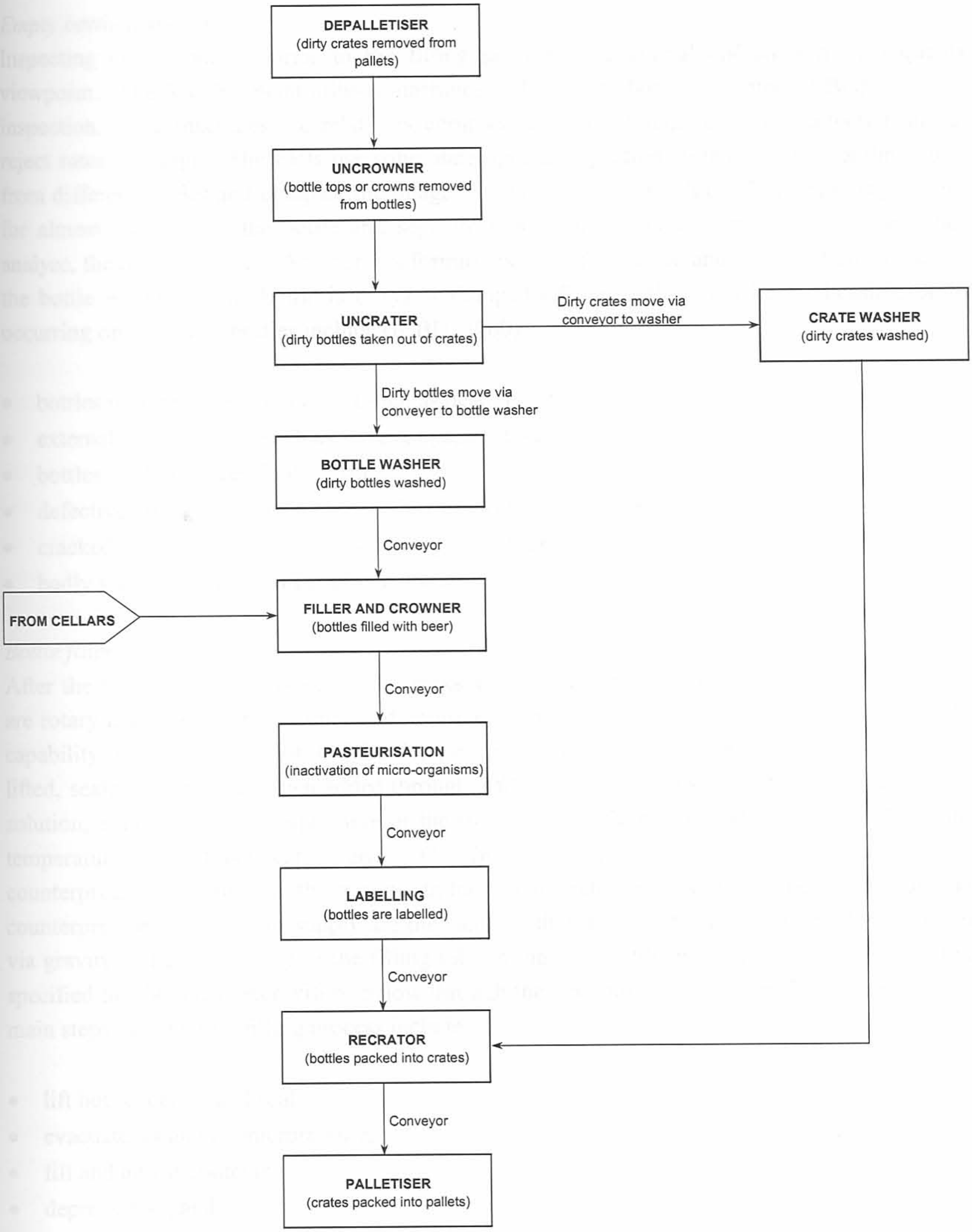

Figure 2.4 A simplified flow diagram of a returnable bottle packaging line.

Empty bottle inspector

Inspecting empty bottles, prior to the filling process, is a crucial operation from a quality viewpoint. The Rosslyn plant utilises machines called empty bottle inspectors (EBIs) for bottle inspection. The machines are relatively compact and do not require manual attention unless reject rates are large. The EBIs use solid state optical inspection systems to inspect the bottles from different angles and compare the images found with pre-set values. Inspection is provided for almost all parts of the bottle and separate sets of optical equipment illuminate, and then analyse, the different parts. Any non-conforming bottles are rejected and conveyed either back to the bottle washer (if the bottle is dirty) or dumped (if the bottle is cracked). Possible faults occurring on imperfect bottles include (ICBD, 2000):

- bottles with residual internal dirt such as dead insects,
- external contaminants such as traces of paper or adhesives,
- bottles containing residual caustic,
- defective bottle openings such as a chipped neck or damaged thread,
- cracked sidewalls or inclusions such as gas bubbles or ceramics, and/or
- badly scuffed bottles that have been used too often.

Bottle filler

After the bottle has been inspected for cracks and dirt, it is conveyed to the bottle filler. Fillers are rotary machines with a diameter of approximately 5 meters, up to 200 filling heads, and the capability of filling up to 100 000 bottles per hour. During filling, the bottles are individually lifted, sealed and the beer then added through a filling tube. To ensure that the CO_2 remains in solution, either a gas counterpressure or the isobarometric filling method is used and the filling temperature is held between 1 and 3°C. In the gas counterpressure method, a CO_2 gas counterpressure is applied to the system. In the isobarometric method, the bottle pressure and the counterpressure on the beer supply are the same so that the beer runs into the bottle effectively via gravity. The positioning of the filling tube in the beer bottle ensures that beer is added to a specified height, since beer will overflow through the vent pipe once this level is exceeded. The main steps in the bottle filling process include:

- lift bottle, centre and seal,
- evacuate air and counterpressure,
- fill and adjust contents,
- depressurise, and
- lower bottle and discharge.

Crowns should be applied to bottles as quickly as possible after filling to prevent air from entering the bottle and to prevent the loss of beer. As a result, the crowning machine (crowner) is integrated into the filler block to get full synchronisation in the two operations. Crowners are usually rotary machines with a number of heads or stations where the bottles are held for a few seconds while the crowns are placed on the bottle tops and then pressed into place (ICBD, 2000).

To prevent quality (taste and stability) problems, it is essential to remove any air present in the headspace of the beer bottle. This is achieved by a process called jetting where a fine stream of water enters the bottle to induce the beer in the filled bottle to rise as foam or fob and displace the air in the space above the beer (Maule, 1983).

Another aspect affecting the quality of the final product is the bottle fill heights. Bottle fill heights are either checked with a gamma source or by infrared methods. Incorrectly filled bottles are diverted back to the bottle washer where the beer is decanted to the drains, subsequently resulting in product loss and increased effluents (Dodd, 1987).

Pasteuriser

Once the beer has been carefully filled into clean bottles and sealed, it is pasteurised. Although the beer may be biologically clean at the time of filling, minor infection with bacteria, brewery yeast, or wild yeast (yeast strain not used by the brewery) would cause a rapid breakdown of the product. There are two types of pasteurisation, flash pasteurisation and tunnel pasteurisation. Flash pasteurisation involves using a plate heat exchanger to rapidly heat the beer up to a temperature of approximately 70°C, holding it at this temperature for some seconds, then chilling it down again. Tunnel pasteurisation, as used at the Rosslyn plant, involves slowly heating the bottle to the correct temperature, holding it at peak temperature (62°C) for a specified time interval and then slowly cooling the bottle down once again so that the bottle leaves the pasteuriser at approximately 30°C. The process normally takes one hour from the time a bottle enters the pasteuriser to the time it exits. This long time span is required since:

- the rate at which heat is conducted through the bottle wall and then through the beer is long,
- using a rapid temperature rise would cause thermal stresses which could result in the bottle bursting and therefore product losses, and finally
- as the highly carbonated beer bottle is heated, there is a steep rise in pressure which again poses a risk of bursting.

Bottles have a wide range of failure pressures but generally are manufactured to withstand pressures up to 6 bar. To prevent bottle breakage and still achieve the desired pasteurisation units over the unit process, a low temperature/long time profile is utilised. One pasteurisation unit (PU) is the unit obtained by holding beer at 60°C for 1 minute and is a measure of the time necessary to ensure the death of microorganisms within a bottle or can. Generally, a beer bottle is effectively pasteurised if 10 pasteurisation units are achieved.

In the pasteuriser, bottles slowly move through and are heated by spraying warm water (from spray sets) onto them. These spray sets are in zones across the length of the machine and are at set temperatures. The first zone, for example, will be at a temperature of 20 to 22°C, to warm the bottles up to between 9 and 10°C (the filled bottle generally enters the pasteuriser at a temperature between 5 and 7°C). The water falling past the bottles and through the conveyor carrying the bottles is collected within a trough underneath the pasteuriser. This water is used for reuse within another zone where cooling of the bottles is required. Water at progressively higher temperatures is sprayed onto the containers to bring them up to 60°C.

The most critical section in the pasteuriser is called the superheat zone which is the last heating zone before the zone where the temperature is held at 60°C. The temperature in the superheat zone must be very accurately controlled at between 61 and 65°C, to ensure that the containers are heated to the correct temperature. The temperature used is machine specific and therefore specified on commissioning to give the required pasteurisation units. Stoppages in the pasteuriser could result in bottles, within the superheat zone, to be overheated resulting in overpasteurisation and burst bottles.

Water in the cooling zones receive heat from the warm bottles exiting the pasteuriser and is pumped to the zones at the front of the pasteuriser where it is used to warm up the cold incoming bottles. The heated water will subsequently lose heat as a result and is then returned to the zones at the end of the pasteuriser to cool down more bottles. At the Rosslyn plant, the final zone of the pasteurisers used on the bottle lines is supplied with water from the cooling towers for efficient cooling of the bottles exiting the pasteuriser. This water is recycled back to the cooling towers.

Each zone in the pasteuriser has facilities for heating up and cooling down its reservoir to cater for start-up and shut-down conditions, as well as occasional stoppages. If the pasteuriser is in equilibrium, then only the superheat zone needs significant steam input, while the other zones require only small additions of water. The energy consumption in a tunnel pasteuriser is high and 50% recovery is the best that can be achieved, since the bottles enter the pasteuriser at between 5 and 7°C and leave at between 25 and 30°C. If a pasteuriser does get out of balance, for example when being emptied for cleaning purposes, then water consumption will rise due to the heat imbalance and overflow of the troughs since the cold water added must reach the correct temperature (ICBD, 2000).

Labeller

After pasteurisation, the bottles are conveyed to the rotary labellers for the application of labels on the bottles. The application of labels is done in stages in order to obtain the high speeds and consistency of glue application needed for a consistent quality appearance. The stages can be listed as follows;

- glue picked up by glue pallet,

- label picked up and glue applied,
- label transferred to the gripper,
- label transferred to the bottle, and
- label brushing.

Recrator and palletiser
Once the bottles are labelled they are packed back into crates. The method of loading returnable bottles is simply the reverse of the decrater machine where an array of clamping nozzles descends onto a batch of marshalled bottles and lifts them into the crates. This is performed by a machine called the recrater. Palletising of bottle packs involves arranging the crates in a pattern and then moving them onto a pallet. This is performed by a machine called the palletiser.

2.3.4.2 Packaging activities on the nonreturnable container line.

The packaging process for non-returnable bottles and cans (containers) has a few differences to that of the returnable bottle packaging lines and is shown in Figure 2.5. The differences between the two types of lines include, *inter alia*,

- the nonreturnable container line does not have bottle washers (bottles are new), but instead the containers are rinsed with a machine called the rinser,
- the nonreturnable container lines does not use uncraters or decrowners,
- cans are closed (seamed) by a machine called the seamer,
- filled containers are sorted in packs of six and shrinkwrapped in plastic by means of a machine called the shrinkwrapper, and
- these packs are then loaded onto trays by means of the traypacker.

Depalletiser
Most nonreturnable containers are on strapped pallets with thin layer-boards between each layer of cans. The pallet is located on a lift and raised to the height of the infeed conveyor, which is a broad slat or belt conveyor with the same width as the pallet. When the containers are level with the conveyor, the top cover board is removed and the first layer of containers are moved onto the conveyor by the depalletiser pusher arm. On the infeed conveyor, the containers are inspected for damage or contaminants, often by having an angled mirror on the side of the conveyor to assist in viewing (ICBD, 2000).

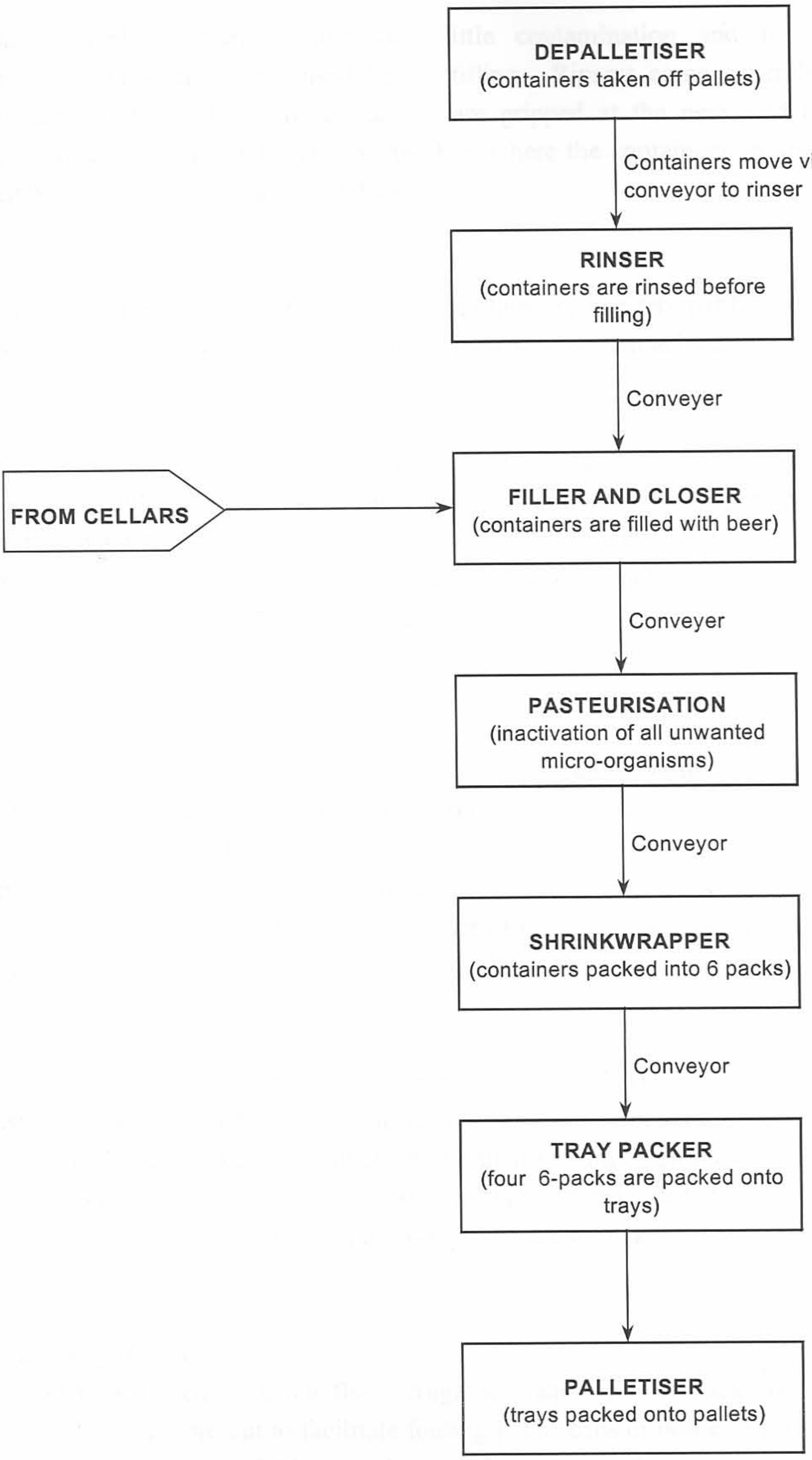

Figure 2.5 A simplified flow diagram of a nonreturnable bottle or can packaging line.

Rinsers

New non-returnable containers have very little contamination and to ensure complete decontamination, containers are rinsed before filling. Rinsers come generally in two forms, either a rotary machine where the containers are gripped at the neck and then inverted for spraying, or linear machines with an inverted belt where the containers are inverted and rinsed and placed back on a conveyor again (ICBD, 2000).

Filler

After rinsing, the containers are filled, similarly to those on the returnable bottle packaging line, and the nonreturnable bottles crowned and the cans seamed by a machine called the seamer.

Seamer

The seaming operation starts back at the filler discharge because the two operations of filling and seaming are fully linked. Fillers are coupled to the seamer and must be perfectly timed to ensure smooth can transfer to avoid, *inter alia,* spillage and fallen cans. After filling, the beer in the cans is topped with foam, containing air which may cause spoilage, which is removed by CO_2 injected into the cans, prior to the seaming operation (ICBD, 2000).

Pasteuriser

Once the bottles and cans are filled and closed, they are pasteurised to kill any microorganisms which may have entered the container. The pasteurisation activity on a can line is very similar to that on a bottle line, except that the water used to rinse the cans in the final zone passes straight to the drains and is not recycled to cooling towers. The reason for the Rosslyn plant not recycling water between the pasteuriser and the cooling towers is that cans come into direct contact with a person's mouth when drinking the beer and water of drinking water quality is thus used to rinse the containers.

Shrinkwrapper

Completed cans and bottles from a packaging line are usually grouped together, six in a pack, with plastic shrinkwrapped by a machine called the shrinkwrapper. Shrinkwrapping involves folding a sheet of plastic over the containers and then moving it on the conveyor through a heat tunnel at between 180 and 200°C, whereupon the plastic shrinks and clings to the containers in a firm pack. The most common way of packaging cans are to make them up into a case of 24 cans (ICBD, 2000).

Traypacker and palletiser

Tray packing is achieved by using flat corrugated blanks from a stack and folding them into shape. (The blanks are pre-cut to facilitate folding.) The cans or bottles are first pushed onto the centre of the board, the sides folded in, glued on the ends and the tray ends folded up to stick to the sidewall overlap piece. Hot melt glue is usually used for this application. If the tray is shrinkwrapped as well, then the two functions are combined in one machine. Tray packing is performed by a machine called the traypacker.

Successive layers of trays alternate in pattern to ensure that there is enough friction to hold them together. Between 8 and 11 layers are typically put into a full pallet, depending on can size. This is all done by a machine called the palletiser (ICBD, 2000).

2.4 WATER MANAGEMENT

As discussed thus far, there are many unit operations involved in a brewery, all consuming water. Specific water use within the brewing process (excluding those associated with malting) will be discussed in the proceeding chapters. A simplified water balance of the water utilised within the Rosslyn plant is shown in Figure 2.6. From the diagram it can be seen that water used inside the brewery either becomes part of the beer, part of the effluent or is evaporated (during wort boiling). The water ratio is described as the ratio of total volume water entering the brewery (A) to the total volume of beer leaving the brewery (B). Ideally, the volume of the effluent (stream C) should be minimised which would reduce the costs of effluent treatment and the costs paid for water, since stream A would also decrease. A major source of effluent in a brewing environment emanates from cleaning operations, since beer is a consumable product and it is important to maintain a clean brewing environment.

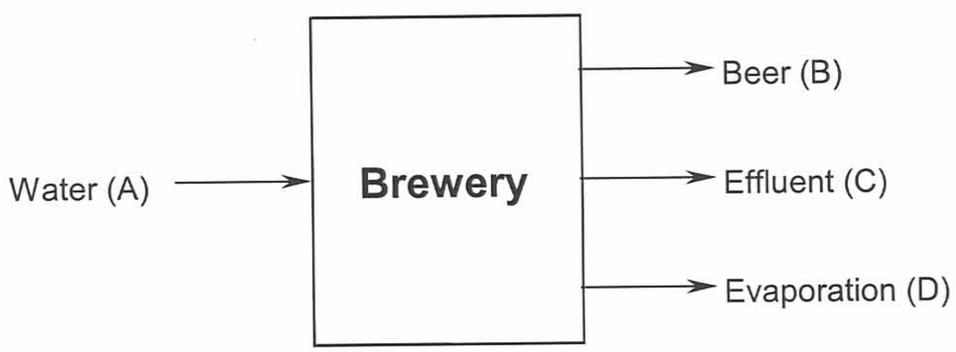

Figure 2.6 Simplified water balance of the Rosslyn plant.

All vessels and pipelines frequently undergo cleaning in place (CIP) which becomes part of the effluent stream. The purpose of the CIP is to ensure that the product is safe for human consumption by keeping the equipment clean. It also ensures that the product is of the correct quality required. Therefore the CIP must be effective, repeatable and deodorising. At the Rosslyn plant they use a solution recovery system which reduces the water and chemical consumption. The vessel to be cleaned is often first rinsed with recovered water from an earlier cycle. A typical CIP regime (dependent on the vessel to be cleaned) employed at the Rosslyn plant includes the following:

- pre-rinse with water from the recovered water tank,
- detergent rinse (typically caustic soda) – to penetrate and remove the organic deposits on the vessel walls,
- water rinse (to remove the detergent in the vessel),
- acid rinse (typically phosphoric/nitric acid) – to neutralise alkaline residues and penetrate and remove the inorganic deposits on the walls,
- water rinse – to remove the acid in the tank,
- sterilent rinse – to sanitise, and finally
- water rinse – to remove residual sterilent in the tank.

Optimisation of these cleaning cycles in the brewery may thus reduce effluent volumes. According to Binnie and Partners (1986), between 65 and 70% of incoming water forms part of the effluent leaving a brewery. In the past, effluent charges associated with this water, were not very high. However, with the drive towards the conservation of the environment, companies are charged higher levies for the discharge and treatment of effluent. It is therefore very costly for a brewery to get rid of waste water and also very expensive to purchase fresh water. The cost of disposal of effluents to, for example, local authority sewage works, depends upon the volume, the concentration of suspended and total solids, and the ability of the effluents to take up oxygen. Therefore every attempt should be made to reduce the volumes of water used and minimise the amount of suspended material in the waste water.