

# **ENERGY MANAGEMENT IN INDUSTRY**

## **A Case Study on the Brewing Industry**

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BY  
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A dissertation submitted to the Faculty of Engineering at the University of Cape Town in partial fulfillment for the degree of Master of Science in Engineering.

April 1992

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Signed by candidate

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M.G. de Villiers BSc.(ENG.)

27<sup>th</sup> day of April 1992.

## ABSTRACT

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The industrial sector is the main energy user in South Africa, using about half the national total, and compared to most other industrialised countries South Africa has a high industrial energy intensity, thus necessitating improved industrial energy management. The malt brewing industry was chosen as a case study industry to illustrate the potential for improved energy management in industry. Ohlsson's brewery in Cape Town was analysed in detail and energy management improvements identified for that brewery were expanded to include the malt brewing industry in general, by comparing Ohlsson's brewery to other breweries in South Africa.

It was found that energy requirements at Ohlsson's Brewery could be reduced by 12 - 20%, by the implementation of economically feasible energy management schemes. However, mainly because of discrepancies in coal prices between Ohlsson's Brewery and most other breweries in South Africa, energy requirements for the brewing industry in general can be reduced by 7 - 13%. This translates to be a monetary saving of R242 000 - R486 000/month, which is evenly spread between coal, electricity, and maximum demand savings. No single large energy saving scheme was identified, but the potential savings are due to a number of schemes. The potential energy savings identified in this study exclude the savings as a result of the implementation of process sensitive schemes, which were considered beyond the scope of this study. Nevertheless some process sensitive schemes, associated with boiling in the brewhouse, could result in substantial savings.

The energy usage target identified for South African breweries is higher than current energy requirements for breweries in the Britain and Germany when climatic and operational constraints are taken into account. This is because Britain and Germany have higher energy costs relative to production costs, government incentive schemes for reducing energy usage, and more stringent environmental legislation often necessitating the recovery of brewhouse vapours.

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# CHAPTER 1

## INTRODUCTION

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### 1.1 MEANING OF ENERGY MANAGEMENT

Because of the ambiguities and negative connotations often associated with the understanding of the terms 'energy conservation' and 'energy efficiency', a new term 'energy management', emphasising a more holistic approach to energy use, has come into being. Energy management is the effective use of energy resources with the prime motivation being economic benefit, but moral obligation, social responsibility, and national interest are other considerations. Energy management is not just concerned with introducing measures that are a benefit at present, but also measures that take into account potential future problems with energy supply. Energy management in industry includes consideration of electricity, waste heat recovery, housekeeping, steam systems, refrigeration, process control, and waste recycling. Furthermore energy in industry is inextricably linked with product quality and output, thus necessitating consideration of these interactions.

### 1.2 IMPORTANCE OF ENERGY MANAGEMENT IN INDUSTRY

Industry is the main energy user in South Africa (SA), using about 47% of the national total in 1989<sup>(1)</sup>, and thus energy reductions in industry will have a considerably favourable impact on national energy usage. Compared to most other countries South Africa has a high industrial energy intensity, defined as the use of energy per unit of economic output. A number of reasons exist for this high intensity, the major one being a larger primary than secondary industrial sector in SA. Another reason for the high intensity is the inefficient use of energy in industry. Potential thus exists for better energy management in industry.

Energy management in industry is important both from a company and a national point of view. The following are potential benefits to a company:

- The company does not spend any more on energy than is necessary.
- With changes in the real price of different forms of energy, the most cost effective energy usage scheme is maintained.

- Reducing energy consumption means less reliance on a commodity over which a company has no price control.
- Energy management can contribute to removing plant bottlenecks thus permitting increased output.
- Potential future problems with energy scarcity, legislation, and prices can be mitigated.

From a national point of view effective energy management results in reduced energy consumption. The White Paper on the Energy Policy of SA<sup>(2)</sup> cites the following reasons for the importance of reduced energy consumption:

- Capital savings on the erection of power stations.
- Reduced energy imports thus having a favourable effect on foreign exchange.
- Increase in the life of indigenous energy sources.
- Reduction of adverse environmental effects.

Furthermore it has been pointed out that investments in energy conservation often yield better returns than investments in energy supply, and investments in energy conservation can often be undertaken in smaller increments than investments in energy supply<sup>(3)</sup>.

### **1.3 INDUSTRIAL ENERGY MANAGEMENT INTERNATIONALLY AND IN SOUTH AFRICA**

Since the two oil crises of the seventies there has been a sharp increase in emphasis on energy management in the industrialised Western countries, mostly due to the efforts of government sponsored research into energy savings. Subsequently it has become evident that much scope exists to reduce energy consumption economically in industry. New and improved design and decision tools for energy management were developed. Consequently during the period 1973-1980 industrial energy intensity dropped by 14% internationally<sup>(3)</sup>. Conversely, in SA, during the same period industrial energy intensity rose by 11%<sup>(1)</sup>. Reasons given are:

- SA was not as adversely affected by the oil crises as the industrialised Western countries because of its relatively high coal and low oil consumption. Consequently there was less incentive to reduce energy usage.

- With large coal resources and excess electricity generating capacity, many consumers had not perceived that the efficient use of energy was important.
- The government had given limited attention to the efficient use of energy, and rather concentrated on energy supply.
- Energy was not seen as an important cost in many industries, whilst labour and the purchase of goods were seen to be more important.
- Prices of fuels and electricity were cheap in SA, by international standards.

Substantial potential thus exists for improved energy management in SA. It is claimed that a 20% reduction in industrial energy consumption by the year 2000 should be readily obtainable<sup>(4)</sup>.

#### **1.4 OBJECTIVES OF THIS STUDY**

It is evident from the above points that, in order to improve energy management in SA, further research is required to show:

- What potential exists for energy management improvements in different industries in SA.
- What design and decision support tools are appropriate to energy management in industry.
- Whether energy efficiencies obtained overseas are realistic for SA.

The purpose of this study is to contribute to the above objectives by applying these objectives to the malt brewing industry. The malt brewing industry was chosen because:

- No previous studies of this nature have been performed in SA.
- Studies have been carried out overseas, and since the malt brewing process is reasonably standard worldwide, constructive comparison with overseas plants can be made.
- The malt brewing process includes various industrial unit processes, and is thus fairly representative of a typical industry.
- Since the malt brewing process is similar on major plants in SA it is only necessary to examine one brewery in detail.

Ohlsson's Brewery in Newlands, Cape Town was chosen as the case study brewery.

## 1.5 THE CASE STUDY BREWERY

Ohlsson's brewery was first built in 1869. Since then four major re-developments have been carried out, the last being in 1973 when programmable-logic-controlled brewing technology was installed. During this study the brewery started to undergo a further expansion from a maximum beer production rate of 49000 hl/week to 85000 hl/week. All data gathered in this study was from before the expansion, but potential energy management improvements were evaluated for conditions after the expansion.

Ohlsson's brewery was chosen as the case study brewery because its size and specific energy consumption (230 MJ/hl beer) are close to the median for malt breweries in South Africa. Furthermore no formal energy management programme has been initiated and thus potential exists for energy savings.

The brewery consumes about  $34 \times 10^6$  MJ of primary energy per month in the form of coal, electricity and fuel oil. The overall energy bill is about R360 000 per month, which is about 5% of production costs.

## CHAPTER 2

# ENERGY MANAGEMENT IN INDUSTRY

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### 2.1 PREREQUISITES FOR AN EFFECTIVE ENERGY MANAGEMENT PROGRAM

Successful energy management is not a once-off project, but an ongoing activity, necessitated by changing needs within the company, fluctuating energy prices, and fuel availability. It is generally accepted<sup>(6)(7)(8)(9)(10)</sup> that for an energy management programme to be successful there must be a top management commitment, energy management committees must be established, energy must be sufficiently monitored, targets must be set, formal action plans formulated, relevant persons should be held accountable for their energy use, and energy awareness must be fostered amongst employees.

#### 2.1.1 Executive energy management commitment

Without total executive management commitment an energy management programme can easily become obsolete. For large companies a management commitment would normally involve setting up a top corporate energy management section or committee with the following tasks<sup>(9)</sup>:

- Act as an advisor to local plant activities.
- Help establish goals.
- Help develop energy related programmes.
- Monitor the success of these programmes.
- Gather and distribute energy related information.

#### 2.1.2 Plant energy management committee

Each plant should have an energy management committee, which should include a representative from production and one from engineering and maintenance. The responsibilities of the committee would be to<sup>(6)(9)</sup>:

- Establish priorities and goals.
- Monitor performance.
- Develop and implement action plans.
- Keep informed on all government actions that could affect energy management.

- Report results to relevant persons.
- Provide news letters, posters, and slogans to foster energy conservation awareness amongst employees.
- Publicize energy conservation efforts and results to the community.

### **2.1.3 Monitoring**

Adequate monitoring systems are vitally important if energy is to be brought under management control. Roberts (1985)<sup>(7)</sup> says 'Indeed, implementation of a monitoring system can probably do more to reduce energy use than any other single action available to management'. A monitoring system allows<sup>(8)</sup> the effects of energy management measures to be evaluated and checked, brings tighter management control over energy costs and usage, and identifies equipment deficiencies at an early stage.

### **2.1.4 Target setting**

Target setting has been an essential part of management philosophy for decades, and there is no reason why it should not apply to energy management. Targeting should apply to all levels of accountability. In order to set realistic targets it is necessary to know appropriate energy-use performance standards, which are often based on historical records. Targets are then set on the basis of energy reductions that are to be achieved<sup>(8)</sup>. Targets may be arbitrarily defined eg 10% reduction by the end of the year (top down approach), or targets can be based on opportunities identified (bottom up approach). Both short- and long-term targets are necessary for a sustainable programme.

### **2.1.5 Action plans**

In formulating action plans<sup>(8)</sup> it is important to appreciate that there is a need for action plans covering a wide range of capital costs and pay-back times. In this way each programme may proceed on a different time-scale and if necessary the whole programme can be made self-financing.

### **2.1.6 Accountability**

Problems are not usually solved unless someone is responsible for those problems, and hence it is important that responsibility for various areas of energy management is not confused. It is reasonable to expect at least a 5% reduction in energy usage through

allocating ownership of the problem<sup>(7)</sup>. Accountability is required at varying levels of authority, and this can normally be broken down to three basic levels<sup>(8)</sup>:

- 1) Senior management - information is required in relation to production or profits on a monthly basis.
- 2) Middle management - information is required in relation to a specific area either daily, weekly or monthly.
- 3) Operational management - information is required in relation to detailed areas on a continuous or near-continuous basis.

### **2.1.7 Awareness**

Energy awareness is a precursor for more efficient use of energy<sup>(6)</sup>, and often leads to previously unnoticed opportunities being highlighted for energy savings. Awareness can be fostered by formal energy training or work-shops, usage of posters, and the displaying of monthly energy statistics.

It is important that operating staff realise that energy supplies to the plant are not simply a service which is provided 'on tap', but that most of the energy used is a valuable by-product of the process itself and that its efficient production and use is in their hands<sup>(6)</sup>.

## **2.2 IDENTIFYING OPPORTUNITIES FOR IMPROVED ENERGY MANAGEMENT**

In order to analyse energy usage on the entire plant, and identify opportunities for improved energy management, it is necessary to first gather information, then represent that information in a useful form, so that potential areas of improvement can be identified.

### **2.2.1 Gathering information<sup>(6)(8)(11)</sup>**

At the outset of a management programme a plant-wide survey must be conducted, which should provide an inventory of all available monitoring facilities such as flow diagrams and schematics, specification manuals, and relevant measuring and recording instrumentation. It could then be ascertained what steps are necessary so that energy can be properly monitored. The monitoring of energy should start from when energy enters as fuel and electricity, and follow energy flows right the way through to its final state

such as radiation, energy in water vapour, energy in effluent, energy in the final product, or mechanical work. Historical information available may also be useful, but it is necessary to ascertain the accuracy of such information.

Energy loads consist of a non-production load, which is independent of the level of production eg radiation losses, tank heaters etc, and a production load, which depends on the production rate. It is of importance to determine the non-production loads so that locations where these loads are significant can be determined. Knowledge of both the production and non-production loads makes it possible to determine the overall energy requirements for different production rates, which is essential when considering or facing changes in the production rate.

## 2.2.2 Representing information

It is convenient to represent energy flows in the form of Sankey diagrams from which it is easier to ascertain where the key energy usage areas are and where energy is wasted. Figure 1 is an example of such a diagram.

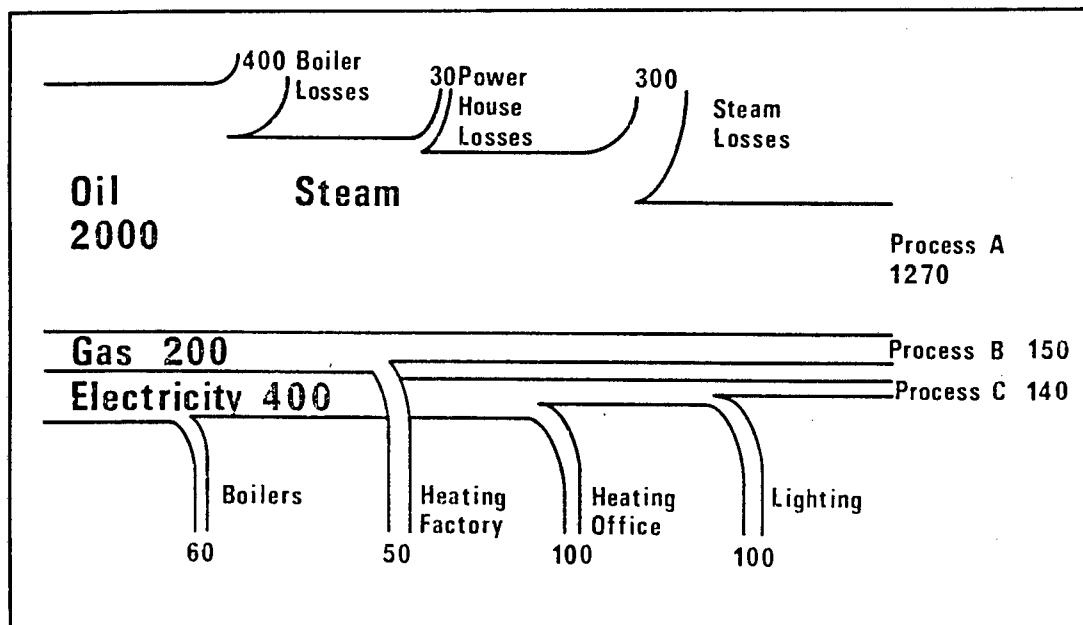


Figure 1. Example of a sankey diagram<sup>(18)</sup>.

For batch processes, it is convenient to express energy demand on a time-energy diagram which represents one cycle of the batch process. Figure 2 is an example of such a diagram.

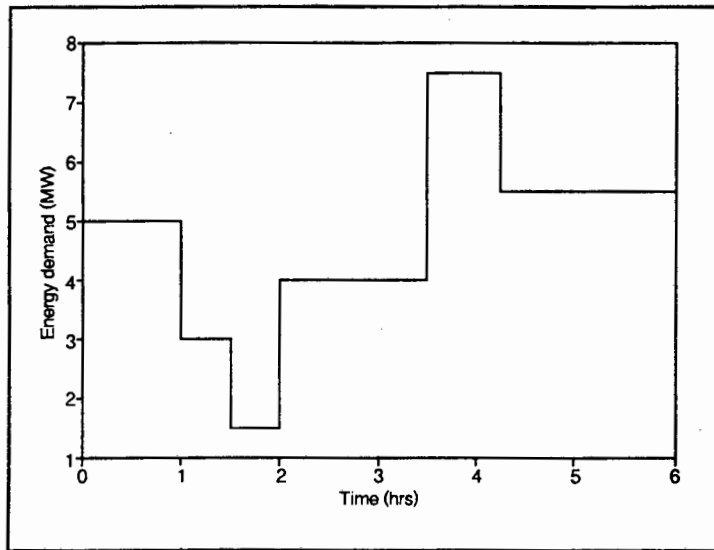


Figure 2. Example of a time-energy diagram for a batch process.

Once it is known where energy is used and wasted, it is possible to determine some commonly calculated ratios. These include specific energy requirement (SER), which is the amount of energy required per unit of product output; and equipment energy efficiency, which is the percentage of input energy usefully employed. These can be calculated for different sections of a plant and for the entire plant, and then compared with expected values so that the potential for energy saving can be determined.

### 2.2.3 Identifying opportunities

Identifying opportunities is often more common sense than anything else. It means:

- Comparing actual energy requirements with other locations, previous periods, and standards.
- Considering process energy exchange.
- Considering recovery of waste energy.
- Looking at process modifications.
- Improving housekeeping.

Appendix A outlines those areas in energy management that have been consistently found to hold opportunity. Those areas of energy management are:

- Tariff analysis and negotiation.
- Electricity demand management.
- Power factor correction.
- Scheduling of process operations.
- Steam boiler efficiency improvement including improved control, use of economisers, use of a steam accumulator, condensate recovery, continuous blowdown, and blowdown heat recovery.
- Flash steam recovery.
- Improved efficiency of refrigeration, air compression, pumping, and lighting.
- Usage of heat pumps.
- Combined heat and power generation.
- Maintenance and inspection, especially of insulation, leaks, and steam traps.

#### 2.2.4 Pinch Technology

A useful design tool for identifying energy recovery opportunities is pinch technology.

Pinch technology is based on the pinch principle, which is derived from fundamental thermodynamics, and on economic optimisation. The technology has been proven in over 500 projects<sup>(12)</sup>, covering a wide range of industries using both continuous and batch operations. Typical retrofit studies have identified 15 - 30% energy savings at a payback of one year or better<sup>(13)</sup>. The energy savings realised were generally a combination of better placement of heat exchangers, and process modifications.

Appendix B gives a detailed outline of pinch technology, but important features are mentioned here. Pinch technology is based on an optimum minimum approach temperature ( $\Delta T_{\min}$ ) which is the minimum temperature difference allowed between two streams in a heat exchanger. The optimum is that which gives the lowest overall cost, which is made up of the capital cost (surface area) and operating costs (utilities). Pinch technology identifies:

- The minimum utility heating and cooling requirements.
- The minimum overall heat exchange area required.
- The minimum number of heat exchange units required.
- The minimum cost target for grassroots designs.

For existing plants, pinch technology will provide targets for minimum heating and cooling requirements, minimum heat exchange area, and minimum number of heat exchange units. Pinch technology can be used to identify those areas on an existing plant which are constraints to improved energy efficiency, such as badly placed heat exchangers. Pinch technology can then be used to predict where those heat exchangers can be most economically relocated. Opportunities for heat exchange between process streams can also be identified, and the economic feasibility of such opportunities then investigated.

In addition pinch technology can be used to examine the effect of changing the place and temperature of utility usage, the possibility of combined heat and power schemes, and the possibility of using heat pumps.

### **2.3 EVALUATION OF PROPOSALS**

Since ultimately energy management is concerned with lowering production costs, the final decision for projects must be an economic one. The most common economic evaluation options available are<sup>(14)</sup> (details in Appendix C):

- Capital investment.
- Payback time.
- Net present value.
- Rate of return.
- Internal rate of return.

There is no best economic criterion on which to judge a proposal, and the method of economic evaluation will depend on the size of the proposal, and specific circumstances of a company. However proposals can usually be divided up into three main areas<sup>(6)</sup>:

- 1) Items that require little or no capital cost that can be implemented immediately. This includes maintenance tasks such as repairing leaks and insulation. In general the older the plant the greater the potential benefits in challenging historical assumptions. No evaluation of these opportunities is required.
- 2) Capital items which have short payback times and which are clearly defined in terms of capital cost and technical scope, such as improved sensors. It is only necessary to calculate the payback times for these opportunities.

- 3) Longer pay-back schemes which may involve significant process changes. These schemes require a more detailed economic evaluation.

A sensitivity analysis is a way of examining the effects of uncertainties in the forecasts of the viability of a proposal. A sensitivity analysis is normally performed by recalculating the performance criteria assuming a range of errors for each of the factors (capital expenditure, energy costs, operating costs etc).

Product quality is of utmost importance, and energy management proposals may affect quality either adversely or beneficially. It is normal to have certain limitations on quality, and if those limitations should not be met by a certain proposal, then the proposal must be rejected. It is difficult to quantify, in monetary value, acceptable adverse effects, and beneficial effects, but it is essential that this be done by considering the risk involved. The methodology of taking into account the risk will depend on specific circumstances.

As well as economic considerations and quality factors many other factors may have to be considered when evaluating proposals, such as<sup>(14)</sup>:

- Safety.
- Environmental problems.
- Government policies.
- Availability of labour.
- Availability of supporting services.
- Company experience in the particular technology.

# CHAPTER 3

## THE MALT BREWING INDUSTRY

### 3.1 THE BREWING PROCESS

In the malt brewing process malt, liquid sugar, hops, and water are the major raw materials, with the malt having been processed from barley in a maltings plant. Malt is first converted to fermentable sugars in the brewhouse, followed by a fermentation period during which CO<sub>2</sub> and alcohol are produced. Most beers are then diluted with water, and packaged and transported from the brewery. Malt brewing is a relatively standard process for the various types of beer, and thus the simplified diagram of the malt brewing process as shown in Figure 3 applies to most breweries and beer types.

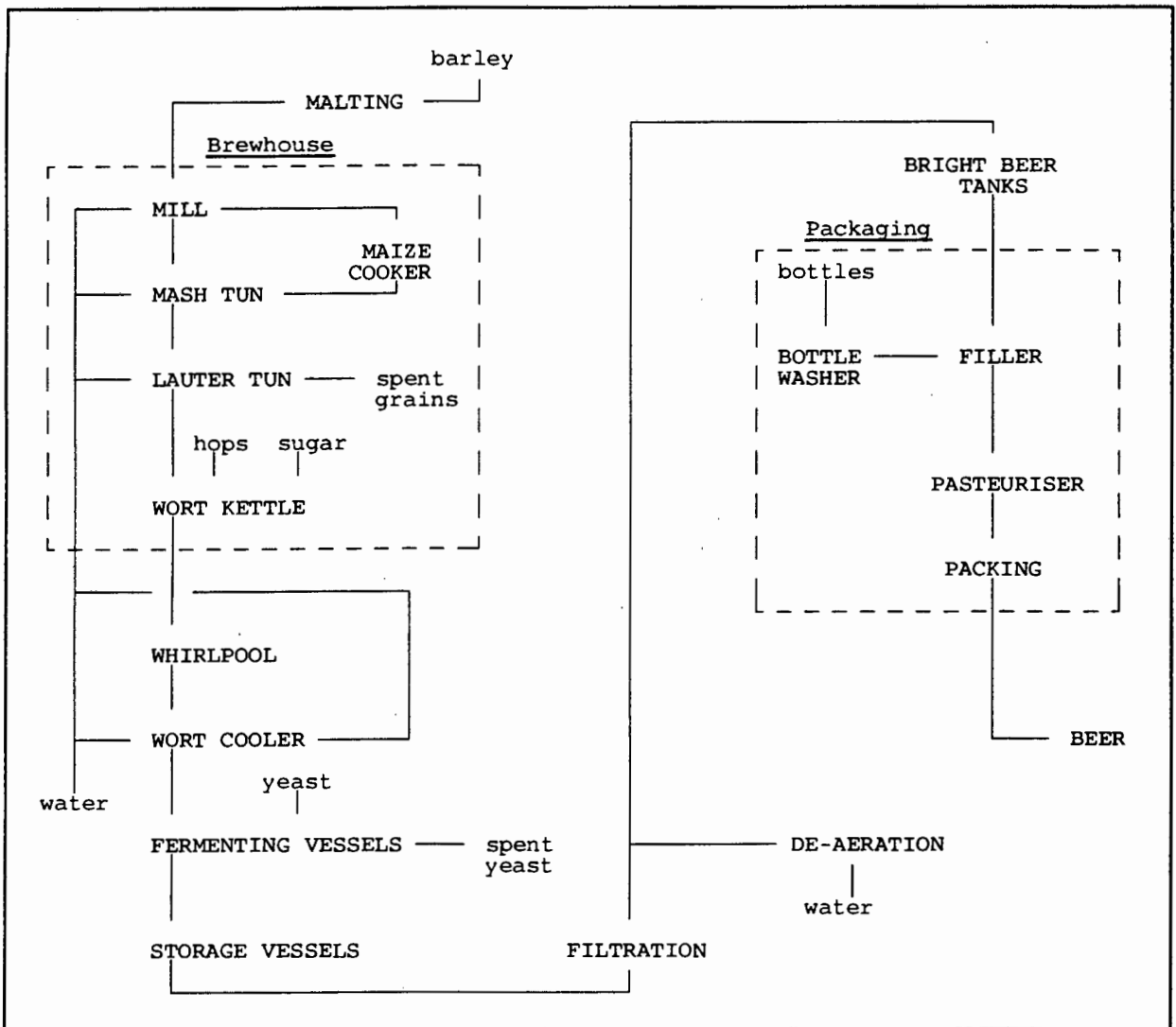


Figure 3. Diagram of the brewing process.

The entire process from malt input to the final beer product takes about three weeks, with the energy consumption varying substantially on an hourly basis. A brief description of the various unit processes is given below.

### 3.1.1 Malting

In the malting process barley is artificially germinated, by which the starch is brought into a suitable state for brewing. The barley is first steeped in water, and then allowed to germinate for a number of days. Growth is then halted by kilning, thus producing dry malt.

### 3.1.2 Brewing

The brewhouse is the first major process area in the brewery, where starch is converted to fermentable sugars. The brewhouse accounts for up to half of the heating requirements in a brewery. Most beer is high-gravity brewed, which means the brewhouse product must still be diluted. The brewhouse process is a batch process comprising the following operations.

**Steeping** - Hydration of the dry malt is achieved by soaking the malt in water after which the malt is gravitated to the grinding mills.

**Milling** - Milling grinds down the endosperm of the malt to enable the maximum yield of extract to be obtained, while maintaining the majority of the husk intact so as to form a suitable filter medium later in the process. The contents are then passed onto the maize cooker and mash tun.

**Maize cooking** - Apart from malt other forms of starch, known as adjuncts, are used in lesser quantities. For some beers produced in SA the main adjunct is maize, with dextrose sugar being used to a lesser extent. Maize requires boiling in order for starches to be readily attacked by the fermentation enzymes. A mixture of maize and about 8% of the malt input is brought to the boil where it is held for about 30 minutes, and the contents then added to the mash tun.

**Mashing** - Milled malt together with the contents of the maize cooker are soaked in hot water, enabling enzymes in the malt to convert starch to sugars, thus producing sweet

wort. The mash contents are held at various temperatures, for a total of about two hours, after which the mash is pumped to the lauter tun.

**Lautering** - The sweet wort is separated from the grains by filtering it through the spent grains, under gravity. Hot water is then sprayed from above to ensure almost complete removal of the sweet wort from the spent grains. The sweet wort is then pumped to the wort kettle.

**Wort boiling** - In the wort kettle hops and sugar are added to the sweet wort and they are brought to the boil for about 90 minutes. At the end of the cycle the wort is pumped to a whirlpool which removes insoluble material called trub by centrifugal forces. The wort is then pumped through the wort cooler.

### **3.1.3 Fermentation and storage**

The wort is cooled to a pre-fermentation temperature of 9°C in a plate heat exchanger, the heat usually being used to produce hot liquor which is used as process water and for rinsing and cleaning in the brewhouse. Yeast is added to the chilled wort which is allowed to ferment for about two weeks in fermenting vessels. Initially the temperature is maintained at 11°C with refrigerant, since the fermentation process is exothermic. After two days the temperature in the fermentation vessel is then allowed to rise to 14°C and this temperature is maintained for about eight days. During this period alcohol and CO<sub>2</sub> are produced. CO<sub>2</sub> is removed, purified, liquefied and stored to be used later in the process. Towards the end of the fermentation cycle the temperature in the fermenting vessels is lowered to 6°C to reduce yeast activity and allow the yeast to settle at the bottom of the vessel, from where it is withdrawn. The beer is then pumped to storage vessels where it is held at -1°C for about four days, during which time more yeast will settle out. The yeast is drawn off and the beer pumped to filtration.

### **3.1.4 Conditioning**

The beer is pumped through kieselguhr filters as well as through pre- and post-filter coolers. High-gravity beer is then diluted with de-aerated water, after which it is pumped to storage tanks (called bright beer tanks) and held at 0°C, from where it is drawn for packaging.

### 3.1.5 Packaging

Bottles and cans are filled with beer together with injected CO<sub>2</sub>. Returnable bottles must be washed in large bottle washers which use steam. The bottled and canned beer must then be pasteurised to prevent contamination and spoilage of the beer by bacteria. This is usually performed in tunnel pasteurisers using steam. Bottles are mechanically placed into crates, and cans are wrapped in plastic, after which the beer is transported to depots.

### 3.1.6 Utilities

Utilities usually include steam, primary refrigerant, secondary refrigerant, cooling water, air, and hot acid and caustic used for cleaning pipes and tanks in place.

## 3.2 THE BREWING INDUSTRY IN SOUTH AFRICA

The following gives the percent energy requirements of each component of the brewing chain, as estimated for the U.K.<sup>(31)</sup>:

Barley growing	28%
Malting	18%
Brewing	31%
Packing	16%
Transport	5%

Barley growing includes fertilizer and fuel requirements. In SA malting is performed at a separate site to the brewery (with the exception of the Alrode brewery), and will not be considered in this study. Transportation of the final product to depots, and barley growing are also not considered, and consequently only brewing and packing are considered in this study (47% of the total beer energy requirement).

There are 11 breweries in SA (including the homelands) that produce over 100 000 hl of beer per year each, and only these breweries are considered. Table 1 gives specific energy requirements, defined as energy requirement per unit of output, for each of the breweries for the 1991 financial year (01/04/1990 - 31/03/1991). The table is ranked in order of increasing specific energy requirements.

Table 1. Volume of beer packaged and specific electricity and coal energy requirements on medium and large breweries in SA<sup>(32)</sup>.

	PACKAGED (hl)	COAL <sup>a</sup> (MJ/hl)	ELECTRICITY (MJ/hl)	TOTAL (MJ/hl)
Rossllyn	6 132 000	143	38	181
Prospecton	3 650 000	151	41	192
Chamdor	2 197 000	175	32	207
Pietersburg	1 045 000	177	47	224
Alrode	3 433 000	194	35	229
Newlands	2 068 000	197	33	230
P.E. <sup>b</sup>	963 000	207	40	247
United Brew.	972 000	210	41	251
Bloemfontein	324 000	233	42	275
Butterworth	661 000	274	36	310
Isando	1 525 000	280	61	341
TOTAL/AVERAGE	22 743 886	181	39	220

<sup>a</sup> Newlands, P.E., and Prospecton use small amounts of oil as well, but this was taken account of by including the coal equivalent.

<sup>b</sup> 23% of the beer produced at P.E. was packaged in East London, and this was accounted for by using the average of hl produced and hl packaged.

In SA 1.17 ton barley/ton malt is required in malting, and 12.7 kg malt/(hl saleable beer) is required in brewing. An energy requirement of about 91 MJ/hl saleable beer (77 MJ/hl fuel and 14 MJ/hl electricity) has been determined for the maltings process from coal and electricity usages at the Alrode maltings plant (41% of the brewery requirement).

It is difficult to make generalisations about the breweries in SA, because there are so few. However some interesting trends can be inferred from Table 1.

- The four breweries which use steam accumulators have the lowest specific coal consumptions.
- The older breweries ie Isando, Bloemfontein, P.E., and Newlands, have higher specific energy requirements than the newer breweries.
- Higher coal prices and do not necessarily imply lower specific energy requirements. There is a large difference in the price of coal between the reef (about R80/ton) and the coastal breweries (Cape Town R190/ton, P.E. R150/ton).
- The larger the brewery the lower the specific energy requirement. Figure 4 shows the relationship. The Isando brewery is the exception to the general trend, because it is an extremely old brewery and will thus be scrapped shortly.

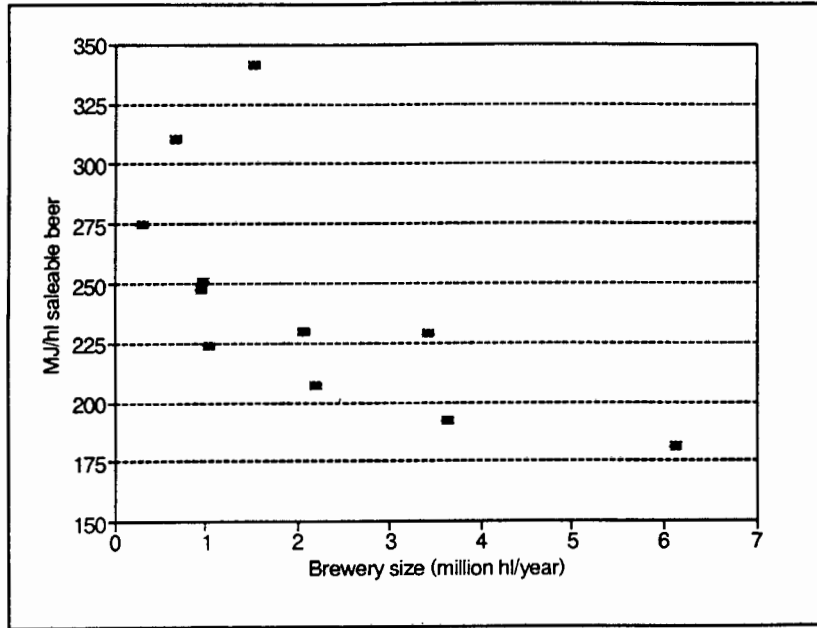


Figure 4. Effect of the size of the brewery on specific primary energy requirement.

The Rosslyn Brewery uses high temperature hot water (HTHW) instead of steam as a heating medium, and it has the lowest specific energy requirement. However Rosslyn is also the largest brewery so it cannot be concluded from the above figures that HTHW systems are necessarily more energy efficient than steam systems.

### 3.3 COMPARISON OF BREWERY ENERGY USAGE IN SOUTH AFRICA AND IN OTHER COUNTRIES

The beer production volumes in 1988 of SA and the largest producing countries are given below in million hectolitres<sup>(33)</sup>:

SA	19
World total	1086
USA	232
Germany	93
China	65
England	60
Japan	58
USSR	54

Table 2 gives specific energy requirements for SA and the most important international beer producers. No overall statistics for the USA could be found, indicating the lower energy awareness in the USA compared to Europe.

*Table 2. Comparison of average brewery specific energy requirement (MJ/hl saleable beer) for SA and overseas countries.*

	SA (1990)	UK <sup>(34)</sup> (1990)	Germany <sup>(35)</sup> <sup>a</sup> (1989)
Fuel	181	165	134
Electricity	39	35	40
Total	220	200	174

<sup>a</sup> These values exclude energy requirements of administration.

Factors adversely affecting energy requirements for overseas countries are:

- 1) European breweries, and some USA breweries, have the additional load of space heating, which increases energy requirements by about 25%<sup>(36)</sup> to 33%<sup>(37)</sup> from summer to winter.
- 2) European breweries are generally smaller than those in SA as can be seen in Table 3.

*Table 3. Percentage of total national beer production by different sized breweries.*

Annual Production (hl)	SA (1990)	UK <sup>(31)</sup> (1977)	Germany <sup>(33)</sup> (1990)	USA <sup>(33)</sup> (1990)
0 - 499 999	1%	23%	16%	2%
500 000 - 1 499 999	16%	34%	28%	3%
1 500 000 +	83%	43%	56%	94%

- 3) European breweries usually only package for one or two shifts per day, whereas many breweries in SA package for two to three (continuously) during the week. Consequently European breweries will use more on heating up. It was calculated in Appendix D that steam consumption for a bottling line would be about 22% higher for daily rather than weekly heating up.

Factors adversely affecting energy requirements in SA are:

- 1) Coal is almost exclusively used in SA while overseas breweries mostly use oil and natural gas for fuel (Table 4). Coal has lower conversion efficiencies and is less compatible with large steam demand fluctuations characteristic in brewing, than oil or natural gas.

Table 4. Percentage fossil fuel distribution.

Fuel type	SA	UK <sup>(31)</sup>	Germany <sup>(38)</sup>
Coal	99%	15%	8%
Oil	1%	55%	44%
Gas	0%	30%	48%

- 2) Overseas breweries produce a far greater proportion of draught beer than SA (Table 5). Draught beer is either unpasteurised or flash pasteurised requiring far less energy than tunnel pasteurisation required for packaged beer (bottled or canned). The containers in which draught beer is stored, mainly kegs and casks, do however require washing and sterilisation. It has been estimated<sup>(39)</sup> that draught beer packing requires only a third of the energy required for bottling.

Table 5. Percentage of national beer production packaged (bottled or canned) and kegged.

	SA	UK <sup>(34)</sup>	Germany <sup>(40)</sup>	USA <sup>(40)</sup>
Packaged	99.6%	25%	29%	88%
Draught	0.4%	75%	71%	12%

- 3) SA's ambient temperatures are generally higher thus increasing all cooling loads, and decreasing the refrigeration plant performance. The average electricity consumption difference in SA, between summer and winter, is 3,3 kWh/hl. It is expected that the difference between SA and Europe is of the same order, and the difference between SA and the USA about half of that for Europe.

Table 6 quantifies the differences between SA and the major brewing countries. It appears that European breweries only use 80% of the energy that would be required in SA, that is they are about 20% more efficient. This is because overseas breweries have more incentive to reduce energy costs, since often government incentive and financial aid

is given to save energy, and energy costs are generally higher, relative to production costs, than in SA. Legislation in Europe regarding brewhouse odours has also provided more incentive to recover energy from brewhouse vapours.

*Table 6. Differences in energy usage conditions between SA and other countries. Figures given are the ranges of expected percentage change in specific energy requirement from that for SA, with parentheses indicating a negative expected change.*

	U.K.	Germany	USA
1) Space heating <sup>a</sup>	12 - 17	12 - 17	6 - 9
2) Brewery size <sup>b</sup>	15 - 20	10 - 15	0
3) Packaging <sup>c</sup>	4 - 9	4 - 9	4 - 9
1) Fuel type	(3) - (5)	(3) - (5)	(1) - (3)
2) Packaging method	(10) - (15)	(10) - (15)	(2) - (4)
3) Cooling	(4) - (8)	(4) - (8)	(2) - (4)
Total % change	3 - 29	(2) - 23	(1) - 13
Average total % change	16	9	6
Corrected specific energy requirement (MJ/hl)	172	176 <sup>d</sup>	
Specific energy req. as a % of that for SA	78	80	

- <sup>a</sup> Took the space heating load to be half of that for winter. The USA's was halved since space heating is not necessary in some regions.
- <sup>b</sup> Estimated from the size distribution of each country's breweries and Figure 4.
- <sup>c</sup> Calculated assuming all packaging operations overseas require 22% more steam than SA and packaging steam requirements are 20% - 40% of total steam requirements.
- <sup>d</sup> Assumed that administration, that was excluded from the original figure, would be about an extra 10%.

### 3.4 LITERATURE SURVEY OF ENERGY MANAGEMENT IN BREWERIES

Sir Oliver Lyle published a classic book 'The Efficient Use of Steam', in 1947, in which he examined the brewery in great detail. He concluded that 'the brewer is content to keep his thermal socks in folds about his ankles'. It seems that this warning has been noted lately, since internationally there have been numerous publications on energy savings in the brewery. Generally there is no single area in which a large proportion of

energy can be saved, but potential exists to save small amounts of energy in many areas, perhaps because of the diversity of the brewing process. Energy management is thus of utmost importance. The rest of this section outlines important aspects of energy management on a brewery that were found in the literature.

### 3.4.1 Anticipated potential savings

It has been suggested<sup>(38)</sup> that large overseas breweries can achieve a specific fuel requirement of 125 MJ/(hl saleable beer) and a specific electricity requirement of 36 MJ/(hl saleable beer), which is 27% less than the average for SA.

A project that was launched in 1987 to calculate what the minimum energy requirements of a new brewery would be<sup>(34)</sup>. The project was carried out by Linnhoff March which is the leading consultancy in pinch technology. The project was based on UK conditions ie 1.5 million hl/year lager and 1 million hl/year ale; brewhouse operation is 24 hours/day and 5 days/week, with packaging working 2 shifts/day and 4 days/week. It was calculated that the minimum fuel requirement is about 88 MJ/(hl saleable beer), taking into account losses, realistic efficiencies, space heating etc. About 29 MJ/(hl saleable beer) electrical requirement should be targeted for, and thus the total energy target for a new brewery is 117 MJ/(hl saleable beer), which is 53% of the average for existing breweries in SA. This emphasises the benefits of using pinch technology for grassroots design of breweries, using the latest technology.

The CSIR<sup>(41)</sup> estimated in 1986, for an existing brewery, a potential energy savings with minimum technology of 10.9%, and with significant technology 14%. These potential savings are expected to vary substantially from brewery to brewery.

### 3.4.2 Energy management committee

Much emphasis has been placed on the importance of a commitment and the formation of an energy committee. It has been proposed<sup>(42)</sup> that the energy committee should be comprised of the chief engineer, electrical manager, brewmaster, bottlehouse manager, warehouse manager, office manager and plant administrator. No energy management committee exists for breweries in SA.

### 3.4.3 Scheduling

To satisfy the market there are significant variations in the brewing pattern from week to week. It has been suggested<sup>(43)</sup> that by implementing a 'Standard Brew Week', energy can be saved by less fluctuation and lower peak demand on the steam and refrigeration systems. However because the shelf life of beer is limited and beer demand inevitably fluctuates through the year, some variation in the brewing pattern will be unavoidable.

### 3.4.4 Steam

Heating, which accounts for about 80% of energy requirements, is achieved with steam. Most of the energy management areas covered in Appendix C were identified for breweries.

Because the brewery has batch operations, steam demand fluctuates substantially. It has been suggested<sup>(42)</sup> that there should be a communication system between the various steam users so that spikes in demand are minimized. Spiking exerts strain on equipment and disrupts boiler air-fuel ratios. Opening of large steam valves too quickly can also cause spiking, and consequently it would be preferable to have large steam valves open over a 5-10 minute interval. The use of a steam accumulator would act as a buffer to demand spikes.

More modern control of the air/fuel ratio in boilers, by measuring the oxygen, was calculated<sup>(44)</sup> to have a pay-back time of less than two months on one brewery and a rate of return of 47% on another. With improved instrumentation and control must come increased operator training in order to sustain the savings<sup>(45)</sup>.

It has been suggested<sup>(38)(46)</sup> that by injecting condensate into the brewhouse steam which is superheated the life of vessels is increased due to operation at saturated temperature, and in addition heating efficiency is improved.

On one brewery<sup>(47)</sup> flash steam was recovered by injecting cold boiler feed water through spray nozzles into a flash steam vent pipe when temperature sensors sense steam. The system had a 1.5 year payback time.

### 3.4.5 High temperature hot water (HTHW)

Some breweries use HTHW instead of steam for process heating. HTHW is generated either directly in a boiler or by steam which is generated in a boiler, and then stored in an accumulator. The HTHW is then pumped from the accumulator to all heating loads, in a closed piping system, before returning to the accumulator. To avoid evaporation of the circulating water the whole system is pressurized well above saturation pressure. Capital costs for a HTHW system are said to be similar to that of a steam system<sup>(48)</sup>.

The advantages of HTHW over steam are claimed to be<sup>(48)</sup>:

- There are no water losses due to flash steam or condensate loss, and consequently less make up water and make up water treatment is necessary.
- All problems with condensate return are avoided.
- De-aeration is not required.
- Reduced operating and maintenance costs.
- More accurate control of the heating surface is possible.
- Minimal corrosion.

The disadvantages of HTHW as compared to steam are claimed to be<sup>(48)</sup>:

- Higher electrical power requirements for the circulating pumps.
- Slower response to heating demand fluctuations.
- Larger heat transfer surfaces required due to lower heat transfer coefficients.
- Maintenance work is difficult.
- Less user acquaintance with HTHW.

HTHW systems are only a consideration for new breweries, and are considered beyond the scope of this study.

### 3.4.6 Refrigeration

Refrigeration normally accounts for 25-45% of the total electricity use (including compressors, condensers, and pumps). Most areas of energy management covered in Appendix C were identified for breweries.

On one brewery<sup>(47)</sup> pumping loads were found to be a sizable 40% of the heat load to be removed from fermenting vessels. It was suggested that the pumping load can be substantially reduced by pumping at low velocities ie around 5 ft/s, and minimizing pressure drops through pipework and fittings.

An absorption refrigeration system, to turn waste heat from wort boiling into chilled water to replace cooling water, is outlined<sup>(44)(49)(50)(51)</sup>. Only one of the articles<sup>(44)</sup> examines the economic feasibility in detail, and reports such a scheme not to be economically feasible, and thus absorption refrigeration was not considered.

A large quantity of energy is lost in the water vapours of cooling towers. It was calculated<sup>(44)</sup> for a brewery that this loss could be reduced with a rate of return of 104%, by installing a double heat exchanger before the condensers to heat water. The problem in SA is to find a use for such low grade energy.

A computer supported control system is described<sup>(52)</sup>, which varies condensing temperature according to ambient temperature, relative humidity, compressor performance curves, and characteristic curves of the condenser system. Cost savings of 5-10% minimum are claimed for the above control system. Another article<sup>(47)</sup> claims that such a system should reduce power requirements by 29%.

The CO<sub>2</sub> plant requires significantly lower refrigerant temperatures than for the rest of the plant. It has thus been suggested<sup>(53)</sup> that it is more economical to have a separate refrigeration plant for CO<sub>2</sub> and operate the main refrigeration plant at a higher temperature. This is practiced at all breweries in SA.

Generally it was found that on most breweries there is scope for better scheduling of refrigeration loads to reduce the fluctuations in demand, and re-scheduling of loads to coincide with cheaper electricity charges. It is claimed<sup>(54)</sup> on one brewery peak cooling was reduced by 22% by changing some loads to night time operation.

### 3.4.7 Air

About 5-10% of total plant electricity is used for air compression. Spent grains removal is a large user of compressed air. It is claimed<sup>(38)</sup> that pneumatic conveying requires about 10 times more electricity than mechanical transport, and thus mechanical transport could be considered for grain transport.

Individual distant users of compressed air can result in significant distribution losses. It has been suggested<sup>(38)</sup> that distant users should have a decentralised local source of compressed air.

### 3.4.8 CO<sub>2</sub>

About 5% to 10% of total plant electricity is used in the CO<sub>2</sub> plant. Production of CO<sub>2</sub> in liquified form is energy intensive due to the high pressures that are required to liquify the CO<sub>2</sub>. It has been suggested<sup>(50)</sup> that it would be more efficient to rather reuse the CO<sub>2</sub> almost immediately at low pressure, employing large volume expanding envelopes. The scheme had a payback time of under two years.

A system in use on a brewery<sup>(47)</sup> linked CO<sub>2</sub>, which had to be vaporised from liquid at -18°C to vapour at 10°C, to refrigerant condensing.

### 3.4.9 Brewhouse

The brewhouse accounts for up to half of the total steam usage on a brewery and about 10% of the total electricity usage, and is thus an area where substantial energy savings can potentially be realised.

#### Mashing

Increasing the temperature in the mash tun by make-up with hot water is a possible area for energy reduction in mashing<sup>(55)</sup>. However this scheme may interfere with stringent brewing parameters.

#### Spent grains

The recovery of energy from spent grains either by combustion or biogas generation has been considered<sup>(55)</sup>. For combustion of spent grains de-watering is initially required to reduce the water content to below 55%, and emissions of oxides of nitrogen and dust particles could be a problem. Biogas generation appears to be the more favourable means of energy recovery, but only laboratory tests have been carried out to date.

#### Continuous Boiling

Continuous wort boiling, which includes pre-heating, four-stage evaporation, and vapour condensation, has been tried. It is maintained<sup>(50)(56)</sup> that this system only uses one third of the energy required for conventional wort boiling without vapour condensation, and

it was calculated<sup>(56)</sup> that for a 900 000 hl/year West German brewery this scheme would have a payback time of four to five years. This scheme could result in significant changes in beer taste and quality, and is thus considered beyond the scope of this report.

#### External vs internal boiling

Wort kettles can either be heated internally with heating coils in a tank, or externally by circulating the wort through a heat exchanger. It is asserted<sup>(57)</sup> that a conventional kettle with internal boiling leaves little scope for energy savings. In an optimisation test, use of an external heater together with an extension in boiling time and reduction in total evaporation from 13% to 6% resulted in a 40% decrease in wort boiling energy requirements<sup>(57)</sup>. Another article<sup>(49)</sup> claims that external boiling should reduce energy requirements by 20%.

#### Wort boiling pressure

High pressure boiling for only a few minutes at about 140°C has been used for wort boiling, with evaporation rates of about 6-9%<sup>(58)</sup>, thus reducing total brewery energy requirements by about 15%. Maintenance and cleaning of such systems is a problem.

Low pressure wort boiling systems (105 to 110°C) usually only require evaporation rates of 3% - 9%<sup>(58)</sup> thus reducing total brewery energy requirements by 10 - 25%. Some claim<sup>(58)(59)</sup> however that this system interferes with the beer flavour.

#### Evaporation rate and boiling time

There is a relationship between evaporation rate, boiling time, and beer quality. It is claimed by the UK Brewing Research Foundation<sup>(59)</sup> that an evaporation rate of 2% produces no difference in quality compared to a rate of 10%, although most brewers would disagree. It seems that optimum evaporation rate and boiling time differs for different types of beer and wort kettle configurations. Consequently it would be advisable for each brewery to perform investigations into optimum boiling conditions, taking into account beer quality and energy use.

#### Control

A microprocessor control system is described<sup>(60)(61)</sup> which controls the steam flow rate to achieve whatever evaporation rate is required, enabling the brewer to reach the optimum evaporation in terms of beer quality and steam usage, which results in lower total evaporation. The project gave an energy saving of 15%, with a payback time of under one year.

### Condensing wort vapours

Vapour from wort boiling is conventionally lost to the atmosphere, and thus represents lost energy. Two methods have recently been used in some breweries to recover this energy, at the same time eliminating brewhouse odours. They are condensing and cooling the wort vapours by the heating of water, or vapour recompression. The feasibility of both these methods will depend on the total evaporation, and the frequency of brews.

Problems with condensing of wort vapours are:

- It is capital intensive.
- Wort kettles normally operate intermittently, and thus it is likely that it would only be feasible for continuous boiling.
- The condensed vapours require treatment as effluent.
- If the heat is recovered as hot water, it must be required somewhere in the brewery. In Germany it is common to use the hot water for space heating<sup>(58)</sup>.

A reduced steam consumption of 69% over a conventional system is claimed<sup>(59)</sup> for a high pressure continuously boiling system where the wort vapour is condensed and the energy used in wort boiling. A system on one brewery consists of a central plate heat exchanger linked to four wort kettles<sup>(56)(62)</sup>. The wort vapours are condensed and half the keg washing water requirement is heated from 10 to 70°C. The scheme had a payback time of four years. Advantages claimed<sup>(63)</sup> for the system are energy savings in wort boiling of up to 85%, easy integration into individual brewhouse layout, and low maintenance.

A patented system<sup>(64)</sup> uses vapour condensing to generate hot water which is used to pre-heat the contents of the wort kettle in the next batch. Storage of hot water is thus required.

### Vapour recompression

Vapour recompression of wort vapour increases the temperature of the vapour, and the hot vapour can then be used in an external heater to heat the contents of the wort kettle. Steam requirements are thus reduced, but electricity is required for compression. To-date only mechanical vapour recompression has been used in breweries<sup>(65)</sup>.

Thirty mechanical vapour recompression units had been installed in Germany, France, Austria, and Switzerland by the end of 1987<sup>(65)</sup>, but no two installations were alike.

Rough cost estimates<sup>(65)</sup> for Germany indicate that vapour recompression only becomes economically viable for 8 to 12 brews per day.

A mechanical vapour recompression system has been tested<sup>(66)</sup> and overall energy requirements were 31% of those for a conventional system. The system uses a screw compressor, and is fully applicable to a conventional wort kettle which is not pressure proofed. The payback time was calculated to be 4 years if used with one wort kettle and about half if used with two wort kettles.

A vapour compressor and external wort heater were installed in a brewhouse with a payback time of 3.8 years<sup>(67)</sup>. Vapour condensate is cooled to 20°C and hot water at 95°C is produced. Heat recovery is claimed to be 50%. Another brewery<sup>(68)</sup> has shown a 50% saving of fossil fuel requirements in the brewhouse, but power consumption increased by 20%.

One brewery<sup>(69)</sup> has installed a vapour recompression unit with an internal wort kettle heater, because of the lower capital cost of an internal heater. A primary energy saving in the brewhouse of 40% has been realised.

Despite the high energy savings possible payback times on such schemes are long and for SA, where fuel is cheaper than in Europe, payback times will be even longer. Consequently vapour recompression is not considered feasible for SA.

### Hot liquor

Hot liquor automatic control and management is usually less fully developed than in production processes thus often requiring more attention. It has been suggested<sup>(31)</sup> that it is not necessary to keep tanks topped up with cold water, as is often practised in breweries. A significant steam saving was observed<sup>(46)(60)</sup> when the chilled liquor:wort ratio for the wort cooler was optimized such that minimum steam heating of hot liquor was required, and the hot liquor storage capacity was increased, so that less would be lost to drain.

### **3.4.10 Wort cooling**

Wort cooling is done in one of two ways. Either the wort is first cooled with water at ambient temperature, and then cooled to its final temperature with refrigerant, or water is first chilled (referred to as chilled liquor) and then used to cool the wort down to its final temperature. Advantages of using chilled liquor are<sup>(49)</sup>; simple construction with

only one heat transfer medium, simple control, and possibility of reducing energy peaks. On the other hand the direct cooling of wort with refrigerant is more efficient.

Several articles<sup>(37)(38)(46)</sup> assert that the chilling of water or refrigerant cooling of wort should be extended over the greatest possible span of time, to obtain a more steady refrigeration load.

### 3.4.11 Packaging

Packaging normally accounts for over one third of total steam usage and over 12% of total electricity usage, and consequently packaging deserves close examination. The largest users of steam and electricity in packaging are the washers and pasteurizers.

It is claimed<sup>(70)</sup> that in general, for can pasteurisers only about 27% of the usable energy finds its way into the beer. The rest is lost in space heating, plant heating, can rinsing, starting and stopping losses, standing losses, and radiation losses. Pasteurisation is thus an area of potential energy saving. It is advised<sup>(42)</sup> that pasteurizers and washers should be checked to see if they are not being heated up for too long, and whether everything is turned off during shutdown.

An existing tunnel pasteurizer<sup>(71)</sup> was modified by re-zoning the machine, providing thermal insulation between tanks, and re-circulating water. Steam consumption was reduced by half and water consumption by 84%. Insulation of pasteurisers and washers was considered<sup>(72)</sup>, and feasibility of insulation was found to depend very much on the cost of the insulation. For the cheaper insulation considered payback time was 3 years, and for the more expensive insulation payback time was 10 years. Maintenance of the insulation was not considered, but such a cost could be significant considering the harsh environment of high temperatures and caustic solutions.

Although energy requirements are far less for flash pasteurisers than for tunnel pasteurisers, more complex fillers are required, more rigorous microbiological control is required, changes in flavour may occur, and there exists a greater risk of contamination. It is claimed<sup>(73)</sup> that it is only feasible to consider flash pasteurisation for new installations. Pasteurisation procedures are considered beyond the scope of this study because of beer quality considerations.

A pilot solar water heater system for pasteurization was installed on the packaging hall roof of a brewery in the USA<sup>(74)</sup>. All collected energy was stored in a thermal capacitor,

providing hot water at temperatures between 72°C and 86°C continuously. An economic evaluation of solar water heating on a brewery was carried out in 1980<sup>(74)</sup> and showed it to be feasible only when a 50% tax credit was assumed. For SA where energy costs are lower in comparison, such a system is not expected to be economically feasible.

### **3.4.12 Cleaning in place**

It has been pointed out<sup>(70)</sup> that during the cleaning break amounts of rinse used, temperature, and times selected are often left more to individual judgement than during production, and thus staff awareness at these times is necessary for effective energy saving.

It has been suggested<sup>(70)</sup> that for systems where cleaning is done infrequently, it would be better to keep the cleaning solution tanks continuously hot, use a regenerative heat exchanger which extracts heat from the returning final rinse to pre-heat the in-going fresh rinse before being heated with steam. Considering that cleaning in place is only a small user of steam this is not considered. Also cleaning solutions are usually maintained in a continual state of readiness, and thus one should apply a thick insulation to acid and caustic tanks.

### **3.4.13 Pumping**

Pumping of liquids accounts for about 34% of the power consumption in a brewery<sup>(75)</sup>. Proper specification and maintenance of pumps thus deserves attention. If the average pump efficiency can be increased from 60% to 70% this should reduce the total electrical consumption by 4 to 5%. For existing plants pump efficiencies can usually only be improved by replacing pumps, which will often be economically unfeasible.

### **3.4.14 Lighting**

Lighting in a brewery normally accounts for about 10% of the total electrical load<sup>(76)</sup>, and conservation measures can significantly reduce electricity consumption<sup>(76)</sup>.

### **3.4.15 Heat pumps**

Heat pumps have been used successfully in malting, but the only other feasible application is for space heating<sup>(65)</sup>. A heat pump (requiring a water treatment plant)

which has been designed for bottle washers, is claimed<sup>(77)</sup> to reduce heating requirements by 88% and water consumption by 80%, and have a payback time of three years. For SA where energy costs are lower this system is not expected to be economically feasible.

#### 3.4.16 Combined heat and power (CHP)

CHP was shown by the 'Brewery 2000' project<sup>(34)</sup> to have a payback period of 2.5-3 years, but they considered the export of electricity and mentioned that savings were sensitive to the electricity price. A rate of return of 52% was calculated<sup>(44)</sup> for CHP on a US brewery. Economic calculations<sup>(65)</sup> show that for Germany the use of internal combustion engines is attractive, with a payback time of about three years. Once again with the lower energy tariffs in SA CHP is at present not expected to be feasible.

#### 3.4.17 Savings identified by pinch technology

Over 20 breweries have benefited from the application of this technology<sup>(34)</sup>. An energy study using pinch technology was performed on a UK brewery with an already low specific energy requirement of 135 MJ/hlsaleable beer<sup>(78)</sup>. Arising out of this work three investment strategies were identified<sup>(79)</sup>:

- Strategy 1: A package of short cheap payback schemes including improved insulation of steam mains, improved condensate return, recovery of flash steam, and improvements to the refrigeration system. This would have saved 10% of the energy bill on a payback time of eight months.
- Strategy 2: As Strategy 1, but including a boiler decentralisation scheme. This would have saved 19% of the energy bill with a payback time of 13 months.
- Strategy 3: As Strategy 1, but including a combined heat and power scheme based on a spark-ignition engine. This would have saved 24% of the energy bill with a payback time of 2-2.5 years.

## CHAPTER 4

### ENERGY USAGE ON OHLSSON'S BREWERY

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Gathering of information was the first stage in the study of Ohlsson's Brewery. This involved historical records, equipment specifications, taking instrumentation readings, and where monitoring was insufficient, performing calculations. Areas of insufficient monitoring were thus identified. The information was then condensed into Sankey diagrams, time-energy diagrams, and graphs, to provide a general picture of energy use on the brewery, and to identify key areas of energy use.

#### 4.1 PRIMARY ENERGY REQUIREMENTS

Ohlsson's Brewery runs continuously 24 hours/day throughout the year. The majority of measurements and data were collected between April and September 1991, and all calculations are based on operating conditions during this period. Since then some operating conditions have changed, and these are discussed later on. Primary energy sources are electricity, coal, and oil. Appendix D contains tabulated information regarding primary energy usage and monthly beer production, and Table 7 shows the average monthly energy usage and cost (September 1991 prices). Seventy nine percent of the primary energy used is in the form of coal, but it accounts for 62% of the energy cost (excluding the maximum demand charge). Fuel oil only accounts for 4% of the energy used.

*Table 7. Primary energy usage.*

	USAGE/MONTH	GJ/MONTH	RAND/GJ	RAND/MONTH
Electricity - energy	1 750 000 kwh	6 300	17,33	109 200
- demand	3854 kVA			67 300
Coal	1 053 ton	29 484	6,75	199 000
Fuel oil	32 876 litres	1 407	9,49	13 400

The ratio of the quantity of beer packaged to that brewed varies substantially from month to month because of the three week delay between brewing and packaging. However energy usage is closely linked to both quantities, and thus specific energy requirements using were calculated using the average of these quantities, called beer produced. Figure 5 shows the variation in the quantity of beer brewed, packaged and produced.

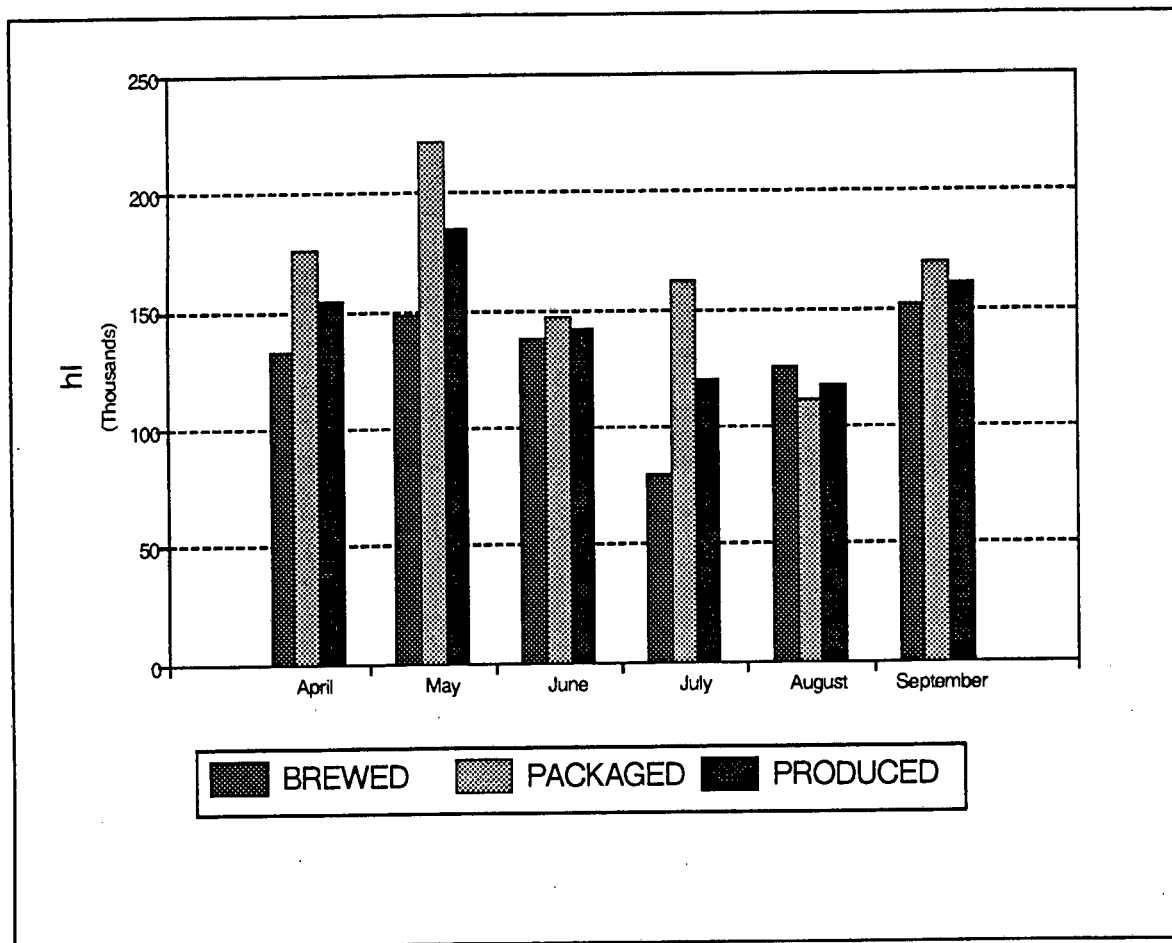


Figure 5. Monthly quantities of beer brewed, packaged, and produced.

Total fuel usage is calculated by adding the fuel oil and coal energy usages, and then calculating the coal equivalent quantity. Figure 6 shows the monthly specific fuel requirements, the average being 7,6 kg coal equivalent/hl produced. Figure 7 helps clarify the variation in specific fuel requirements ie the higher the monthly beer production, the lower the specific coal equivalent requirements.

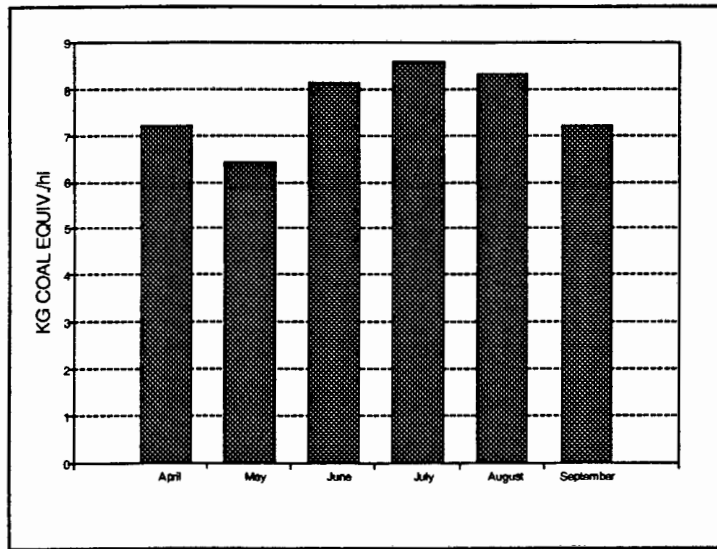


Figure 6. Monthly specific coal equivalent requirements.

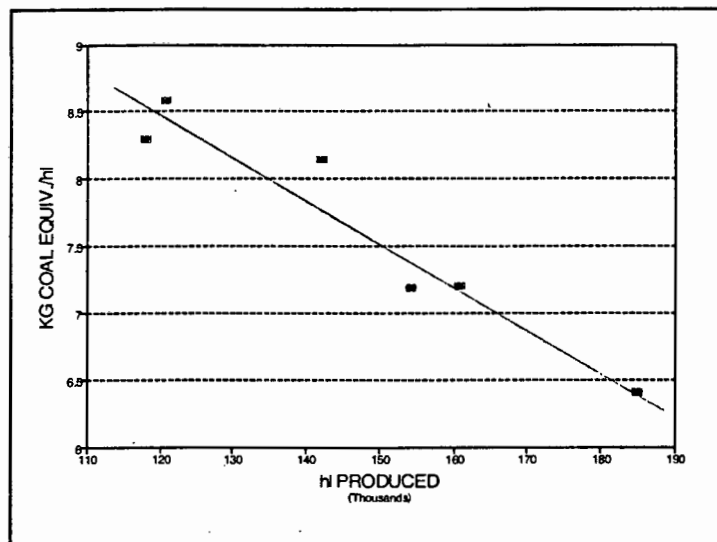


Figure 7. Specific coal equivalent requirements for various monthly quantities of beer produced.

Figure 8 shows the monthly specific electricity requirements, the average being 12,2 kWh/hl produced. Figure 9 shows how specific electricity requirements decrease with increasing beer production; the same trend as for fuel is evident.

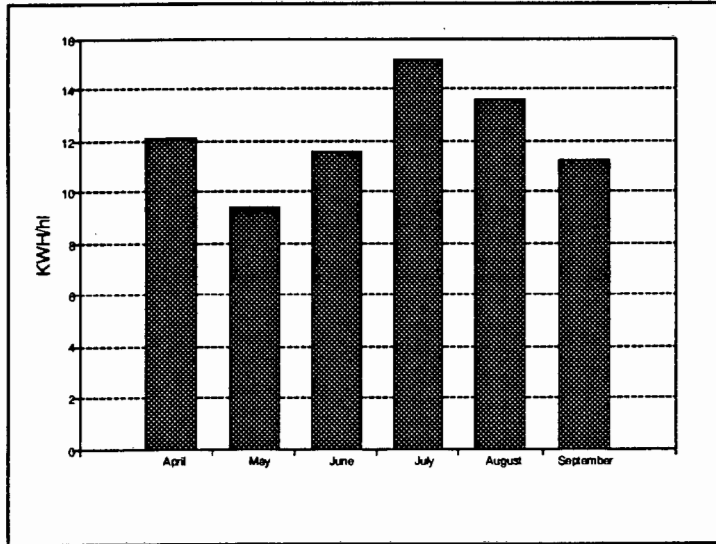


Figure 8. Monthly specific electricity requirements.

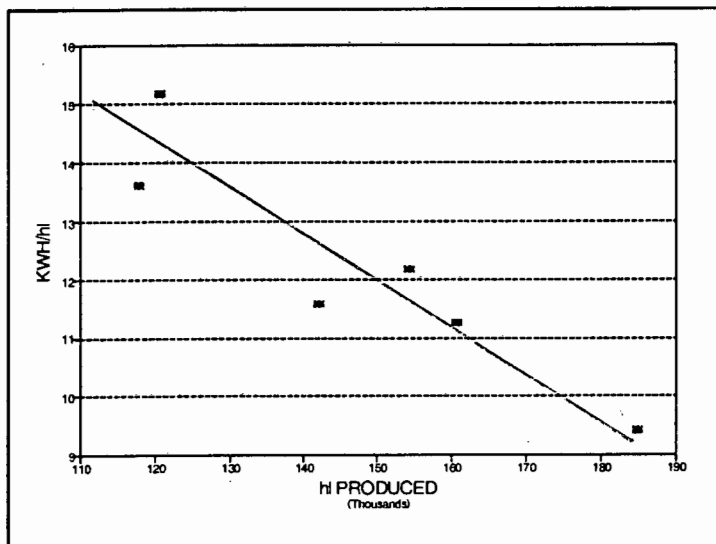


Figure 9. Specific electricity requirements for various monthly quantities of beer produced.

## 4.2 STEAM REQUIREMENTS

Figure 10 is a simplified diagram of the steam/condensate system. There are three coal-fired boilers (which use Grade A pea coal) and one oil-fired boiler, and steam is generated at 900 kPag, and generally used at about 450 kPag. Condensate is only collected from the brewhouses, and is temporarily stored in condensate tanks before being pumped to the hotwell. The hotwell is maintained at about 75 °C using direct steam, and the level is controlled with make-up water. No operational steam measuring equipment was available.

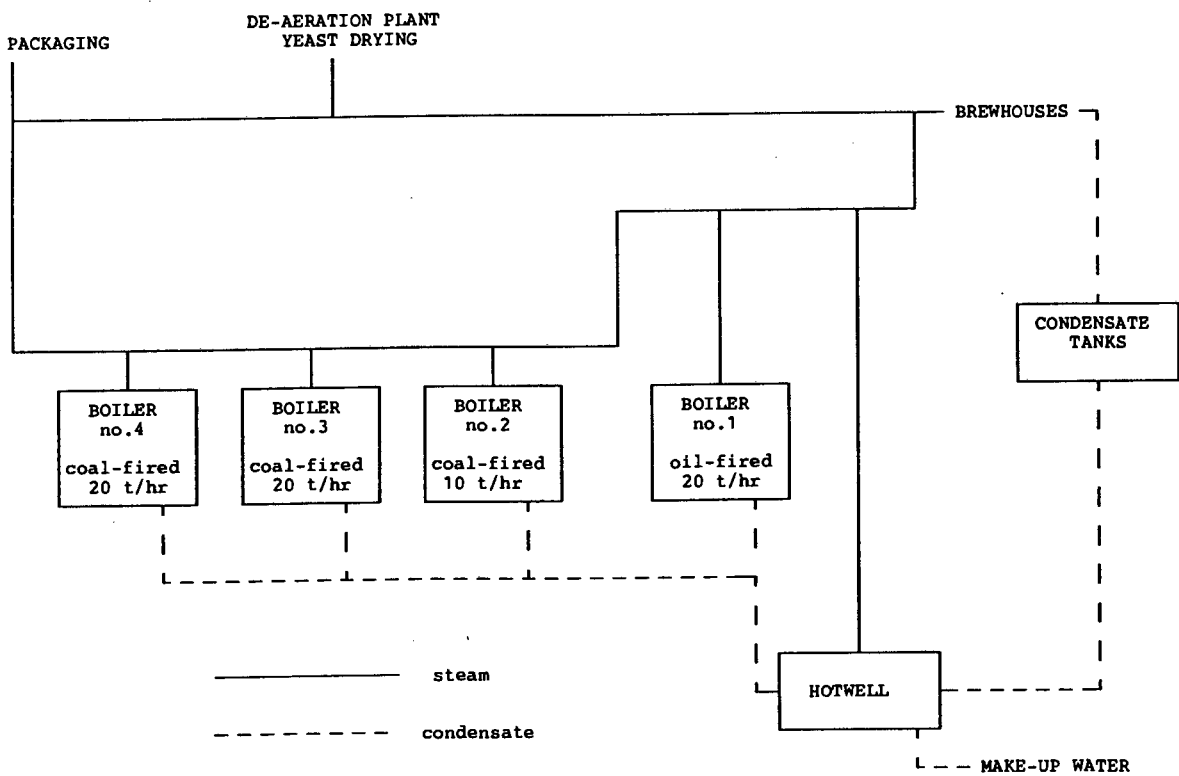


Figure 10. Diagram of the steam condensate system.

### 4.2.1 Average steam requirement

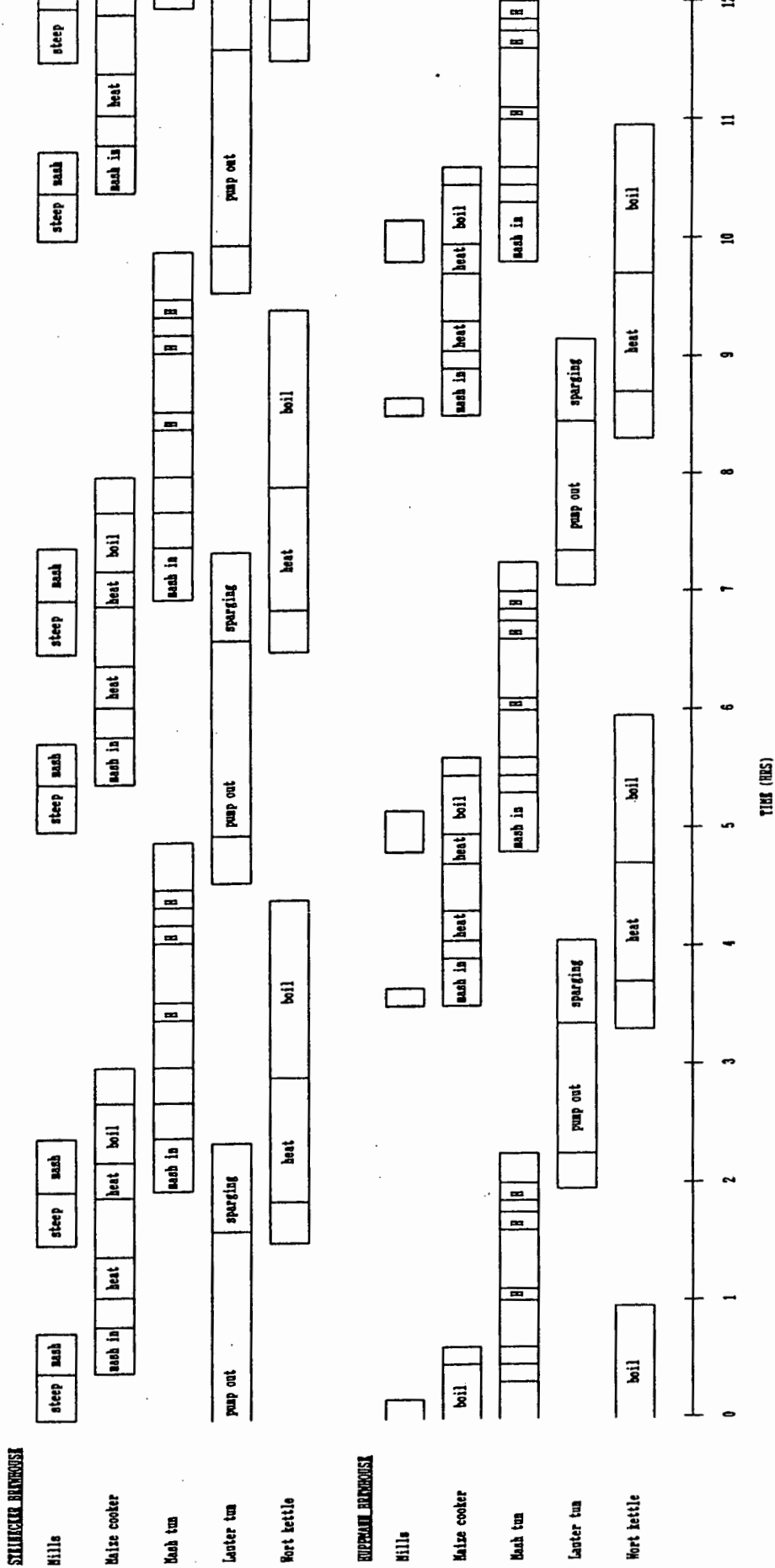
Table 8 gives a summary of the various average steam requirements. An overall distribution loss of 10% was assumed.

*Table 8. Average steam requirements.*

	AVERAGE STEAM DEMAND (kg/hr)	PERCENT
Brewhouses	4 800	43,2
Packaging	3 474	31,3
De-aeration plant	547	4,9
Hotwell	427	3,9
Cleaning solution tanks	259	2,3
Yeast drying	193	1,7
Hot liquor system	164	1,5
CO2 plant	100	0,9
Flash pasteuriser	33	0,3
Distribution loss	1 111	10,0
<b>Total</b>	<b>11 108</b>	<b>100</b>

### 4.2.2 Brewhouse steam requirements

There are two brewhouses, the Steinecker and Huppmann brewhouses, which operate such that wort boiling, which is energy intensive, is staggered. The Huppmann brewhouse has a slightly larger throughput, but the total evaporation during wort boiling is slightly less. Steam is used between pressures of 180 and 480 kPag. Figure 11 shows how the brewhouse operations are co-ordinated. The cycle repeats itself every 5 hours. The brewhouses are thus capable of 9,6 brews/day, but have averaged 6,76 brews/day. Figure 12 is a time-energy diagram for the two brewhouses operating on a 5 hour cycle (calculations are shown in Appendix E). Instantaneous steam demand varies substantially, between 0 and 16 400 kg/hr, with an average demand of 6520 kg/hr (9,6 brews/day). It is unlikely that there is a linear relationship between brews/day and average steam requirements, since vessels will cool down in periods of shutdown. In reality it is expected that for 6,76 brews/day the average steam requirement will be about 5% higher. Average steam requirement was thus estimated as 4800 kg/hr.



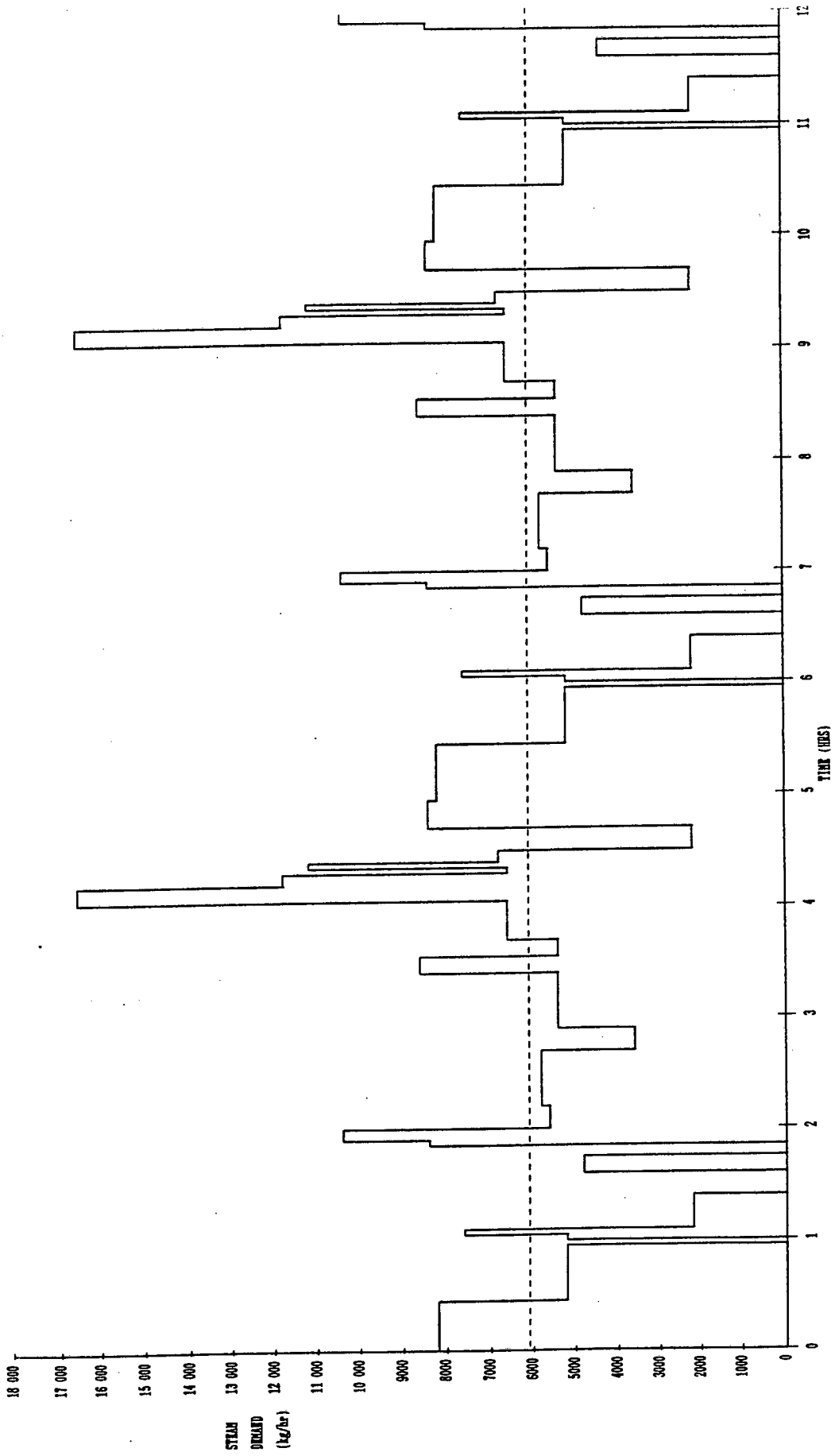


Figure 12. Time-energy diagram for the two brewhouses.

### 4.2.3 Packaging steam requirements

The next most important steam user is the packaging hall. Steam users are the bottle washers and the pasteurizers, and steam requirements were obtained from manufacturers' specifications. All washers and line 1 and 2 pasteurizers are indirectly heated by steam through coils. Pasteurizers on lines 3 and 4 use live steam for heating.

Each line has a certain period of planned shutdown (Appendix E), but due to equipment failures and fluctuation in production rate demand, the lines have many unplanned shutdowns as well. The duration of these periods of stoppage was calculated using machine efficiency, defined as the ratio of rated production for the time the machines were running, to actual production. In addition line 2 was being commissioned and ran intermittently. Steam usage on each machine is constant during normal production, but during unplanned stoppages steam usage declines. Steam demand is high during the heating up period, and pasteurisers also have a 6 to 10 minute starting up period during which time the steam demand is even higher. Appendix E contains detailed tabulations of steam requirements for each machine. Specific steam requirements are shown in Table 9.

*Table 9. Specific steam requirements for the packaging lines.*

	hl/MONTH	kg/hl	MACHINE EFF.
Line 1	104 100	11,3	65%
Line 2	14 100	23,7	42%
Line 3	17 600	14,7	71%
Line 4	26 500	27,9	61%

Specific steam requirement for line 1 is low because of its high production rate, and that for line 2 is high because of the low machine efficiencies and the high number of start ups and shutdowns. Line 3 has no bottle washer but the steam requirement for the pasteuriser is high, as is the case for line 4.

Figure 13 shows how steam demand would have expected to vary over an average week. Line 2 is assumed to be in operation from 08h00 to 16h00 each week day, as was usually the case during September. Heating up requirements are not shown.

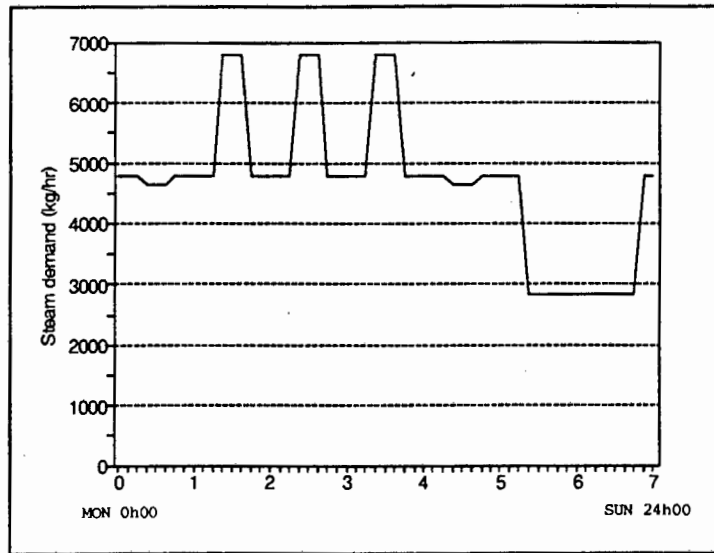


Figure 13. Typical packaging steam requirements over a week.

#### 4.2.4 Peak steam demand

The peak steam requirement is calculated assuming a yearly worst case and a weekly worst case. The assumptions are based on observation of operating procedures.

##### Yearly worst case assumptions

- the brewhouses are operating on a 5 hour cycle.
- the brewhouse steam requirement is at the peak of the cycle.
- lines 3 and 4 in packaging are at 100% production.
- lines 1 and 2 heating up.
- all the other steam users are in operation.

##### Weekly worst case assumptions

- the brewhouses are operating on a 5 hour cycle.
- the brewhouse steam requirement is at the peak of the cycle.
- lines 2 and 3 in packaging are at operating at 100% production.
- line 1 is heating up.
- all the other steam users are in operation.

Table 10 gives steam requirements assuming the above scenario.

Table 10. Peak steam demand.

	YEARLY WORST PEAK STEAM DEMAND (kg/hr)	WEEKLY WORST PEAK STEAM DEMAND (kg/hr)
Brewhouses	16 400	16 400
Packaging		
Line 1	8 800	8 800
Line 2	10 500	3 389
Line 3	976	976
Line 4	2 560	0
De-aeration plant	831	831
Yeast drying	344	344
Flash pasteuriser	327	327
Hot liquor system	164	164
CIP plants	259	259
CO <sub>2</sub> plant	100	100
Hotwell	473	473
Distribution loss	4 585	3 563
Total	45 850	35 626

The peak steam requirement will determine the boiler capacity required.

The total boiler capacity is larger than rated capacity over short periods, due to the accumulator effect of the boilers. During periods of high steam demand the pressure in the boilers will decrease, and consequently a portion of the water in the boilers will flash. This is an additional 2,5 tons of steam if three large boilers are in use, which is an extra 10 tons/hr if used over 15 minutes.

## 4.3 BOILER EFFICIENCY

### 4.3.1 Different methods of boiler efficiency calculation

Boiler efficiency was calculated using three different methods (calculations are shown in Appendix F).

#### Measuring the amount of steam raised

Boiler efficiency was calculated by measuring the coal and oil consumption for two weeks, as well as amount of steam generated. No flowmeters were available for measuring the steam flowrate, but the feed-water flowrate to the boilers could be measured, and a 3% blowdown was subtracted. Average boiler efficiency was calculated to be 80% for the two week period. Unfortunately due to the necessity to sometimes bypass the boiler feed-water flowmeter, no measurements longer than the two week period could be made.

#### Summing all the average steam requirements over the plant

The calculated total average steam requirement was 11 108 kg/hr and the average coal equivalent usage 1 463 kg/hr, from which boiler efficiency is calculated to be 64%.

#### Calculation from boiler operating conditions

Boiler efficiency was calculated by summing all the losses during boiler operation (Appendix F):

Dry flue gas loss	12,6 - 31,5%
Unburnt carbon loss	3,1 - 4,4%
Moisture loss	4,3%
Incomplete combustion	2%
Radiation	2%
Blowdown	0,4%
Unaccountable loss	1%
 Total loss	 25 - 46%

Boiler efficiency is thus calculated to be between 54% and 75%.

### 4.3.2 Reasons for discrepancies in boiler efficiency calculations

The discrepancy between the measured and calculated boiler efficiency is attributed to the flowmeter being incorrect. The same conclusion was reached in a project report<sup>(80)</sup> on energy usage at Ohlsson's brewery in 1990. The efficiency calculated using the steam requirement method cannot be expected to be accurate because of the many assumptions that had to be made, but nevertheless the calculated boiler efficiency falls within the range of that calculated from boiler operation losses. It is thus concluded that boiler efficiencies vary between 54% and 75%. The main reason for the high fluctuation is that steam demand fluctuates excessively at times, thus not allowing boiler operation to reach equilibrium. For excessive fluctuations boiler efficiency can be expected to fall by 5% to 12%<sup>(81)</sup>. In addition the boilers are not soot blown, but are cleaned out manually about once every month, and control of the air/fuel ratio may not be optimum.

## 4.4 SUMMARY OF THE STEAM SYSTEM

Figure 14 is a Sankey diagram of coal, oil, and steam usage. Appendix G gives the assumptions in the calculations of the Sankey diagram. As can be seen significant areas of energy loss are boiler losses, brewhouse vapours, flash steam, condensate, packaging radiation, and distribution losses. All of these areas thus require further investigation into recovery of energy losses.

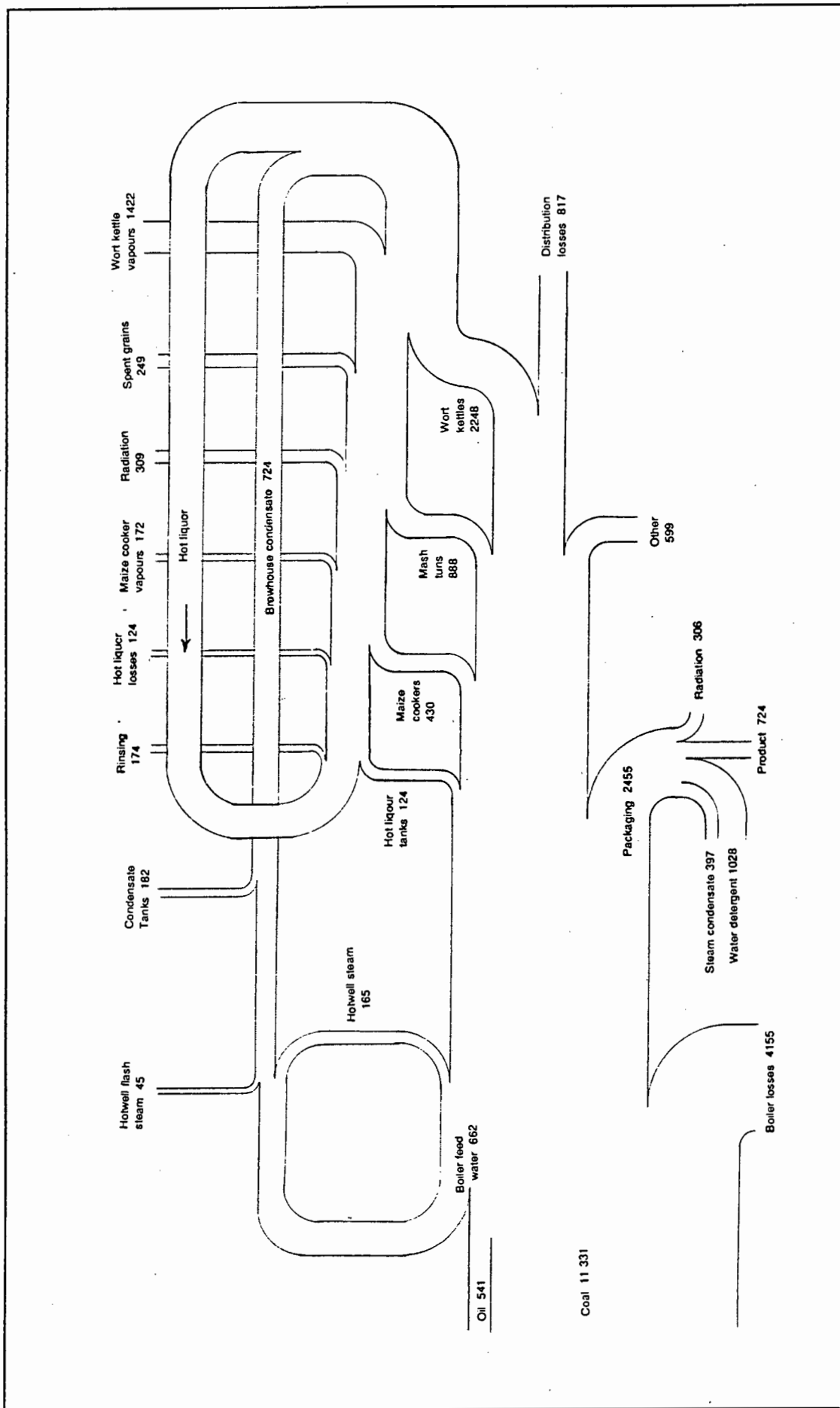


Figure 14. Sankey diagram for fuel and steam.

## 4.5 ELECTRICITY

### 4.5.1 Maximum demand

No maximum demand control is practised on the plant. Only the overall plant maximum demand is measured. Figure 15 shows how maximum demand varies from month to month. There is little correlation between monthly maximum demand and monthly electricity consumption. Figure 16a shows how demand varies over a day, Figure 16b over a week, and Figure 16c over a month. Daily peak demand usually occurs at about 15h00 when coolings loads are greatest, but daily peak demand also sometimes occurs any time between 6h00 and 15h00 when all four packaging lines may be operation. Busiest packaging times are between 6h00 and 17h00. Packaging times are planned from week to week, so periods of potential peak demand can be predicted only when the packaging schedule is known. Figure 17 shows the correlation between maximum demand and packaging demand.

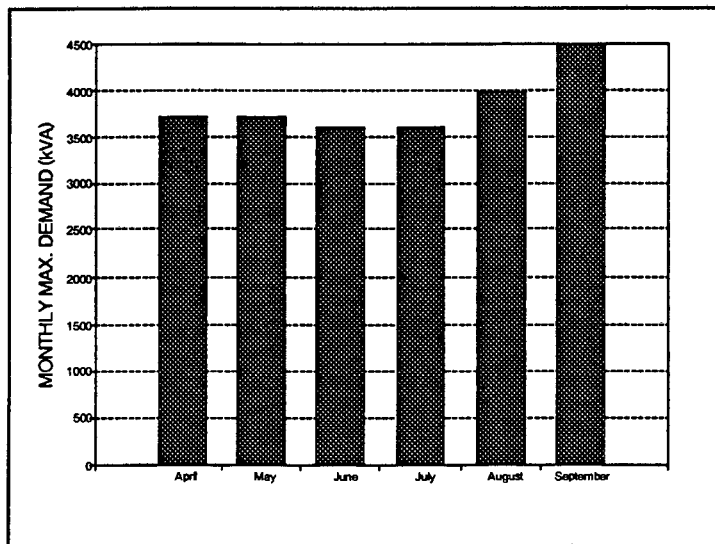
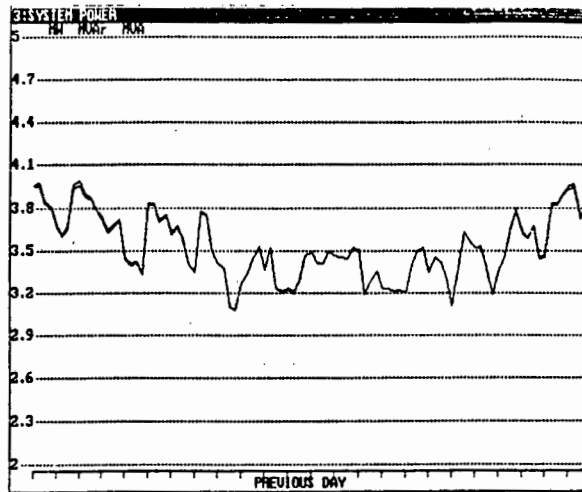
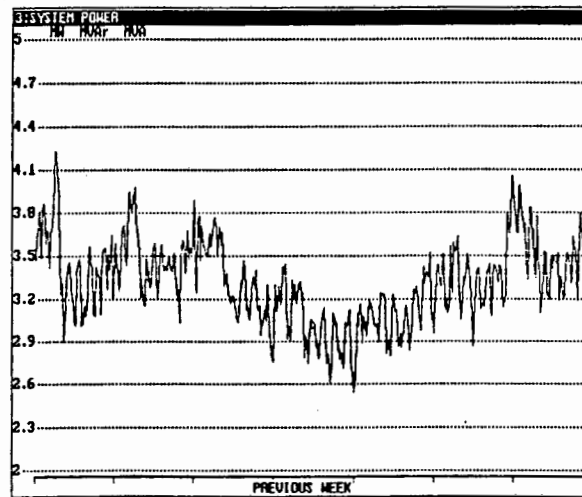


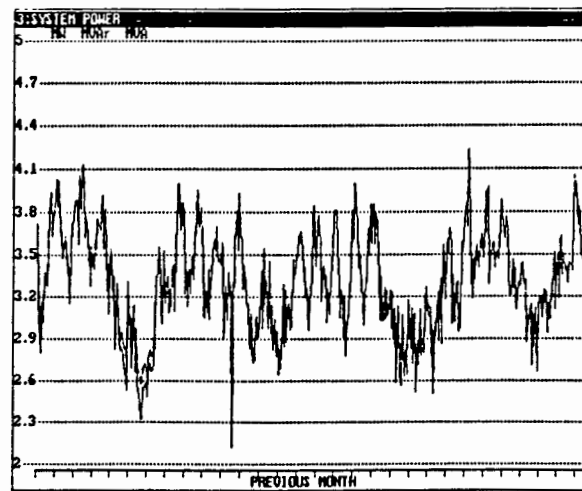
Figure 15. Monthly electrical maximum demand.



(a)



(b)



(c)

Figure 16. Typical maximum demand profiles over a a) day b) week c) month

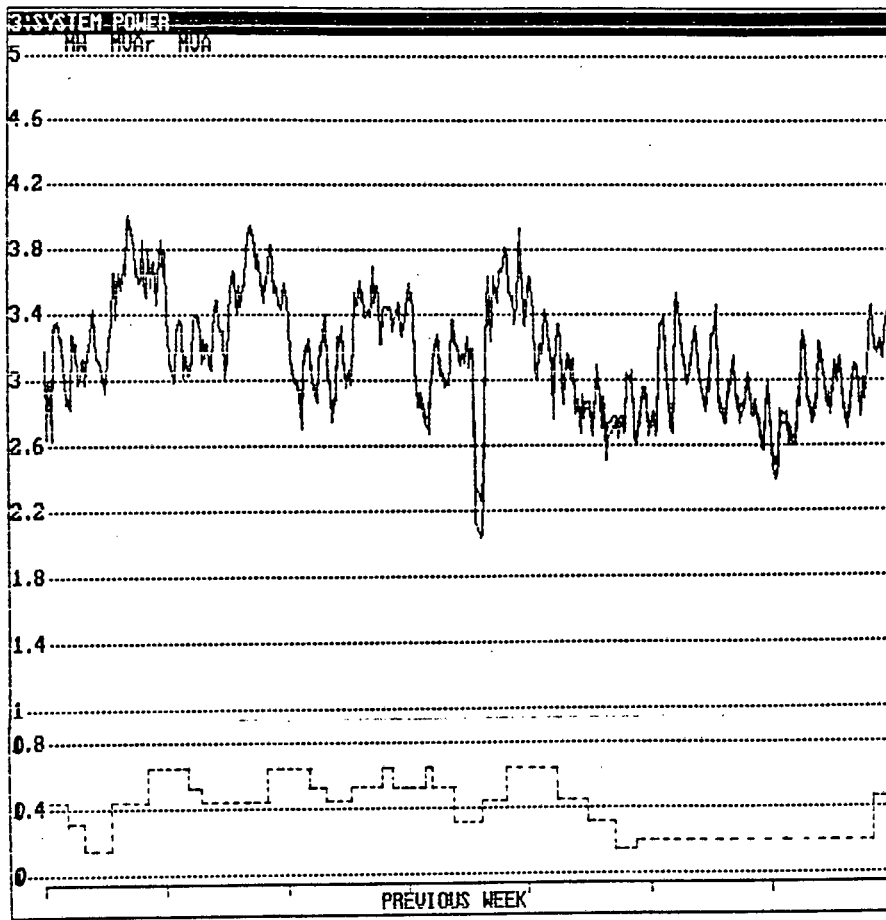


Figure 17. Correlation between maximum electrical demand and packaging demand.

#### 4.5.2 Power factor

Until October 1991 power factor correction was carried out at various decentralised points. Three centralised banks of capacitors have recently been installed and came into operation on 31/10/1991. No accurate measurement of power factor was available before installation of the capacitor banks, but localised measurements indicate the overall power factor was in the range of 0,8 - 0,95, whereas now it is better than 0,99.

### 4.5.3 Electricity energy demand

Table 11 summarises average electricity requirements (Appendix H).

*Table 11. Average electricity requirements.*

	kWH/MONTH	PERCENT
Refrigeration	591 000	33,8
Packaging	270 000	15,4
Air plant	133 000	7,6
CO2 plant	126 000	7,2
Brewing	114 000	6,5
Boiler operations	113 000	6,5
Water pumps	84 000	4,8
Filtration and offices	79 000	4,5
Warehouse	36 000	2,1
Admin. block	20 000	1,1
Workshop	8 000	0,5
Engine room lighting	6 000	0,3
Old rail store	6 000	0,3
<b>Total</b>	<b>1 586 000</b>	<b>90,6</b>
<b>Actual average</b>	<b>1 750 000</b>	<b>100,0</b>
<b>Unaccounted</b>	<b>164 000</b>	<b>9,4</b>

#### Refrigeration

The condensing temperature is 35 °C and the evaporating temperature is -8 °C giving a theoretical COP of 6,16.

Table 12 summarises all refrigeration loads (Appendix I has the calculations):

Table 12. Refrigeration loads.

	AMMONIA (kW)	GLYCOL (kW)	TOTAL (kW)
Wort cooling	410		410
Fermenting vessels		533	533
Chilling after fermentors		167	167
Storage vessels	20	20	40
Filtration	126		126
Bright beer storage		58	58
De-aeration plant		317	317
Flash pasteurisation		3	3
Yeast and yeast propagation		43	43
Hop store	19		19
Pumping losses	18	121	139
Piping losses	11	39	50
<b>Total</b>	<b>651</b>	<b>1078</b>	<b>1905</b>

The fermenting vessels have the largest cooling load, but this load is not continuous and varies substantially during the course of the 14 day fermentation period. Figure 18 shows how the refrigeration load varies for one batch (Appendix J gives calculation details).

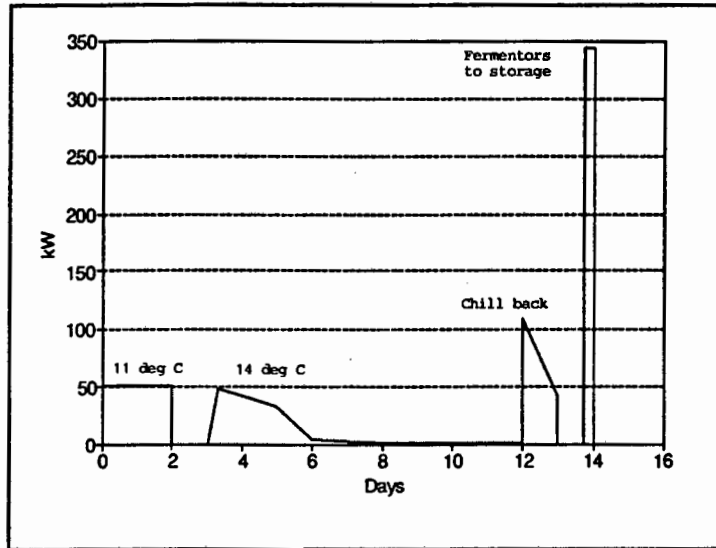


Figure 18. Fermentation load profile for one batch.

Average ammonia compressor specific electricity requirements were 2,85 kWh/hl produced giving an average compressor power requirement of 581 KW; so actual COP using the above cooling requirements, is 3,28. This gives an efficiency of 53%, which is normal, but this value is based on various assumptions and cannot be expected to be accurate.

Figure 19 is a Sankey diagram for the refrigeration plant. The evaporative condenser load includes all refrigeration loads, and most of the electrical energy used, most of which is converted to heat through friction.

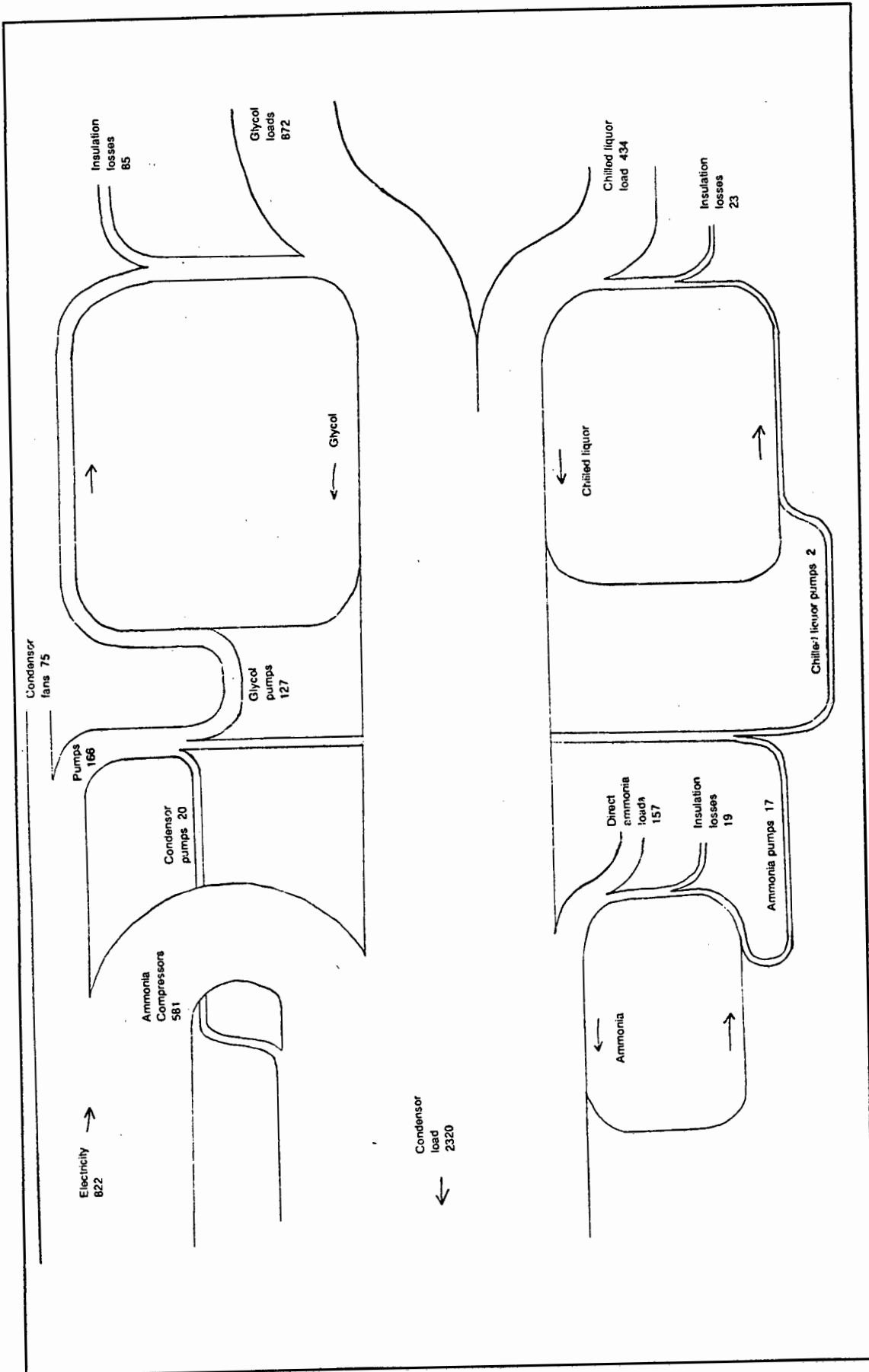


Figure 19. Sankey diagram for the refrigeration system.

Packaging

Electricity consumption is measured monthly on each line, except line 2 which started being commissioned in June. It was assumed that because of the low machine efficiency on line 2 (it was below 40% for three months), the specific electricity requirement was about 3 kWh/hl. Table 13 gives average specific electricity requirements for each packaging line.

Table 13. Specific electricity requirements by packaging lines.

	hl/MONTH	kWh/hl	MACHINE EFF.
Line 1	104 100	1.04	65%
Line 2	14 100	3.00	42%
Line 3	17 600	2.62	71%
Line 4	26 500	2.26	61%

The approximate breakdown in electricity usage in packaging is as follows:

Fillers	6%
Pasteurizers	24%
Washers	18%
Bottle conveyors	16%
Case conveyors	24%
Other	12%

Compressed air

There is one centralised compressed air plant comprising four compressors, two air dryers, and three air receivers (6m<sup>3</sup>, 6m<sup>3</sup>, 8.4m<sup>3</sup>). Electricity requirements are about 0,81 kWh/hl produced. Control is carried out by each compressor having a low and high pressure set point. When the air pressure comes down to the low setting the compressor begins running until the high pressure setting is reached when the compressor unloads; runs unloaded for 10 minutes, and then switches off. The larger compressors have lower set points so they are used more often. Compressed air is generated at 700 kPag and used for:

- packaging at 200 to 500 kPag.

- top pressure on vessels at 200 kPag.
- instrumentation at 200 kPag.
- general cleaning.

There is no measurement of compressed air usage, but it does fluctuate excessively since operation of the compressors fluctuates. Compressed air for the pneumatic conveying of coal and grain is generated by localized blowers.

### CO2 plant

Almost all electricity usage is by the compressors, and a little by electric re-heaters and trace heating. The CO2 plant requires about 0,8 kWh/hl produced. There are three dry compressors of 75 kW, 30 kW, and 18.5 kW, with the large compressor running continuously. There are three liquifying compressors of 75 kW, 45 kW, and 45 kW , with the large compressor running continuously. Compressors are controlled by the amount of CO2 in the storage balloon.

## CHAPTER 5

# PINCH ANALYSIS

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### 5.1 STRATEGY FOR THE PINCH ANALYSIS

The pinch analysis was performed with the assistance of a computer software package UCTNET<sup>(82)</sup>. Initially an overall plant pinch analysis was performed, where average energy requirements were used (the 'time averaged model'). It was found that some possibilities for process heat exchange were not feasible because of the large distances between the energy users, and because many energy users are intermittent.

The distance problem can be overcome by dividing energy users up into spatially separate sections. Only the brewhouse section has enough energy users to justify a separate pinch analysis.

The problem of time can be overcome by using the Overall Plant Bottleneck approach for batch processes (explained in Appendix B). Energy requirements are divided into time intervals and a pinch analysis performed on each interval (the 'time slice model'). Unfortunately too many time intervals exist on the brewery, with too few active energy users in each time interval, to justify use of the time slice model.

The pinch software package UCTNET was only capable of handling a single cold utility. The different types and levels of cooling utility made it difficult to assign a cost and specify a heat transfer coefficient for a single cold utility, and consequently a costing optimisation analysis could not be performed.

### 5.2 OVERALL PLANT ANALYSIS

A pinch analysis was performed over the entire plant, whereby all process heating and cooling requirements were accounted for. Average power requirements for the period 01/04/91 - 30/09/91 were used. Table 14 is a summary of the streams and data used in the pinch analysis (a more detailed table is given in Appendix K).

Table 14. Stream data for the overall pinch analysis.

	$T_{in}$ (°C)	$T_{out}$ (°C)	AVERAGE POWER (kW)	
<b>COOLING REQUIREMENTS</b>				
1	Brewhouse wort	100	9	1849
2	Fermenting (11 deg C)	12	11	160
3	Fermenting (14 deg C)	15	14	176
4	Chill back	14	6	163
5	Fermenting to storage	6	-2	158
6	Storage	0	-2	39
7	Pre-filter	1	-2	59
8	Post-filter	2	-1	59
9	De-aeration	100	2	1142
10	Bright beer tanks	1	-1	57
11	Pasteurisation	63	27	1190
12	CO2 condensing	-27	-28	71
<b>HEATING REQUIREMENTS</b>				
13	Water for maize cooking	18	56	175
14	Water for mashing	18	45	209
15	Water for lautering	18	76	656
16	Water for cleaning	18	84	174
17	Heating in maize cooker	56	99	200
18	Boiling in maize cooker	99	100	172
19	Heating in mash tun	45	78	519
20	Heating in kettle	76	99	522
21	Boiling	99	100	1422
22	De-aeration	18	106	955
23	Pasteurisation	5	63	1917
24	Heating wet yeast	20	99	13
25	Yeast drying	99	100	77
26	Cleaning water	18	85	154
27	CO2 vaporisation	-28	-27	47

Figure 20 shows the composite curves for the entire plant. The minimum temperature difference specified was  $8^{\circ}\text{C}$ , which is the minimum achieved at Ohlsson's Brewery.

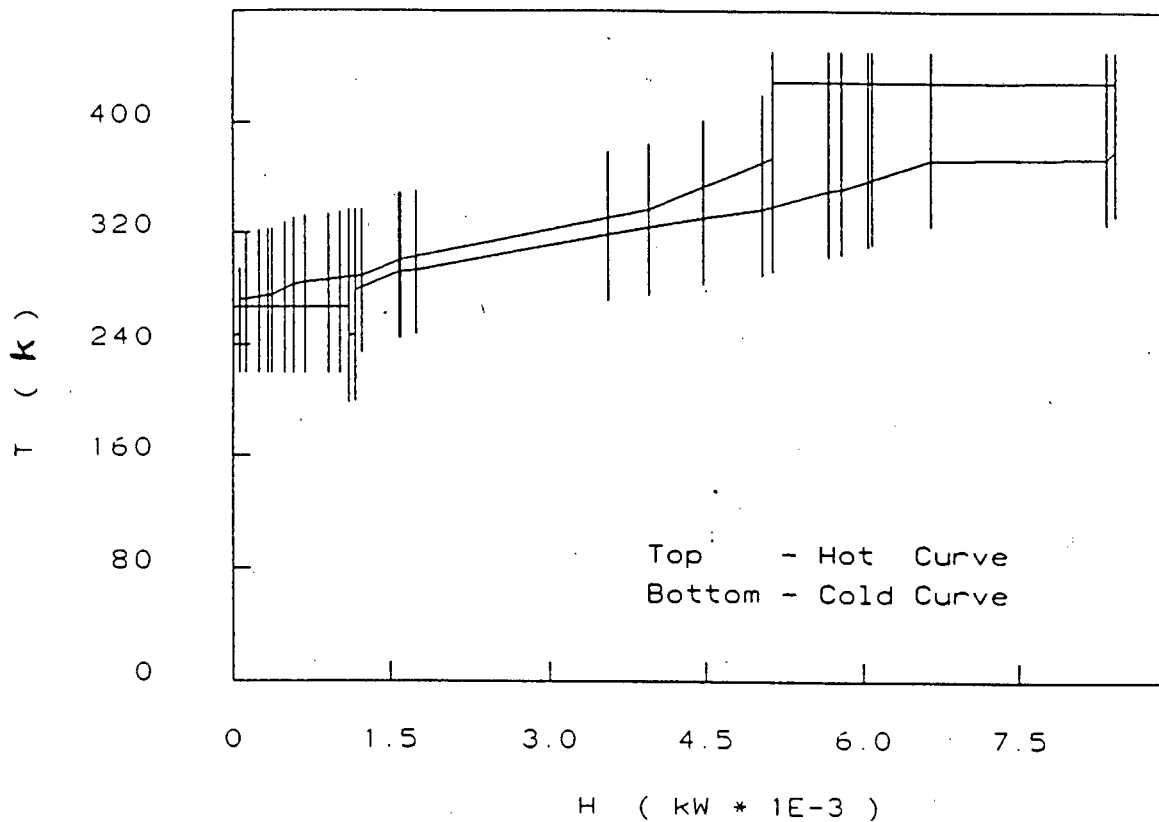


Figure 20. Composite curves for the entire plant.

It can be deduced from the composite curves that:

- The minimum hot utility (steam) requirement is 3263 kW.
- The minimum cold utility requirement is 1103 kW.
- The pinch temperature is  $11^{\circ}\text{C}$ , so hot utility should only be used above  $7^{\circ}\text{C}$  and cold utility should only be used below  $15^{\circ}\text{C}$ .

### 5.2.1 Identifying cross-pinch heat exchange

There are three areas of process heat exchange:

- 1) Dilution water de-aeration - The exit stream preheats the inlet stream, and all heat exchange is above the pinch temperature.
- 2) Wort cooling and heating of process water for the brewhouse - A small amount of heat exchange (12 kW) does occur across the pinch point.
- 3) Pasteurisation - The incoming cold beer indirectly cools the outgoing beer with circulating water. A small amount of cross-pinch heat exchange takes place (66 kW).

There are two areas where cross-pinch utility usage occurs:

- 1) Brewhouse water chilling - Water is chilled to 1°C using glycol, and then the water used to cool the wort. This is equivalent to using glycol to cool the wort in which case cross-pinch exchange (224 kW) takes place on the wort stream between 26°C and 15°C.
- 2) De-aerated water chilling - The hot de-aerated water is cooled to 26°C when pre-heating the feed water. Glycol is then used to chill the water to 2°C, so cross-pinch exchange (128 kW) takes place down to 15°C.

The cross-pinch exchange can be eliminated by linking pasteuriser inlet stream heating to de-aerated water cooling above the pinch, wort cooling above the pinch, and any of a cooling requirement of 66 kW below the pinch. However spatial and timing constraints exclude these possibilities. In addition 47 kW of cooling is available from CO<sub>2</sub> vapourisation, for which ambient air is used, but this is too variable to be linked to a process load. However the possibility of linking this load to non-process loads is discussed in Chapter 6.

The 430 kW of mostly unavoidable cross-pinch heat exchange increases both the minimum hot and cold utility requirements by 430 kW.

### 5.2.2 Hot utility requirements

The actual amount of primary fuel heating power used on the plant was 11 872 kW. However most of the primary fuel energy is lost, with the breakdown given in Table 15 (the percentages are based on the figures given in the Sankey diagram, Figure 14, and average boiler losses given in section 4.3.1). Condensate returned from the brewhouse

and hotwell steam to pre-heat the feed are not included in Table 15 since their energy is continuously circulated.

Table 15. Primary fuel energy usages over the entire plant.

AREAS OF ENERGY USAGE	AVERAGE POWER (kW)	PERCENTAGE
1) <u>Boilers</u>		
Flue gases	2505	21,1
Water vapour	510	4,3
Unburnt carbon	499	4,2
Incomplete combustion	237	2,0
Radiation	237	2,0
Blowdown	47	0,4
Other	119	1,0
<b>TOTAL</b>	<b>4155</b>	<b>35,0</b>
2) <u>Brewhouses</u>		
Wort heating*	994	8,4
Wort kettle vapours*	1422	12,0
Maize cooker vapours*	172	1,5
Spent grains	249	2,1
Radiation	309	2,6
Hot liquor losses	124	1,0
Rinsing	174	1,5
<b>TOTAL</b>	<b>3444</b>	<b>29,0</b>
3) <u>Packaging</u>		
Water detergent	1028	8,7
Steam condensate	397	3,3
Radiation	306	2,6
Product*	724	6,1
<b>TOTAL</b>	<b>2455</b>	<b>20,7</b>
4) <u>Other users</u>		
De-aeration*	163	1,4
Yeast drying*	90	0,8
Cleaning water*	154	1,3
Other steam users	192	1,6
Condensate losses	175	1,5
5) <u>Flash steam</u>	227	1,9
6) <u>Distribution loss</u>	817	6,9
<b>TOTAL</b>	<b>11 872</b>	<b>100</b>
<b>PROCESS USAGE</b>	<b>3 719</b>	<b>31,3</b>
<b>LOSSES</b>	<b>8 153</b>	<b>68,7</b>

\* Process heating.

The energy requirements used in the pinch analysis are all actual process requirements and exclude any losses. These requirements have been marked with an asterisk in Table 15, and total 3719 kW which is 456 kW greater than the pinch target. Cross-pinch heat exchange accounts for 430 kW, and the 26 kW discrepancy is due to calculation inaccuracies. Cross-pinch heat exchange is negligible in comparison to heating losses, and thus more attention should be given to reduction of heating losses.

### 5.2.3 Cold utility requirements

Table 16 is a breakdown of actual cold utility usages on the plant.

*Table 16. Actual cooling loads over the entire plant.*

AREA OF COOLING	LOAD (kW)	PERCENTAGE
Wort cooling (water chilling)	378	19,1
Fermenting vessels	499	25,3
Fermenting to storage	158	8,0
Storage vessels	39	2,0
Filtration	118	6,0
Bright beer storage	59	3,0
De-aeration plant	280	14,2
CO <sub>2</sub> condensing (Freon)	71	3,6
Small users	62	3,1
Wort cooling losses	32	1,6
Fermenting vessel losses	34	1,7
De-aeration losses	37	1,9
Miscellaneous losses	20	1,0
Pumping losses	139	7,0
Piping losses	50	2,5
<b>TOTAL</b>	<b>1976</b>	<b>100</b>
<b>PROCESS USAGE</b>	<b>1664</b>	<b>84,2</b>
<b>LOSSES</b>	<b>312</b>	<b>15,8</b>

Actual process cold utility usage on the plant, excluding small users, is 1602 kW, which is 499 kW greater than the target, and this is accounted for by cross-pinch heat exchange. Cross-pinch heat exchange is of similar quantity to losses, but both seem to be unavoidable.

### 5.3 BREWHOUSE ANALYSIS

The brewhouse was analysed as a separately to identify whether there are any heat exchange opportunities in the brewhouse. A summary of the streams used for the brewhouse pinch analysis are shown in Table 17 (a more detailed table is given in Appendix K).

Table 17. Stream data for the brewhouse analysis.

	$T_{in}$ (°C)	$T_{out}$ (°C)	AVERAGE POWER (kW)
<b>COOLING REQUIREMENTS</b>			
1 Brewhouse wort	100	9	1849
<b>HEATING REQUIREMENTS</b>			
2 Water for maize cooking	18	56	175
3 Water for mashing	18	45	209
4 Water for lautering	18	76	656
5 Water for cleaning	18	84	174
6 Heating in maize cooker	56	99	200
7 Boiling in maize cooker	99	100	172
8 Heating in mash tun	45	78	519
9 Heating in kettle	76	99	522
10 Boiling	99	100	1422

The composite curves are shown in Figure 21. Once again a minimum temperature difference of 8°C was used.

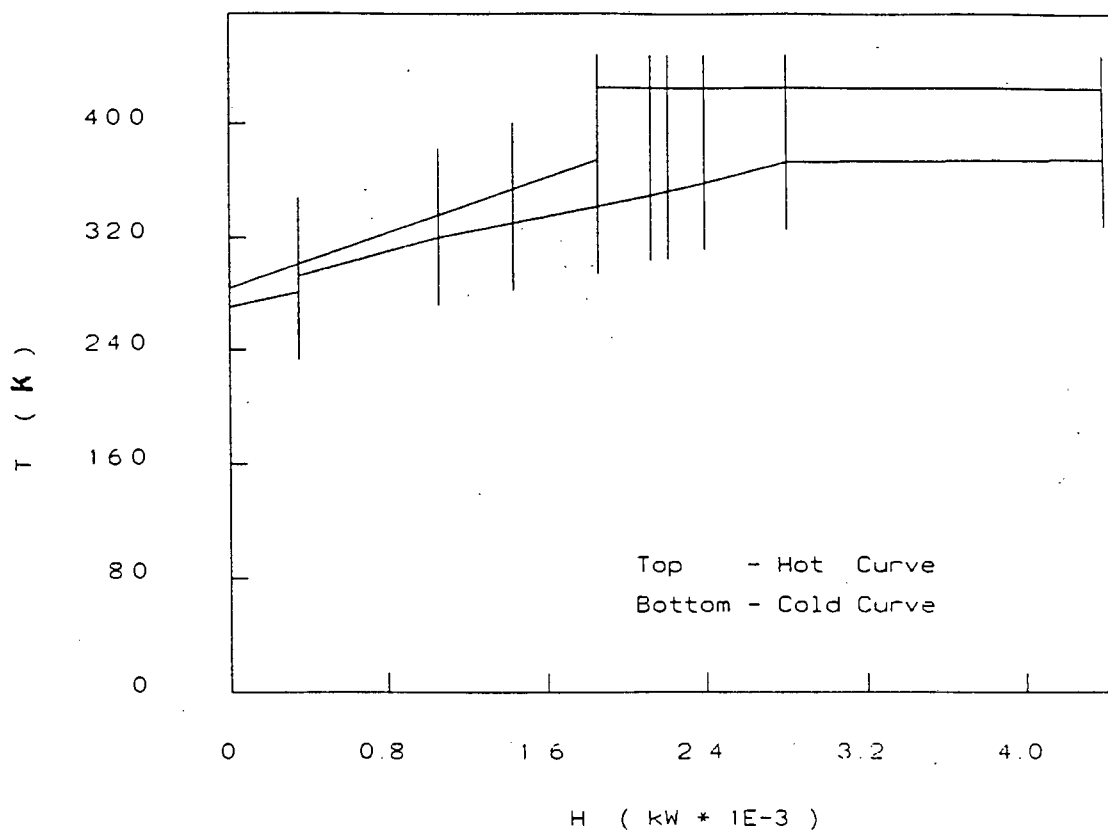


Figure 21. Composite curves for the brewhouse.

It can be deduced from the composite curves that:

- The minimum hot utility requirement is 2546 kW.
- The minimum cold utility requirement is 345 kW.
- The pinch temperature is 22 °C, so hot utility should only be used above 18°C and cold utility should only be used below 26°C.

Heat exchange only takes place at one heat exchanger, wort cooling/hot water production, where 33 kW of cross-pinch heat exchange takes place. No cross-pinch utility usage occurs, since the pinch temperature for the brewhouse is 22°C when it is viewed in isolation. Little scope exists to reduce utility requirements.

The composite curves show that the wort should be cooled from 26°C to 9°C with cold utility. What actually occurs is that cold utility is used to pre-chill the water required in wort cooling (Figure 22). The energy requirement is approximately the same although losses may be slightly larger since cooling takes place at two points. In addition the heat exchange area used by the present system will be larger than if the wort were directly cooled, since the average temperature difference is smaller. The present system does however have the advantage of reduced cooling peaks on the refrigeration system, and simpler control.

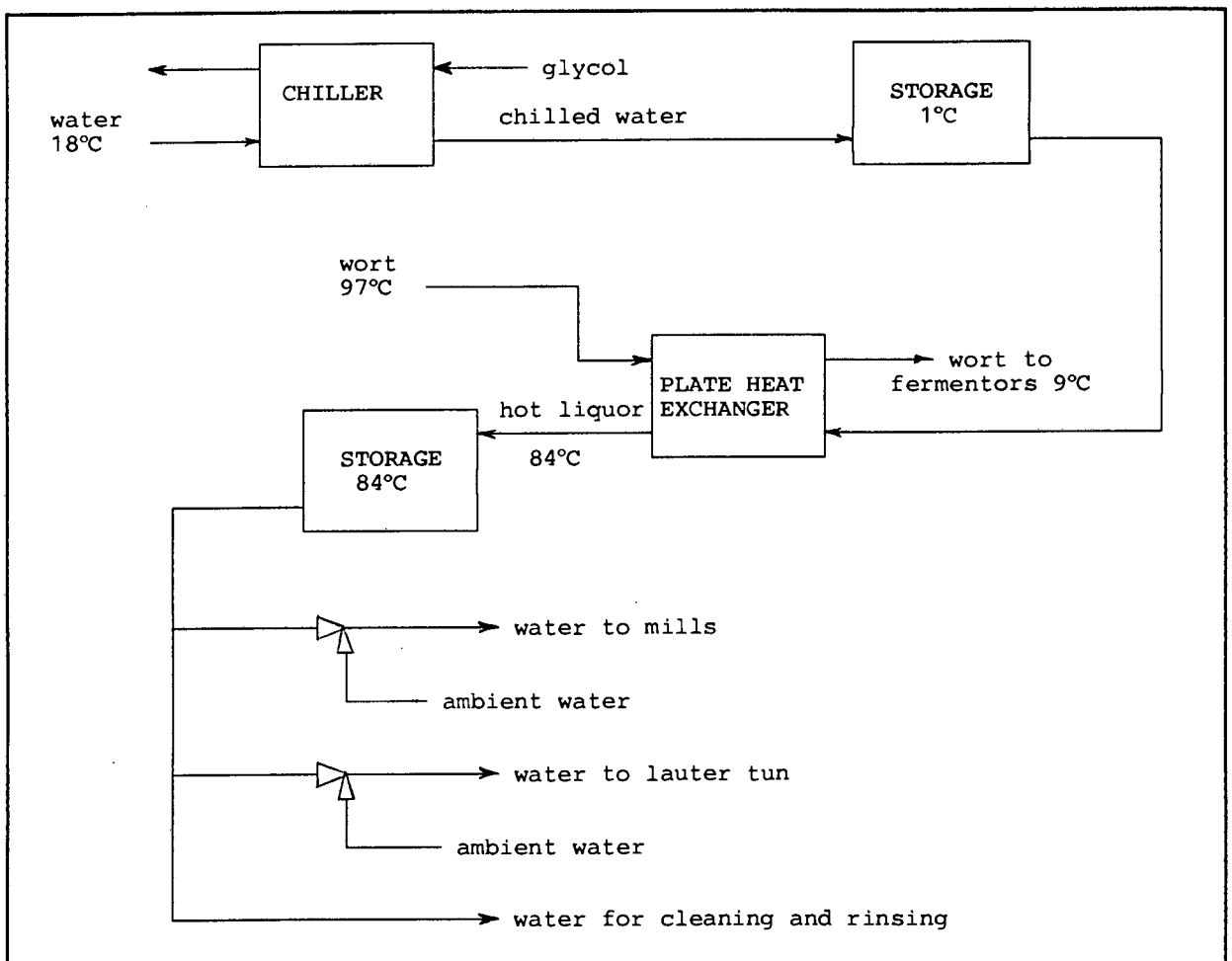


Figure 22. Wort cooling/hot water production system.

## 5.4 CONCLUSIONS

The pinch analysis was limited by the following factors:

- The cooling utility levels which could not be incorporated into the costing optimisation of UCTNET.
- Differing cost structures for different types of heat transfer equipment could not be included in UCTNET.
- The unpredictable nature of certain process utility requirements.
- The large distances between various process energy requirements.
- The batch nature of many of the processes.
- Inflexible heating and cooling rates required by many of the unit processes.

Nevertheless it was possible to ascertain the following:

- 1) A small amount of cross-pinch process heat exchange (78 kW) occurs in pasteurisation and wort cooling, but no feasible alternatives could be identified.
- 2) A significant amount of cross pinch utility usage occurs (352 kW), but no practical opportunity could be identified to significantly reduce this.
- 3) Hot utility usage (excluding losses) is about 13% greater than the thermodynamic minimum requirement, while hot utility losses are 69% of the hot utility usage. Clearly focus should be placed on reduction of losses.
- 4) Cold utility usage is about 39% greater than the thermodynamic minimum requirement, while losses are 37% of the minimum requirement. However the losses are mostly unavoidable, and no feasible process changes could be found to reduce cold utility usage.

## CHAPTER 6

# ASSESSMENT OF ENERGY MANAGEMENT SCHEMES

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### 6.1 ECONOMIC CRITERIA

Proposals were initially evaluated by calculating the pay-back time, and if this was less than two years the proposal was considered economically feasible. Sensitivity calculations were sometimes carried out, in which case a range for pay-back time was calculated. If most of the range was less than two years then the proposal was considered feasible. For large capital projects a rough internal rate of return was calculated, with the required rate of return being 20%.

Opportunities have been divided into low capital (under R20 000), medium capital, and high capital (over R0.5 million) schemes.

### 6.2 BASIS FOR CALCULATIONS

#### Production rate

Opportunities were assessed for Ohlsson's Brewery on the basis of production after the expansion. The brewery will then be capable of producing 85 000 hl/week of saleable beer. Initially once the expansion is complete the brewery will rarely run near full production. However in the long term a plant capacity utilisation factor of 85% is expected, giving an average production rate of 72 300 hl/week saleable beer. This means the brewhouses will produce an average of 54 000 hl/week, which is 83 brews/week.

#### Energy requirements

Coal requirements at Ohlsson's Brewery have recently been 6,7 kg/hl saleable beer. With maize cooking no longer practiced, and the higher packaging efficiencies expected, this figure is estimated to drop to 6,5 kg/hl. This means the coal requirement will be 1880 ton/month at the expected production rate. With an expected average boiler efficiency of 70%, 8,2 kg steam will be generated per kg of coal, so an average of 21,4 ton/hr of steam will be generated.

Electricity requirements were 10,6 kWh/hl saleable beer and this is expected to fall to about 10 kWh/hl thus giving a monthly consumption of 2 892 000 kWh/month. The

maximum electrical demand has been 3700 kVA - 4500 kVA and is expected to increase to about 6000 kVA.

### Cost of heating energy

Table 18 summarises the running costs associated with producing steam.

*Table 18. Running costs to produce steam.*

	USAGE/TON STEAM	COST	COST/TON STEAM
Coal	8,2 ton	R190/ton	R23,17
Chemicals			R 1,00 <sup>(83)</sup>
Electricity	12 kWh	R0,0624/kWh	R 0,75
Make-up water*	0,3 ton	R0,00/ton	R 0,00
Effluent	0,3 ton	R0,40/ton	R 0,12
TOTAL			R25,04

\* Borehole water is used which is of negligible cost.

Each ton of coal saved is a saving of R205. If it is assumed that steam is used at 450 kPag then the cost of energy in the form of steam is R11,97/GJ.

### Cost of cooling

Table 19 summarises the running costs associated with refrigeration. The current electricity charge of 6,24 c/kWh was used.

*Table 19. Running costs of cooling.*

	ELECTRICITY USAGE (kW/kW COOLING)	MONTHLY COST OF COOLING (RAND/kW)
Compressors	0,303	13,60
Circulating pumps	0,076	3,41
Condensers	0,049	2,20
TOTAL		19,21

### Boiler utilisation

A boiler feedwater de-aerator is planned for the expansion, in which all water to be fed to the boilers will be heated, with live steam, to a temperature of 130 °C. Once the

expansion is complete the following boilers will be available (ratings refer to steam production rate).

<u>Boiler rating</u>	<u>Actual rating</u>	<u>Practical rating</u>
3x20 ton/hr coal	18,4 ton/hr	15,6 ton/hr
1x10 ton/hr coal	9,2 ton/hr	7,8 ton/hr
1x12 ton/hr oil	12,0 ton/hr	12,0 ton/hr

The actual maximum output of each boiler is calculated assuming a de-aerator feed water temperature of 80 °C. It is not advisable to operate the coal boilers close to maximum capacity, otherwise rapid fouling occurs. Consequently the coal boiler capacities were multiplied by 0,85 to arrive at practical ratings. Usually there is one boiler undergoing cleaning or maintenance, so assuming the boiler to be a large one, the maximum available boiler capacity will be 51 ton/hr. The total boiler capacity is 66,6 ton/hr, and with the average steam demand being 21,4 ton/hr, boiler utilisation will be 32%.

### 6.3 CHOOSING ENERGY MANAGEMENT OPPORTUNITIES

Opportunities for improved energy management at Ohlsson's Brewery were obtained from ideas from the literature review, the analysis of energy usage at Ohlsson's Brewery, and the pinch analysis.

The cost of energy can be reduced by:

- 1) Reduction of energy requirements.
- 2) Reduction of energy losses.
- 3) Heat exchange.
- 4) Reduction of maximum electrical demand.
- 5) Tariff analysis and negotiation.
- 6) Fuel switching.

The first three methods mentioned above require closer scrutiny to identify specific opportunities.

### 6.3.1 Reduction of energy requirements

Reduction of energy requirements can be achieved by introducing process changes, especially in energy intensive areas. Potential areas are given below, but these areas were not evaluated in detail because of effects on beer quality and taste:

- The total evaporation in wort boiling.
- Alternative boiling techniques ie continuous wort boiling and pressure wort boiling.
- Flash pasteurisation instead of tunnel pasteurisation.
- Alternative methods of the de-aeration of dilution water.

### 6.3.2 Reduction of fuel losses

From the fuel losses given in Table 15 the following areas were assessed for possibilities of reducing fuel losses.

#### 1) Boilers

At best coal boiler efficiency can be expected to be about 80%, whereas at present the average efficiency is about 65%. If boiler efficiency can be increased by only 5% this would be a saving of R29 700/month. Flue gas and unburnt carbon losses can be reduced by improved combustion control, a reduction in steam demand fluctuations, and by energy recovery using economizers. Blowdown losses can be reduced by reducing blowdown and recovering the blowdown heat. The surface moisture on the coal is within the specified range for coal boilers, and thus no scope exists to reduce water vapour losses. Radiation and incomplete combustion losses are unavoidable.

#### 2) Brewhouses

The energy lost in the wort kettle vapours is worth R39 600/month, and most of this can be recovered either by the production of hot water by the condensation of the wort vapours, or by vapour recompression. As discussed in chapter 3, vapour recompression is unlikely to be feasible, but condensation of wort vapours is simpler and more widely practised, thus justifying further assessment. Recovery of heat from spent grains would be difficult because of the problems of the conveying of spent grains and if hot water should be produced (maximum temperature 66 °C) there does not appear to be any point of use to justify its production. The brewhouse vessels are well insulated and the assumed 5% radiation losses are unavoidable.

### 3) Packing hall

Effluent water in the packaging hall arises from:

Coil heating steam condensate	2500 kg/hr at 100 °C
Direct steam heating condensate	965 kg/hr at 35 °C
Unbalanced pasteuriser operation	2500 kg/hr at 35 °C
Water from the bottle washers	4000 kg/hr at 40 °C
Hose points	500 kg/hr at 20 °C

Returning of coil heating steam condensate to the boilers would provide a saving in coal of about R8 700/month. The rest of the water is low grade energy not suitable for heat recovery, and as pointed out earlier, heat engines are unlikely to be feasible. Water from the bottle washers is dirty and cannot be re-used.

Radiation losses are high partly because none of the machinery is insulated, but as pointed out in the literature review insulation of pasteurizers and washers is unlikely to be economically feasible, and in addition maintenance of the insulation could be costly.

### 4) Flash steam

Flash steam from the condensate tanks is worth about R8 600/month and is a was consequently investigated.

### 5) Distribution

Distribution losses are unknown and were only estimated, but previous studies have identified that distribution losses can be significantly reduced by improved housekeeping.

## 6.3.3 Reduction of electricity losses

Most electrical energy input results in friction, either on compressors, pumped liquids, or mechanical equipment. This energy is then lost by radiation, or transferred to the refrigeration system from where it lost to the atmosphere in evaporative condensers. Unfortunately the heat is low grade and difficult to recover.

### 6.3.4 Heat exchange

Opportunities for process heat exchange were investigated using pinch technology, as outlined in Chapter 5, but no possibilities were identified. In addition there are several heating and cooling loads in the engine room. These are summarised in Table 20, and have been calculated for after the expansion. CO<sub>2</sub> vaporisation could provide up to R1 900/month Potential exists to link CO<sub>2</sub> vaporisation with ammonia condensing, glycol chilling, chilling of cooling water, or air drying.

Table 20. Heating and cooling loads in the engine room.

	T <sub>in</sub> (°C)	T <sub>out</sub> (°C)	CURRENT ENERGY SOURCE	AVERAGE POWER (kW)
<b>HEATING REQUIREMENTS</b>				
CO <sub>2</sub> vaporisation	-28	5	ambient air	99
<b>COOLING REQUIREMENTS</b>				
Ammonia compressors	47	46	ammonia	1166
Ammonia condensing	36	35	c/w*	4255
Glycol chilling	2	-4	ammonia	1994
Air compressors	60	59	c/w	137
Air inter-coolers	145	27	c/w	81
Air after-coolers	150	30	c/w	94
Air drying	20	2	glycol	70
CO <sub>2</sub> compressors	60	59	c/w	130
CO <sub>2</sub> inter-coolers	125	15	glycol	65
CO <sub>2</sub> condensing	27	-28	ammonia	161

\* Cooling water.

## **6.4 LOW CAPITAL SCHEMES**

### **6.4.1 Tariff analysis and negotiation**

Coal tariffs are standard, and oil tariffs do not vary significantly. No choice on electricity rates is available at present, but there is always scope for tariff negotiation, for example lower electricity charges at night.

### **6.4.2 Housekeeping**

This includes the following areas:

- 1) Repairing of leaks from piping and faulty valves, in the air, CO<sub>2</sub>, steam and refrigeration systems. The compressed air leakage rate can be determined during plant shutdown by operating a single compressor and monitoring the operating time. At the same time air leaks can be located by sound. Realistically the leakage rate can be reduced to about 5% of air usage during production. It was noticed that numerous steam leaks occurred from valves and fittings despite the maintenance programme at Ohlsson's Brewery.
- 2) Removal of redundant piping and valves in the air, CO<sub>2</sub>, steam, and refrigeration systems. This is especially valid for Ohlsson's Brewery which is undergoing expansion and process modification.
- 3) Repairing of damaged or wet insulation.

### **6.4.3 Improved boiler control**

With the absence of soot blowing and excessive fluctuations in load it is expected that control of the boiler air/fuel ratio is not optimum. The cost given<sup>(84)</sup> for a boiler expert to examine and reset boiler controls is R87/hour, and about one day would be required ie R700 in total. Expected improvement in boiler efficiency is anything from 1% to 5%. Only a 1% saving in coal would amount to a saving of R3 572/month, which gives a pay-back time of well under one month.

#### 6.4.4 Measurement of steam flowrate

At present steam flowrate measurement equipment is either non-existent, not connected up, or does not give reliable readings. Consequently steam demand profiles, essential for steam management, are not known. In addition boiler efficiencies cannot be determined, so the effects of different operating conditions on boiler efficiency are unknown. It is impossible to quantify the benefits of steam measurement, but it is an accepted fact in any industry, that the benefits of steam measurement justify the expenditure on measurement equipment.

#### 6.4.5 Improved refrigeration control

The high electricity usage in refrigeration, which costs R38 000/month at present, justifies investigation of cost reducing. The refrigeration compressor sequencing and control system is not optimal as compressors are run up to 80% capacity and then the next compressor is brought on, so compressors rarely run above 80% capacity. Ideally compressors should be run up to 100% capacity before the next one is started. Table 21 shows the improvement in overall coefficient of performance (COP) if the system were run optimally (Appendix L1 gives COP as a function of load). A future cooling load of 3500 kW was assumed, which gave a saving of R3 000/month with improved compressor sequencing.

Table 21. Improvement in COP for optimal sequencing of compressors.

TOTAL COOLING LOAD (% OF THE MAX. CAPACITY OF ONE COMPRESSOR)	COP (at present)	COP (optimum)
260	2,96	3,19
280	2,98	3,25
300	3,06	3,30
320	3,11	3,17
340	3,00	3,17
360	3,00	3,22
380	3,07	3,26
400	3,11	3,30
AVERAGE COP	3,04	3,23
kWh/MONTH	829 000	780 000
COST (RAND/MONTH)	51 700	48 700

A limitation on the system is that the transformer overheats if compressors are started too often. It is thus sometimes necessary to keep a compressor running at low load instead of switching it off.

#### **6.4.6 Load shedding**

To reduce monthly maximum demand without knowing anything about maximum demand profiles, load shedding with non-essential loads can be done. Air conditioning is a non-essential load, but the system is de-centralised and the load small. Unfortunately because of the precision required in brewing almost all large loads are essential and load shedding is not feasible on any of the significant users of electricity.

#### **6.4.7 kVA monitoring**

If the main contributors towards maximum demand can be ascertained then measures can be taken to reduce their contribution. Daily peak demand usually occurs between 6h00 and 15h00, and there seems to be a correlation between packaging and refrigeration loads and peak demand. However little more can be said as no other relevant information is available. It is thus necessary to know what are the main contributors towards maximum demand, and this requires kVA monitoring equipment. Maximum demand recorders should be installed on feeders to major electricity users ie refrigeration, packaging, air compressors and the CO<sub>2</sub> plant. They will highlight the main contributors towards maximum demand, and show where activities should be re-scheduled. These recorders should have adjustable alarm limits, and by setting the alarm to a target maximum demand, staff will be aware of when this is exceeded. They can then determine what is causing the maximum demand, and decide what to switch off to lower the demand. Total cost of a kVA meter with recorder is about R4 500. The cost of four such systems will be R18 000, and if they can result in maximum demand being reduced by only 3% ie 180 kVA the savings would be R3 143/month with a pay-back time for the monitoring being 6 months.

#### **6.4.8 Re-scheduling of electricity users**

If the times that peak demand occurs is known, then certain electricity users could be re-scheduled so as not to operate during these times. Only two possible areas of re-scheduling could be identified; chill back in the fermenters and chilling the beer between fermenters and storage vessels. It occurs on occasions that five fermenting vessels are put on chill back simultaneously. The cooling load would then increase by about one third.

About a twelve hour leeway exists on when to start chill back, so it would be possible to either stagger chill back, or initiate chill back only during periods of lower peak demand. Figure 23 shows the effect of staggering five chill back loads three hours apart. The improvement in cooling demand is not significant. It would be better to identify peak demand periods when chill back should not be initiated. The same could be done for chilling between fermenters and storage.

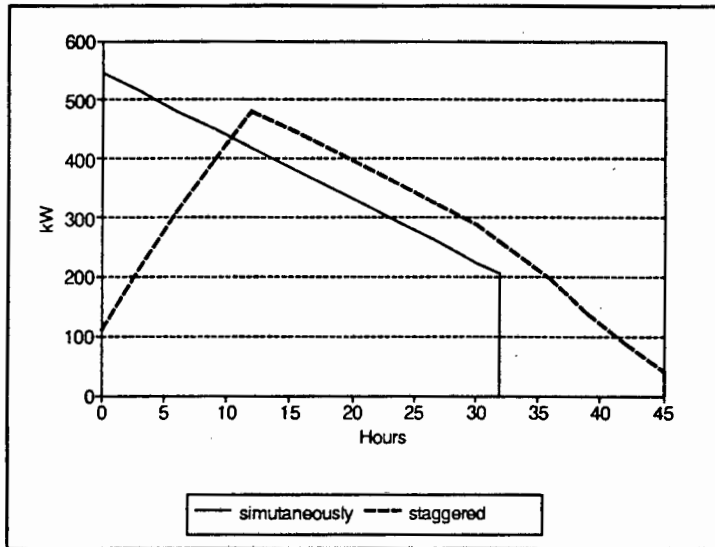


Figure 23. Effect of staggering five chill back loads three hours apart.

### 6.4.9 Lighting

It was noticed that some of the outside lights remain on during the day. This problem would be solved by greater energy awareness. Lighting accounts for about 10% of electricity usage on a brewery, so if the lighting bill can be reduced by 10%, then overall electricity usage will be reduced by 1% (R1805/month).

## 6.5 MEDIUM CAPITAL SCHEMES

### 6.5.1 Flash steam recovery

Flash steam in the condensate tanks of the brewhouse can be recovered by spraying softened make-up water at the top of the vessels thus condensing most of the flash steam. With a 60% recovery of flash steam, the savings in coal would be R5137/month

(Appendix L2 has details). The capital cost of the spray condensers will be about R24 000<sup>(85)</sup>, with the total installed cost expected to be R36 000, thus giving a pay-back time of 7 months.

### **6.5.2 Energy recovery from CO<sub>2</sub> vaporisation**

The vaporisation of CO<sub>2</sub> could be linked with one of the following operations:

#### Ammonia cooling

A problem is the pressure of the ammonia is 1100 kPa and that of the CO<sub>2</sub> is 1500 kPa, which means there is a possibility of CO<sub>2</sub> leaking into the ammonia system. This would result in the refrigeration plant becoming non operational due to the formation of ammonium carbonate. This would necessitate a secondary system reducing cooling efficiency and increasing the equipment requirements.

#### Cooling of service water for the engine room

A problem is under low CO<sub>2</sub> demand conditions a back-up cooling system will be necessary which should be sized for peak loads. In addition it would necessary to have extensive controls and buffers to match the water flowrates to suit the CO<sub>2</sub> vaporisation rate.

#### Cooling of glycol

No major problems are anticipated, but the CO<sub>2</sub> can only be heated to not more than 0 °C (since the average incoming temperature of glycol is about 4 °C). Approximately 99 kW (Appendix L3 has details) will be available from CO<sub>2</sub> vaporisation, and if 80% of this energy can be recovered the saving will be R1 250/month (R15,80/kW from Table 20). For a two year pay-back time, not more than R30 000 should be invested in the scheme. The cost of heat exchange equipment is expected to be well above R30 000.

#### Drying of compressed air

In the compressed air dryers the inlet temperature is about 35 °C and the outlet temperature about 20 °C. Although the air temperature is reduced to 2 °C some of the energy is recovered. Overall compressed air dryer cooling requirements will be about 38 kW, so a saving in electrical energy of R1707/month is possible (Appendix L4 has details). The cost of heat exchangers and auxiliary equipment is estimated to be R30 000 - R50 000, giving a pay-back time of 18 months to 29 months. This scheme is borderline and requires closer scrutiny.

### 6.5.3 Continuous blowdown

Continuous blowdown saves energy by keeping blowdown at the minimum level. The capital cost of blowdown equipment for five boilers is about R50 000<sup>(85)</sup> with about R5 000 installation cost. Savings are difficult to calculate since the current blowdown rate is not known, but based on one blowdown per shift it is expected that blowdown is a third extra than the minimum. On this basis the pay-back time for continuous blowdown is 3,3 years (Appendix L5 has details). Unless accurate flow measurements of blowdown show the actual rate to be more than a third larger than the minimum, continuous blowdown on its own is not considered feasible.

### 6.5.4 Blowdown heat recovery

The most efficient method of recovering blowdown heat is to flash off steam and return the steam to the boiler feedwater hotwell or de-aerator. For such a system continuous blowdown is necessary. Only one flash vessel is required to serve all the boilers. The cost of such a vessel would be R17 000, and together with continuous blowdown and installation costs, the total cost would be R75 000. The pay-back time for blowdown heat recovery would then be 2,6 years (Appendix L6 has details), but once again this is subject to the uncertainties in the savings of continuous blowdown.

### 6.5.5 Condensate recovery in the packaging hall

Condensate recovery is not possible from two of the pasteurisers since they use direct steam. Condensate recovery from the rest of the pasteurisers and washers with an 80% assumed recovery was evaluated (Appendix L7 has details). Coal savings alone were calculated to have a value of R8690/month. Such a scheme is being installed and the capital cost is of the order of R100 000, giving a pay-back time of 1 year.

### 6.5.6 Oxygen trim control on the boilers

Oxygen trim control has been estimated<sup>(86)</sup> to give about a 1% saving in coal. The cost of an oxygen analyzer is about R12 000, giving a total cost of R108 000 (one per flue). Excluding the cost of the control systems the pay-back time is already 2,5 years.

### 6.5.7 Energy recovery from air compressors

It is possible to modify the water cooling circuit of the air compressors such that hot water can be produced. About 80% of the shaft power can be recovered in the form of hot water at about 80 °C. The problem is to find a use for this hot water. The only practical use, would be to heat fresh make-up water to the boilers, which would then be heated to 70 °C. The budget cost to modify one 220 kW compressor is R116 000, and costs of the heat exchanger and auxiliary equipment is about R30 000, giving a total cost of R150 000. The saving in fuel is R2454/month (Appendix L8 has details), giving pay-back of 5,1 years, which is not feasible.

### 6.5.8 Conversion from coal to oil boilers

Because of the large distances over which coal must be transported to Cape Town, coal is expensive in comparison to its cost in the interior. The use of heavy fuel oil (H.F.O) is thus attractive. Conversion to H.F.O has the following advantages:

- H.F.O has a much faster response to steam demand fluctuations.
- H.F.O occupies 50% less space and weighs 30% less than coal on a heat content basis.
- Boiler cleaning is far less frequent with H.F.O.
- H.F.O is generally a much cleaner fuel.
- Reduced labour and maintenance costs.
- The price of coal is expected to increase at a faster rate than oil.

Conversion to oil has the following disadvantages:

- H.F.O is more expensive than coal.
- SA may have to set a higher internal oil price, compared to the international price, to enable local oil production to be economically feasible.
- The cost of conversion of a 20 t/hr coal fired boiler to oil firing would be of the order of R160 000 - R180 000.

The difference in cost of generating steam from coal and fuel oil were calculated in Appendix L9, and it was found that fuel oil is 33% more expensive than coal.

### 6.5.9 Washer insulation

It is claimed<sup>(87)</sup> that the insulation of the washer on line 1 can save up to 10% of the washer energy requirements. This would amount to a saving of 1400 MJ/hr, based on calculated steam usage for an average of 16,7 hr/day operation. The saving would thus

be R1195/month, and with the total insulation cost being R230 000, the pay-back time would be 16 years.

### 6.5.10 Economizer

Since each boiler has a separate chimney, an economizer for one 20 ton/hour boiler will be considered. A boiler-economizer pre-heating boiler feedwater could heat the water from the de-aerator at 130 °C to about 155 °C with a two-bank economizer<sup>(88)</sup> (Appendix L10 has details). With a boiler utilisation of 32% the boiler will produce an average of 5 ton/hr of steam. An economizer would then produce a coal saving of R3 985/month. The budget price of such an economizer together with auxiliary equipment and installation is R350 000<sup>(84)</sup>, so the pay-back time would be 7,3 years. A problem would be that the economizers could not be sootblown at Newlands, thus giving reduced heat transfer.

## 6.6 HIGH CAPITAL SCHEMES

### 6.6.1 Accumulator

An accumulator was considered for the worst case when the brewhouses are out of phase, such that boiling in both brewhouses can occur simultaneously. It was found that 10,6 ton of storage would be required, but accounting for the 2,9 tons storage available in the boilers, 7,7 tons storage was designed for. The working level of the accumulator would be at 80%. The required size of the accumulator is 229 m<sup>3</sup>. The accumulator was scaled and costed<sup>(89)</sup>, and the cylindrical accumulator would have dimensions of 4,2m (length) x 17,4m (diameter). Such an accumulator would have the following associated costs:

Vessel	R 800 000
Transport and installation	R 120 000
Controls	R 150 000
Total	R1 070 000

Fluctuations in steam demand typical of a brewery can be responsible for lowering boiler efficiency by 6% to 12%<sup>(88)</sup>. A small amount of fluctuation is still likely with an accumulator so savings are expected to be 5 to 10%. Savings would thus be between R19 270/month to R38 540/month (Appendix L11 has details). Assuming all running costs

associated with the accumulator are R3 000/month, pay-back time is calculated to be 2,5-5,5 years. The rate of return is calculated to be 18% - 40%. The use of an accumulator would also reduce total boiler capacity requirements, since boilers would operate at higher average capacities. This could also result in investments such as economizers and continuous blowdown equipment becoming economically viable. Another non-quantifiable benefit would be the longer lifespan of boilers due to more steady operation. It is thus concluded that an accumulator would be viable.

### 6.6.2 Wort vapour condensation

HUPPMANN<sup>(64)</sup> have patented a system, which is shown in Figure 24, which makes good use of the recovered energy.

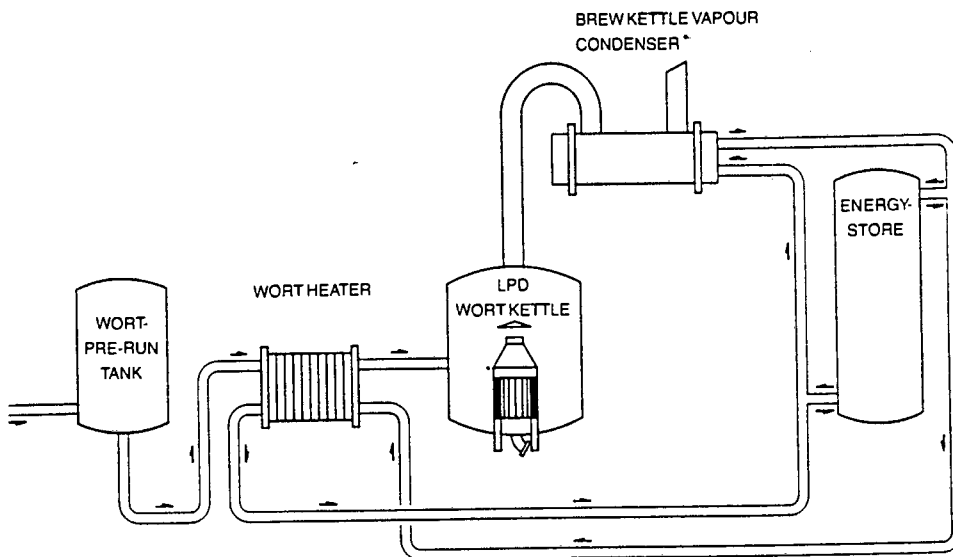


Figure 24. Wort heat vapour recovery system.

The wort vapour is condensed using water which is heated from 78 °C to 98 °C. Wort is pre-heated from 74 °C to 95 °C in a plate heat exchanger using the hot water. The Steinecker brewhouse is incompatible with wort vapour condensation since large amounts of air are drawn in during boiling to prevent foaming. The wort vapour temperature is thus low, increasing the size of heat recovery equipment required. It is possible that the kettle will be replaced shortly. The costs to install such a system on the Huppmann brewhouse are<sup>(90)</sup>:

Wort vapour condensing

Shell and tube heat exchanger	R200 000
Fittings	R 30 000
Piping	R 30 000
Controls	R100 000

Wort pre-heating

Hot water tank	R100 000
Plate heat exchanger	R 80 000
Controls	R 30 000
Pump and piping	R100 000
Insulation	R 50 000

Commissioning	R 50 000
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<u>Total</u>	<u>R770 000</u>
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In Appendix L12 the energy savings are calculated to be R20 337 - R25 424/month, and the running costs associated with pumping, maintenance, and labour are estimated to be R2500/month. This gives a pay-back time of 2,8 - 3,6 years, and a rate of return of 28 - 36%, which is economically feasible.

## 6.7 PROCESS SENSITIVE SCHEMES

The following schemes require further investigation into their effects on beer quality, but the potential energy savings are nevertheless calculated.

### 6.7.1 Lowering the total evaporation

The average total evaporation during wort boiling at Ohlsson's Brewery is about 10% - 12%. Table 22 shows what the monthly energy savings would be if the total evaporation chosen was reduced (assuming 12% evaporation at Ohlsson's Brewery).

Table 22. Energy savings for different total evaporation.

TOTAL EVAPORATION <sup>a</sup>	BOILING ENERGY REQUIREMENT (MJ/BREW)	ENERGY COST (RAND/MONTH) <sup>b</sup>	ENERGY SAVINGS (RAND/MONTH)
8%	12 873	48 087	24 043
9%	14 482	54 098	18 032
10%	16 091	60 109	12 021
11%	17 700	66 120	6 010
12%	19 309	72 130	-

<sup>a</sup> Based on 700 hl (pumped from the mash tun to the wort kettle), which gives 660 hl pumped from the brewhouse.

<sup>b</sup> Assuming 218 000 hl brewed/month, 2.1 MJ/kg steam, 8 kg steam/kg coal, R190/ton coal.

### 6.7.2 Pressure wort boiling

There are generally three types of wort boiling systems related to pressure;

- Atmospheric boiling (as is practiced at all breweries in SA).
- Low pressure boiling at 130 kPag.
- High pressure boiling at 250 kPag.

Table 22 shows how the energy costs would differ on Ohlsson's Brewery for each type of boiling system, where the energy requirements of each system are those typically achieved at overseas breweries (no heat recovery with atmospheric boiling).

Table 23. Comparison of the energy costs for different wort boiling systems.

BOILING SYSTEM	TOTAL BOIL OFF (%)	BREWHOUSE ENERGY REQUIREMENT <sup>(58)</sup> (MJ/HL BREWED)	ENERGY COST (RANDS/MONTH) <sup>a</sup>
<u>Atmospheric</u>	12,5	66	163 000
<u>Low pressure</u>	6	28	69 000
<u>High pressure</u>	7	33	81 000

<sup>a</sup> Assuming 218 000 hl brewed/month, 2.1 MJ/kg steam, 8 kg steam/kg coal, R190/ton coal.

### 6.7.3 Continuous wort boiling

A continuous wort boiling system was demonstrated at a German brewery<sup>(56)</sup>, with 900 000 hl/year capacity. Brewhouse energy requirements are 14 MJ/hl brewed, compared to about 60 MJ/hl for Ohlsson's Brewery. Potential energy savings are thus R113 000/month.

## 6.8 SUMMARY OF FINDINGS

Table 24 summarises proposals that have been found to be feasible for Ohlsson's Brewery.

*Table 24. Summary of feasible energy management schemes for Ohlsson's Brewery.*

	% COAL REDUCTION	% ELEC. REDUCTION	% MAX DEMAND REDUCTION
<u>LOW CAPITAL SCHEMES</u>			
Housekeeping	2 - 5	2 - 5	2 - 5
Boiler control	1 - 3		
Compressor sequencing		1,7	
kVA monitoring			2 - 5
Re-scheduling			2,0
Lighting		1,0	
<u>MEDIUM CAPITAL SCHEMES</u>			
Condensate recovery	2,4		
Flash steam recovery	1,4		
<u>HIGH CAPITAL SCHEMES</u>			
Accumulator	4 - 8		
Vapour condensation	4,6 - 5,8		
TOTAL	15,4 - 22,6	4,7 - 7,7	6,0 - 12,0
THOUSAND RAND/MONTH	55 - 81	8,5 - 13,9	6,3 - 12,6

The possible reduction in specific energy requirement is 11,6 - 20,0%. The specific energy requirement of the plant after the expansion is expected to be 210 MJ/hl, without any of the above schemes being implemented. If all the above schemes were implemented specific energy requirements can be reduced to 186 - 168 MJ/hl. The total energy savings would be R69 800 - R107 500/month.

## 6.9 RECOMMENDATIONS TO OHLSSON'S BREWERY

Some of the schemes investigated in this study will be implemented with the expansion, and these are:

- 1) Steam flowrate measurement equipment.
- 2) Improved refrigeration compressor sequencing and control.
- 3) Condensate recovery from the packaging hall.

In addition the following is recommended:

- 1) Implementation of the remaining schemes given in Table 24. These are:
  - improved housekeeping
  - boiler control
  - kVA monitoring
  - re-scheduling of refrigeration loads
  - lighting conservation
  - flash steam recovery
  - use of a steam accumulator
  - wort kettle vapour heat recovery
- 2) Formation of an energy management committee comprising a representative from each of engineering, projects, electrical, packaging, brewing, and fermentation departments.
- 3) An assessment should be made to decide where extra energy monitoring is required.
- 4) A detailed monthly energy report should be produced, with statistics on each section of the plant.
- 5) Each section of the plant should have a person who is held accountable for specific energy usage of that section.
- 6) Energy awareness should be fostered amongst employees, during training, and by dissemination of energy statistics.

## CHAPTER 7

### CONCLUSIONS

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#### 7.1 ENERGY MANAGEMENT ANALYSIS ON OHLSSON'S BREWERY

A full energy analysis of Ohlsson's Brewery was not possible because of the lack of records and monitoring equipment. Consequently much of the energy usage had to be calculated from vendor specifications and theoretical energy requirements, which could potentially give inaccurate results. With the expansion of the brewery more monitoring will be installed which will enable more accurate energy analyses.

Economically feasible energy saving schemes identified for Ohlsson's Brewery can reduce total primary energy requirements by 11,6 - 20%, which would be a saving of R70 000 - R108 000/month. A few of these schemes are already being implemented, and they should reduce total primary energy requirements by about 2,3%

#### 7.2 POTENTIAL ENERGY SAVINGS FOR THE SOUTH AFRICAN BREWING INDUSTRY

Potential energy savings identified for Ohlsson's Brewery will differ to those for other breweries in SA because some of the schemes proposed for Ohlsson's Brewery are already in use at some of the other SA breweries, some schemes presently at Ohlsson's Brewery could be implemented at other breweries, and some feasible fuel saving schemes for Ohlsson's brewery may not be feasible at other breweries because of discrepancies in coal prices. Breweries can be divided into three coal price groups:

Low-price coal (R60/ton - R90/ton)	73%	of beer production
Medium-price coal (R90/ton - R150/ton)	11%	"
High-price coal (>R150/ton)	16%	"

Most beer production in SA is at breweries in the low-price coal group, but Ohlsson's Brewery is in the high-priced group.

The following are schemes proposed for Ohlsson's Brewery that are expected to have similar potential energy savings for most other breweries in SA:

- All the low capital schemes - These are improved housekeeping, improved boiler control, optimal compressor sequencing, kVA monitoring, re-scheduling of process operations, and lighting.
- Flash steam recovery.

The following are schemes proposed for Ohlsson's Brewery that are expected to have different potential savings for most other breweries in SA:

- Condensate recovery - Condensate recovery is generally slightly higher at other breweries than at Ohlsson's Brewery, but there is still room for improvement. At the Rosslyn Brewery no condensate losses occur since a high temperature hot water system is used.
- Steam accumulators - Four breweries have steam accumulators, and they account for 58% of the beer produced in SA. Little scope exists for the installation of more steam accumulators, since, except for the Alrode Brewery, the large breweries already have accumulators and accumulators are not expected to be feasible for the smaller breweries, especially those in the low-price coal group.
- Wort kettle vapour heat recovery - No breweries in SA practise vapour heat recovery. Wort kettle vapour heat recovery is only economically feasible for the high-price coal group.

Table 25 shows the estimated potential energy savings for the brewing industry in SA. The 'other' category takes into consideration any energy saving schemes that are not relevant for Ohlsson's Brewery, but could be for other breweries.

Table 25. Estimated energy savings for the brewing industry in SA.

	% COAL REDUCTION	% ELEC. REDUCTION	% MAX DEMAND REDUCTION
<u>LOW CAPITAL SCHEMES</u>			
Housekeeping	2 - 5	2 - 5	2 - 5
Boiler control	1 - 3		
Compressor sequencing		1,7	
kVA monitoring			2 - 5
Re-scheduling			2,0
Lighting		1,0	
<u>MEDIUM CAPITAL SCHEMES</u>			
Condensate recovery	1,5		
Flash steam recovery	1,4		
<u>HIGH CAPITAL SCHEMES</u>			
Accumulator	0,8 - 1,6		
Vapour condensation	0,7 - 0,9		
<u>OTHER</u>	0 - 3	0 - 3	0 - 3
TOTAL	7,4 - 13,4	5,7 - 10,7	6,0 - 15,0
THOUSAND RAND/MONTH	87 - 157 <sup>a</sup>	92 - 172 <sup>b</sup>	63 - 157 <sup>c</sup>

<sup>a</sup> Coal usage is estimated at 13 000 ton/month. Took average price to be R90/ton.

<sup>b</sup> Electricity usage is estimated to be 23 000 MWh/month. Took average price to be 7c/kWh.

<sup>c</sup> Estimated the average electricity load factor to be 0,55. Took the average maximum demand charge to be R18/KVA.

From Table 24 the overall potential reduction in primary energy requirements are calculated to be 7,1% - 12,9%. These savings compare well to 10,9% - 14% estimated by the CSIR in 1986 (section 3.5.1). With all the above mentioned energy management schemes being implemented the specific energy requirement of the brewing industry would be 192 - 204 MJ/hl. The overall potential savings are R242 000/month - R486 000/month.

In addition research into the relationship between beer quality and the total evaporation in wort boiling, may result in the adoption of reduced total evaporation during wort boiling, resulting in significantly reduced energy requirements.

## **7.3 COMPARISON WITH OTHER COUNTRIES**

### **7.3.1 Comparison with energy targets**

Target specific energy requirement for breweries in Germany has been given<sup>(38)</sup> as 147 MJ/hl (converted to SA conditions). The discrepancy with that calculated for SA can be attributed to:

- Higher energy costs relative to production costs in Germany.
- Government incentive schemes for energy saving, such as tax reductions.
- Legislation regarding the forbidding of brewhouse vapours, means in many cases breweries have no choice but to condense the vapours.

### **7.3.2 Comparison with actual energy usages.**

In Chapter 3 it was shown that under SA conditions breweries in the UK and Germany would have specific energy requirements of about 175 MJ/hl. The target for SA breweries is slightly greater, which can be attributed to the reasons given in 7.3.1.

## CHAPTER 8

### RECOMMENDATIONS TO THE BREWING INDUSTRY

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The following are generally recommended:

- 1) The malt brewing industry in South Africa should establish a centralised energy committee to gather and disseminate information to each brewery, give advice on energy management programs, and monitor the success of these programs. Since the malt brewing industry in SA is monopolized by one company, the establishment of a centralised energy committee is not difficult.
- 2) Each brewery should form an energy management committee comprising a representative from each of engineering, projects, electrical, packaging, brewing, and fermentation departments. The purpose of the committee would be to establish energy targets, organise channels of accountability, develop and implement action plans, and report results to relevant persons.
- 3) Initially an assessment should be made on each brewery to decide where extra energy monitoring is required.
- 4) Each brewery should produce a detailed monthly energy report, with statistics on each major section of the plant.
- 5) Each section of the plant should have a person who is held accountable for specific energy usage of that section.
- 6) Energy awareness should be fostered amongst employees, during training, and by dissemination of energy statistics.

From the present investigation the following specific recommendations are made:

- 1) Research should be conducted into the relationship between total evaporation in the wort kettle and beer taste. In this way the energy cost can be evaluated for various total evaporations and associated beer tastes, and an appropriate total evaporation, taking into account energy costs, can be selected.
- 2) Alternative wort kettle boiling techniques, such as pressure boiling or continuous boiling, should be assessed for new breweries.
- 3) Housekeeping should be given more attention, which would involve improving maintenance and inspection programmes.
- 4) All schemes assessed for Ohlsson's Brewery in this study should be re-assessed for each brewery.

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## IMPORTANT AREAS IN ENERGY MANAGEMENT

### Tariff analysis and negotiation<sup>(6)(8)</sup>

It is important to periodically survey all fuel sources available and their different tariffs, to check that the fuel mix being used is the most economical one. There may also be sliding tariffs available or discounts for bulk which must be taken into account. It is most convenient to compare tariffs on the basis of cost per unit of useful energy where conversion efficiencies have been included. Tariff analysis would only be the first step in choosing fuels, since other factors must also be considered such as labour requirements, maintenance, fuel security, equipment costs etc.

Electricity is often available on more than one tariff scheme and it should be periodically checked that the most economical tariff scheme is being used. It is sometimes possible to negotiate for a lower demand charge if maximum demand should occur in off-peak times.

### Electricity demand management<sup>(11)(15)</sup>

The first step in demand management is to be able to monitor the demand continuously for the whole plant, and preferably for sub-processes as well. Subsequently it will be possible to obtain a typical daily and monthly electricity load curve, as shown in Figures A-1a and A-1b respectively.

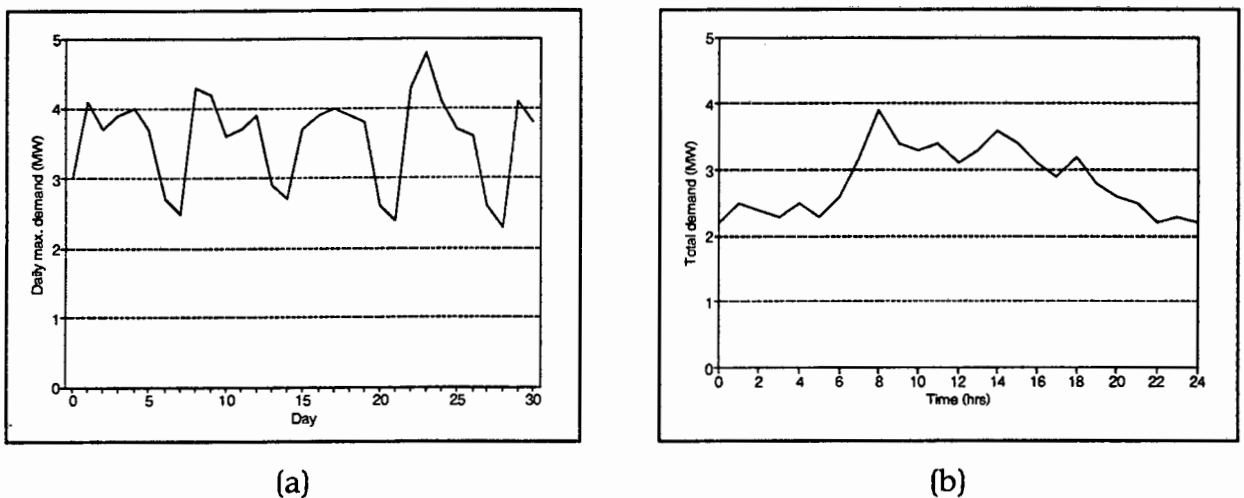


Figure A-1. Typical load curves a) Daily b) Monthly

From the monthly load curve it can be determined how the load varies over the month, and if any significant peaks should occur, the causes can be further investigated. The typical daily load curve should be broken down into its components. Each electrical load should then be categorized into one of the following areas for different time periods of the day<sup>(15)</sup>:

- Essential - cannot be shut off without affecting some important process.
- Interruptible - can be shut off for short periods.
- Housekeeping - must be run sometimes, but not essential to the process.
- Unnecessary - should not be switched on.

The daily load curve can then be divided into the four possible load groups. At this point demand management is easy as unnecessary loads can be shut off, housekeeping loads re-scheduled to off-peak times, and decisions can be made about controlling interruptible loads to limit peak demand.

### **Power factor Correction<sup>(6)</sup>**

Without the installation of power factor correction equipment, the power factor will normally range from 60% to 80%, depending on the ratio of the inductive to resistive loads. Power factor correction is almost always viable, and it is an economic decision as to the level of correction and whether manual switching and/or automatic control is to be used. Advantages of high values are<sup>(6)</sup>:

- Reduces maximum demand charges.
- Increases the load the electrical system can carry before exceeding the maximum kVA demand.
- Reduces load on an existing feeder, thus saving on number of feeders or allowing more load per feeder.
- Reduces voltage drop which will increase torque output of motors, decrease full load current, and decrease heating in motors.

### **Scheduling**

The efficient scheduling of operations will reduce substantial fluctuations in energy demand thus reducing the size of equipment and enabling equipment to operate more efficiently. In addition the maximum electricity demand charge will be reduced.

## Insulation<sup>(16)</sup>

Thermal insulation is used to reduce heat loss or gain of a surface. Generally insulation may either contain enclosed air pockets thus imparting a low thermal conductivity on the material, or it may be reflective thus preventing heat loss by radiation. When choosing an insulation the following criteria should be considered<sup>(16)</sup>:

- Performance in terms of thermal efficiency.
- Temperature range of the insulation.
- Durability.
- Cost.
- Flammability.
- Resistance to expected environment eg chemicals.
- Permeability to liquids.

Cold surfaces can attract water vapour by vapour pressure difference through an insulation layer. This vapour may condense saturating the insulation and reducing its insulating efficiency. Vapour sealing of cold insulation is thus important.

The most economic thickness depends on the cost of heat lost or gained, and the cost of the insulation, and can be determined by minimizing the total cost, as shown in Figure A-2.

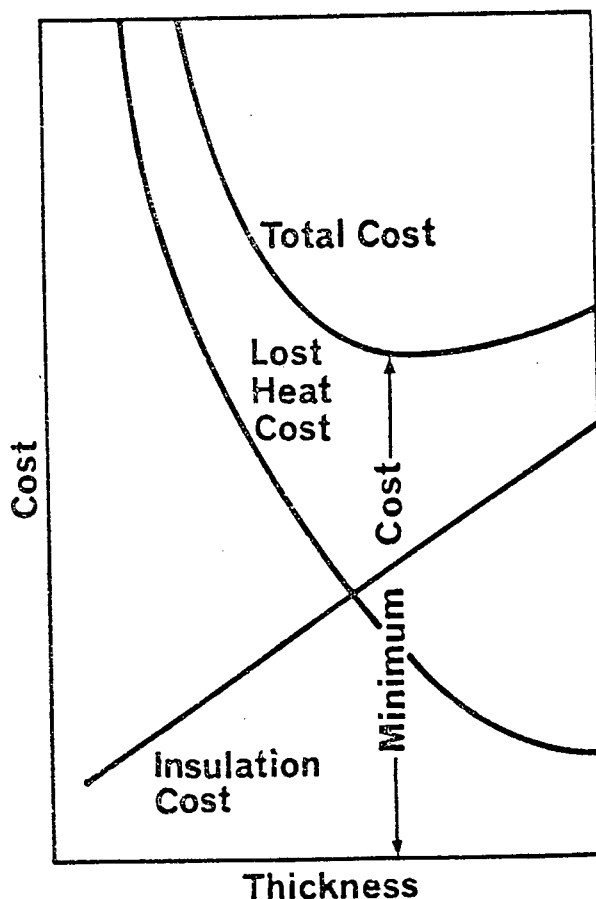


Figure A-2. Minimum insulation cost<sup>(18)</sup>.

## Steam

Steam is the common heating medium used on industrial sites, and in most cases deserves most energy management attention.

### Boilers<sup>(6)(17)(18)(19)</sup>

Generally it is better to operate boilers at their lowest possible pressures, or operate at the lowest allowable pressure required in the process (including transmission pressure drops). Superheated steam is less efficient for process heating than dry saturated steam.

Boiler efficiencies at full load should be over 80%, but in practice efficiencies normally range from 60-85%, and typical contributions to losses are:

Dry flue gas loss	5-30%
Water vapour loss	3-5%
Carbon loss	1-3%
Incomplete combustion	1-2%
Blowdown loss	0,5-1%
Radiation loss	1-2%
Unaccountable loss	1-2%

**Dry flue gas loss** - This loss arises as nitrogen and the gaseous combustion products leave the boiler at elevated temperature. Optimisation of the air/fuel ratio ensures that no more excess air than that required is used. Older controls generally give high air/fuel ratios at low loads, and thus boiler efficiency will decrease. Controls based on measuring the oxygen in the flue gases have been found to be an effective method of optimizing the air/fuel ratio. Sootblowing at frequent intervals ensures fouling of the fireside heat transfer surface is kept to a minimum, thus enabling the hot gases to impart more of their sensible heat to the boiler water. Use of economizers or air pre-heaters to recover flue gas heat, generally saves 3-4% of the fuel. However the flue gas temperature should not be allowed to fall below the acid dew-point (about 130°C) otherwise corrosion could be a problem.

**Water vapour loss** - Water entering the boiler with the fuel, and water formed by the combustion of the hydrogen, leave the boiler as superheated vapour. A certain amount of surface moisture is desirable for coal, ie 3-5% water by mass, but excessive surface water can reduce boiler efficiency.

**Carbon loss** - Some carbon will be left in the ash, which can be significant if the fuel/air ratio is not correct.

**Incomplete combustion** - Small amounts of CO, H<sub>2</sub>, and hydrocarbons are found in the flue gases.

**Blowdown loss** - a certain amount of blowdown is necessary to ensure that the total dissolved solids does not rise too high otherwise scale can form. Proper blowdown control ensures that the minimum amount of blowdown necessary occurs. Blowdown heat recovery can recover some of the heat lost in the blowdown. It is possible to buy automatic blowdown and heat recovery equipment. Continuous blowdown has the advantage of less blowdown and the possibility of continuous heat recovery.

**Radiation loss** - Proper insulation is necessary to reduce radiation losses. The smaller the percentage load of the boiler the more significant radiation loss becomes.

#### Steam accumulators<sup>(6)(19)</sup>

Boiler efficiency decreases as less of the boiler capacity is used, and with increased fluctuation in steam demand. If steam demand should fluctuate significantly it is often feasible to install a steam accumulator to absorb the fluctuations, enabling boilers to operate more efficiently. Accumulators will also reduce the maximum required boiler capacity, and may enable the plant to operate on fewer boilers.

#### Distribution<sup>(18)(19)</sup>

Redundant piping should be removed, pipes adequately insulated, and provision made for removal of condensed water in steam pipes.

#### Steam traps<sup>(18)(19)</sup>

Steam traps can be a significant source of wasted energy if faulty. Regular inspections should be made to check that traps are not blowing through ie steam passes through the trap, and that traps have not fail closed, so that condensate builds up on the steam side, reducing heat transfer efficiency.

#### Steam leaks<sup>(17)</sup>

Figure A-3 shows the cost of various size leaks (based on coal costing R100/t, with a calorific value of 27,5 MJ/kg, and with a 75% conversion efficiency to steam). It is apparent that the costs of locating and repairing steam leaks would be negligible compared to the cost of the lost steam.

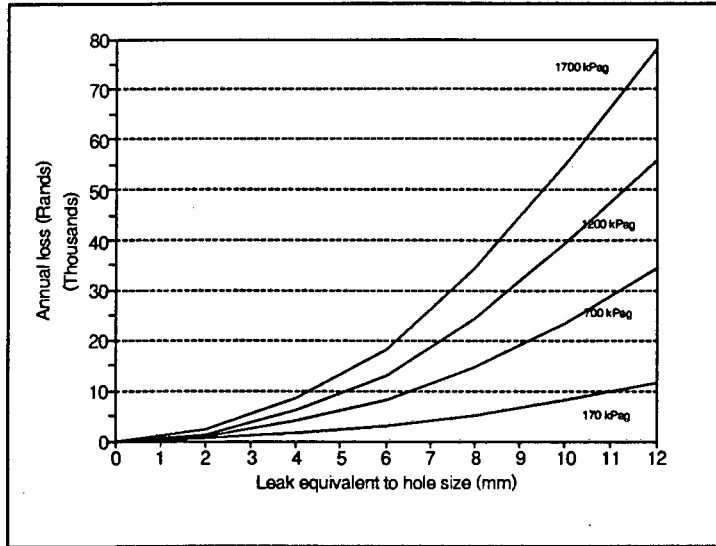


Figure A-3. Annual cost of steam leaks<sup>(18)</sup> (R4,85/GJ).

Condensate return<sup>(17)(18)</sup>

Figure A-4 shows how returning condensate can save on fuel. An 80% condensate return at 85°C will save 10% of the fuel required if no condensate is returned. Returning condensate also saves on chemical treatment.

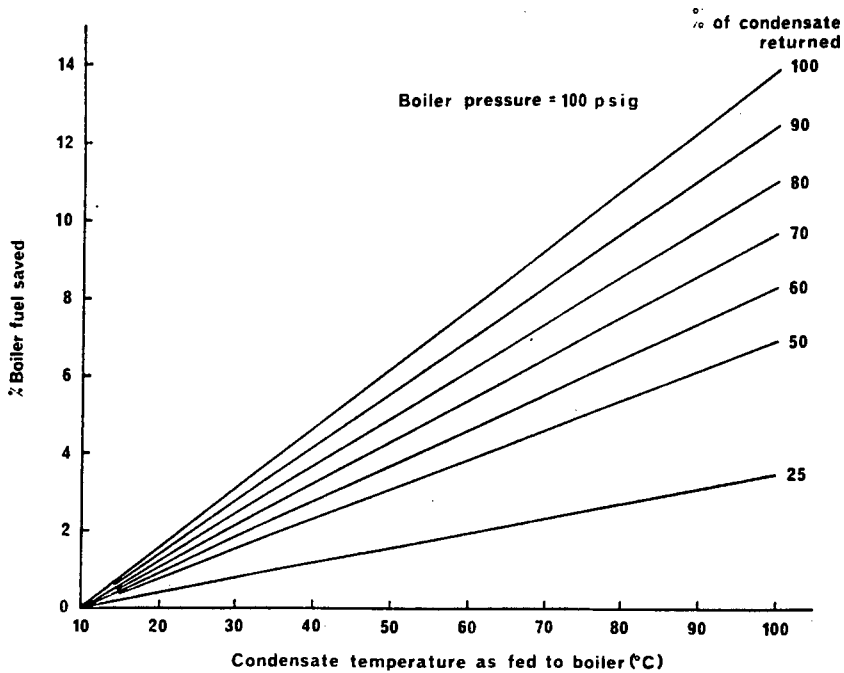


Figure A-4. Boiler fuel savings as a result of condensate return<sup>(17)</sup>.

**Flash steam heat recovery**<sup>(18)(19)</sup>

When the pressure of saturated water is reduced a certain portion of that water evaporates forming flash steam. Figure A-5 shows the quantities of flash steam produced under various operating conditions.

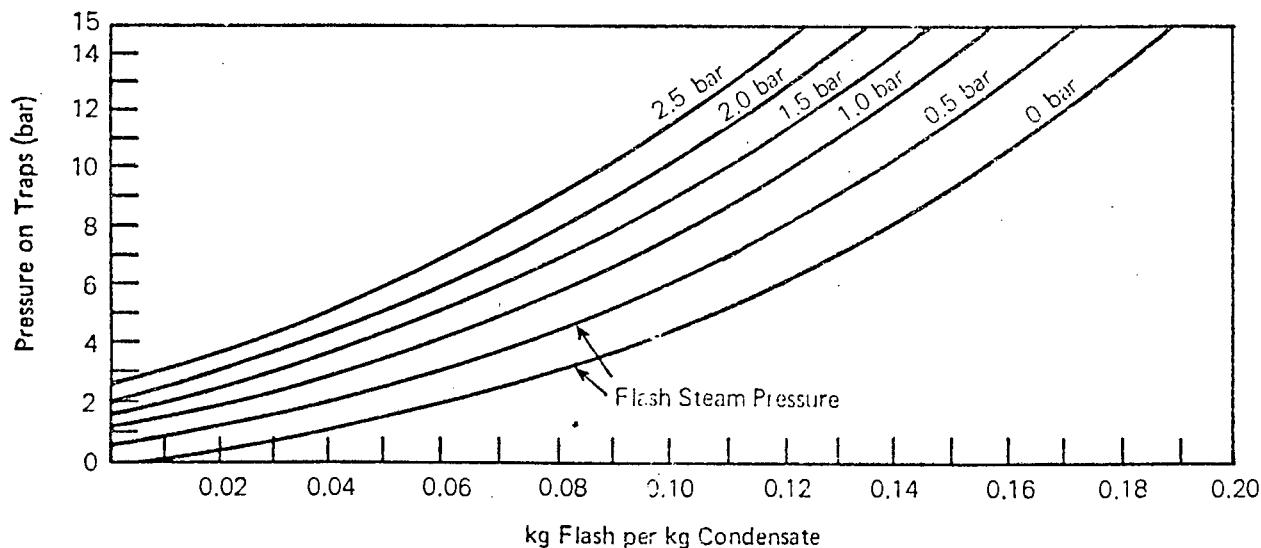


Figure A-5. Quantities of flash steam available under various operating conditions<sup>(18)</sup>.

For a trap operating at 700 kPag discharging condensate at 100 kPag (gauge) 10% of the condensate will flash. This flash steam could be used for heating thus saving on fuel. The flash can be recovered by using a flash vessel either in the common condensate return system or after the traps on large units using high pressure steam.

**Refrigeration**<sup>(6)(20)(21)(22)</sup>

Basically the refrigeration process extracts heat from a colder body and rejects it to a hotter body. Refrigeration efficiency is given by the coefficient of performance (COP) which is defined as the ratio of the energy absorbed from the cooler body to the energy rejected to the hotter body. The maximum COP (Carnot refrigerator) can be derived from fundamental thermodynamics to be:

$$\text{COP} = T_1 / (T_2 - T_1)$$

T1 - evaporator temperature  
T2 - condenser temperature

Consequently the closer the evaporator and condenser temperatures, the higher the COP, and thus the less electrical work required for an equivalent amount of cooling.

Evaporation pressure should thus be as high as possible, and condensing pressure as low as is practical. The actual COP is usually 60% of the theoretical value.

Factors affecting refrigeration energy requirements are:

- Choice of refrigerant.
- Type, capacity, and number of compressors required.
- The use of a secondary refrigerant, and if so the temperature level and type of secondary refrigerant to be used. Disadvantages of primary refrigerant use are possible safety hazards and cost of primary refrigerant is often prohibitive. However the main advantage is that higher evaporating temperatures can be used since one heat exchange step is eliminated.
- Type of expansion device.
- Design and operation of cooling utility heat exchangers.
- Scale and corrosion on condensers.

Some energy saving techniques are:

- Waste heat recovery from compressors.
- Running most efficient machines first.
- Automatic sequencing of compressors.
- Checking condensers for scale and corrosion.
- Providing cold-room doorways with plastic strip curtains.
- Reducing unnecessary refrigerant flows, as about 95% of the electrical input to the pump ends up as frictional heat in the refrigerant. Doubling the flow through a pipe increases pump power by a factor of 8.

### **Compressed air<sup>(11)(23)</sup>**

Compressed air is an expensive service and it should not be used unnecessarily for cleaning or cooling. Compressors should be sized correctly so that they operate at maximum efficiency, instead of running unloaded or partly loaded most of the time. The minimum air pressure possible should be used. This means reviewing all air systems to determine what minimum pressures equipment must have to operate, and considering the use of remote compressors if air pressure requirements should vary considerably. Lowering discharge pressure has the advantage of reducing energy consumption, for example lowering air pressure from 700 kPa to 350 kPa reduces power by about 30 %.

In addition compressor capacity is increased, and life of parts is extended due to the lower compression heat.

Leakage can often account for 25-30% of the total compressor capacity in badly maintained systems. It is easiest to detect air leaks when the plant is quiet ie during shutdown. Figure A-6 shows the cost of various sized leaks (based on an electricity energy tariff of 7c/kWh). As with steam leaks, it is evident that the cost of locating and repairing air leaks would be negligible in comparison to the cost of wasted compressed air.

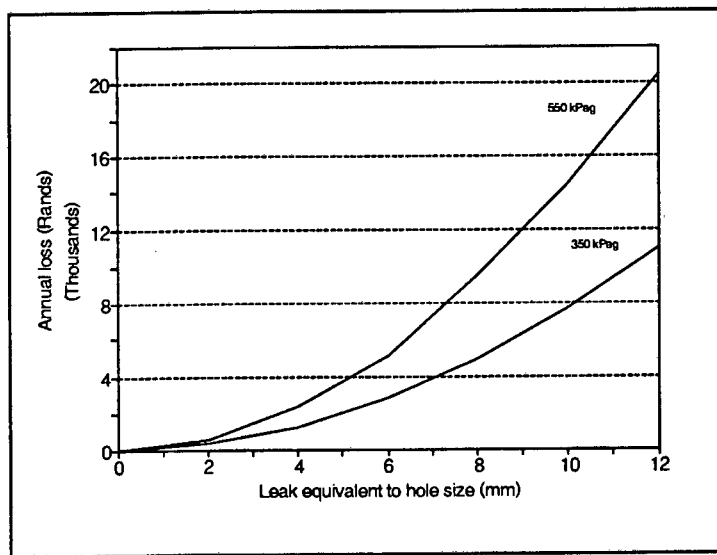


Figure A-6. Annual cost of compressed air leaks<sup>(18)</sup> (7c/kWh).

Efficiency of air compression is about 18%, with the rest of the energy being wasted in the cooling system. Recovery of this heat from the cooling medium ie water/oil/air should be considered.

## Pumping<sup>(6)</sup>

Pumping is usually a major consumer of power, and thus increasing hydraulic efficiency by better specification of pumps requires careful consideration. As an example it is desirable to have about a 15% safety factor when selecting a centrifugal pump, so the pump chosen would be one with a characteristic curve such as in Figure A-7.

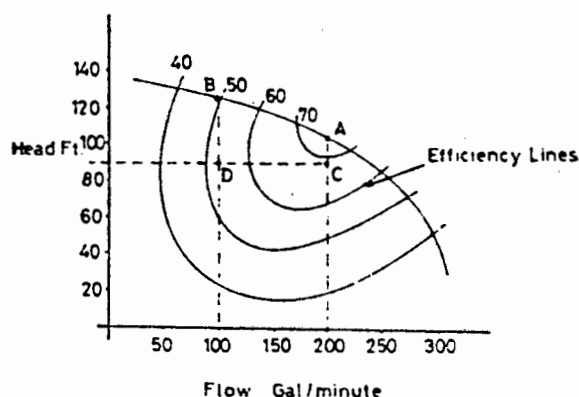


Figure A-7. Efficiency curves for a centrifugal pump<sup>(44)</sup>.

If the actual liquid volume pumped is half that designed for, then one would operate at point B although the head requirements is only that at point D. Thus only 75% of the generated head is utilised and pump efficiency is 53%, giving a total hydraulic efficiency of only 40%. If operation was at C then the hydraulic efficiency would have been 58%.

## Lighting<sup>(24)</sup>

Lighting that is left on unnecessarily during the night costs about R307/kW per annum (at 7c/kWh). A further consideration is the relative efficiency of various lighting sources, normally expressed as lumens/watt. Light sources with the highest lumens/watt should be used. Typical values for various light sources are<sup>(24)</sup>:

	Lumens/Watt
Tungsten filament lamps	15
Tungsten halogen lamps	22
High pressure mercury vapour discharge lamps	50
Fluorescent tubes	65
High pressure sodium vapour discharge lamps	100

### **Combined heat and power generation (CHP)<sup>(6)</sup>**

There are a variety of equipment combinations that can make up a CHP system. The most common method is by producing superheated steam at a high pressure in a boiler and then expanded down to the pressure required for the process through a back pressure turbine which drives an electric generator thus producing electricity. It will be necessary to retrofit a superheater to a boiler. Thermal efficiencies may be as high as 80% for well designed and maintained systems. For any industrial plant which uses large quantities of steam (over 20 ton/hr), and imports all of its electricity from the public supply, the feasibility of CHP should be evaluated.

Stationary internal combustion engines running on fossil fuels have been used during high tariff and high demand times in some overseas plants. However in South Africa the price of electricity is still too cheap to justify their use in most industrial applications.

### **Heat pumps<sup>(25)</sup>**

A heat pump is a system that raises heat from a low temperature level to a higher temperature level at which it can be exploited. Physically it corresponds to the compression refrigeration cycle, and performance is likewise measured by the COP, which is typically 2,5-3. Heat pumps have so far only found low temperature applications (< 100°C), because high temperature working media are prohibitively expensive. Heat sources in industrial processes are usually low grade heat such as waste water or exhaust air.

### **Maintenance and inspection<sup>(11)</sup>**

There is often a close relationship between energy efficiency and the level of maintenance on a plant, and hence the motivation for having a maintenance representative on the energy committee. Planned maintenance and inspection is essential in preventing corrosion, cracking, fouling, leaks, malfunctioning equipment (eg steam traps), and inaccurate or inoperative control devices.

## PINCH TECHNOLOGY

**Minimum approach temperature**

The minimum approach temperature ( $\Delta T_{\min}$ ) allowed between two streams in a heat exchanger is generally assigned a global value for a particular network. The optimum is that which gives the lowest overall cost for the network, where the overall cost is the sum of the capital cost and the operating cost. It is however, possible to incorporate stream-dependent  $\Delta T_{\min}$  values into the analysis.

**Composite curves**

Composite curves are used to show energy flows within a specified network. Streams are divided into hot streams, which require cooling; and cold streams, which require heating. A hot composite curve is then drawn up, by first plotting temperature against enthalpy for the hot streams, as shown in Figure B-1. By combining the curves for all the hot streams, a composite curve can be generated, as shown in Figure B-2.

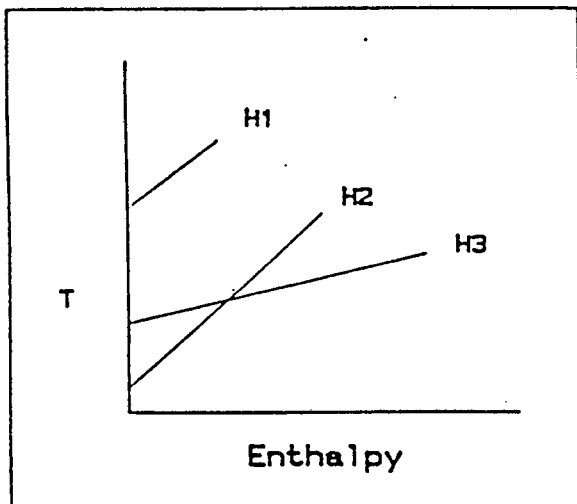


Figure B-1. Temperature vs enthalpy<sup>(28)</sup>.

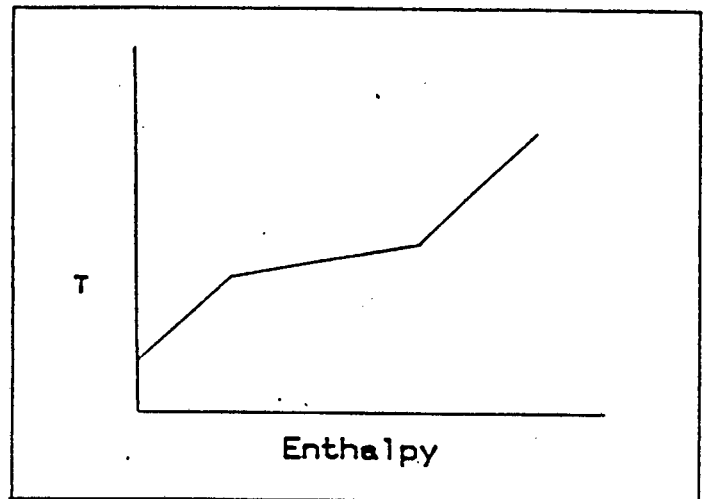


Figure B-2. The hot composite curve<sup>(28)</sup>.

A cold composite curve can be similarly generated, and then the composite curves are plotted on the same diagram such that the minimum vertical distance between the composite curves is  $\Delta T_{\min}$ , as shown in Figure B-3.

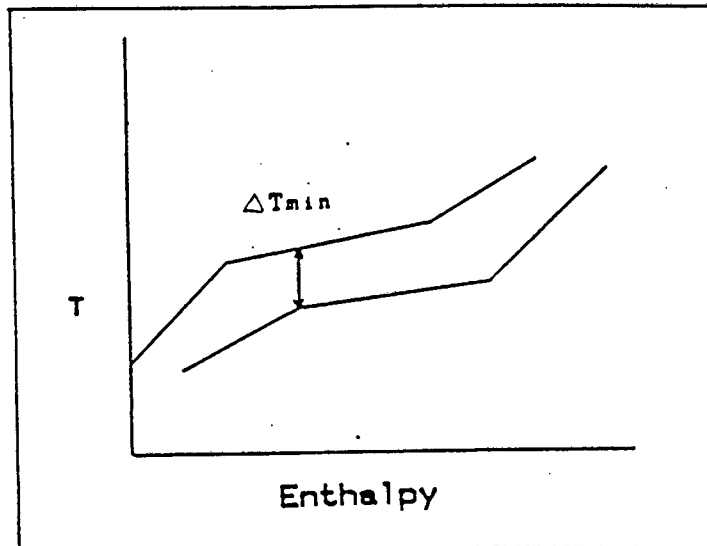


Figure B-3. Hot and cold composite curves with  $\Delta T_{\min}$  <sup>(28)</sup>.

### Minimum utility usage

The minimum hot utility requirement ( $Q_{h\min}$ ) is the final enthalpy of the cold curve minus the final enthalpy of the hot curve, and the minimum cold utility requirement ( $Q_{c\min}$ ) is the initial enthalpy of the cold curve minus the initial enthalpy of the hot curve. The point at which  $\Delta T_{\min}$  occurs is called the pinch, and the significance of the pinch is that it divides the system into two thermodynamically separate subsystems. Maximum energy efficiency will be achieved if three basic rules are observed<sup>(27)</sup>:

- 1) The cold utility should only be used to cool streams that are below the pinch temperature. For every MW of cooling above the pinch, an extra MW of heating is required.
- 2) The hot utility should only be used to heat streams above the pinch temperature. For every MW of heating below the pinch, an extra MW of cooling will be required.
- 3) No heat exchange should occur between process streams when their temperatures lie on either side of the pinch temperature. For every unit of heat transferred across the pinch, an extra unit of heating and an extra unit of cooling will be required.

## Heat exchange area

The composite curves can be divided into enthalpy intervals as shown in Figure B-4.

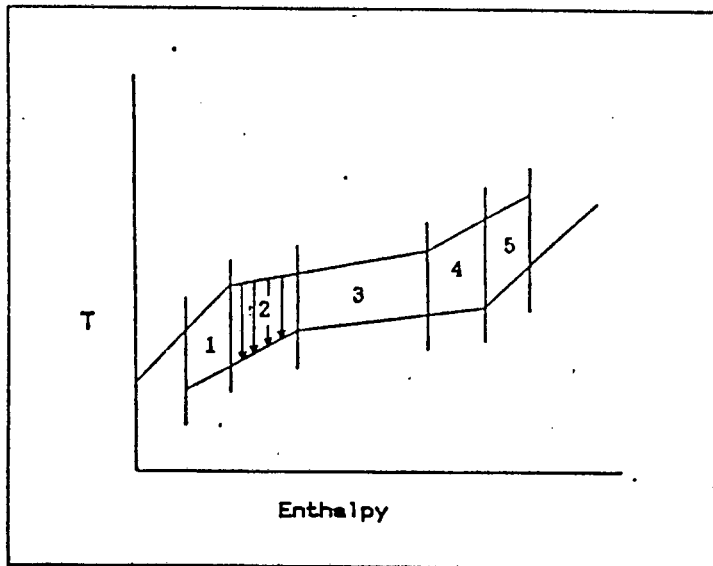


Figure B-4. Enthalpy intervals<sup>(28)</sup>.

Each interval may be assumed to represent an imaginary counter-current heat exchanger, with area given by:

$$A = Q / (U * \Delta T_{lm})$$

where  $A$  = area for heat exchange

$Q$  = energy transferred

$U$  = overall heat transfer coefficient

$\Delta T_{lm}$  = log mean temperature difference

The minimum heat exchange area is given by the sum of the heat exchange areas for each interval ie

$$A_{min} = \sum_j Q_j / (U_j * (\Delta T_{lm})_j)$$

### Number of heat exchange units

The minimum number of heat exchange units can be calculated using Euler's Network Theorem, which can be modified for a heat exchanger network ie

$$\text{Minimum number of units} = \text{number of streams} + \text{minimum number of loops} - \text{maximum number of subsets}$$

For most networks there are no loops and one subset<sup>(27)</sup> ie

$$\text{Minimum number of units} = \text{number of streams} - 1$$

The minimum number of heat exchange units required for maximum heat recovery is found by treating the networks above and below the pinch as two independent problems. The minimum number of units for the entire network will frequently be less than that for maximum heat recovery, but requires heat transfer across the pinch ie thus increasing  $Q_h$  and  $Q_c$  above the minimum values. Only an economic analysis can determine which system is better. Essentially the most economic system will be a trade-off between required equipment area and utility costs.

### Applying pinch technology to existing plants

The methodology described thus far, only applies to grassroots designs. Retrofit projects have to be improvised, since each candidate has a unique problem with opportunities and constraints, with the most economically viable design possibly looking quite different from the optimum grassroots design.

Figure B-5 (next page) shows minimum area vs energy requirements for a particular problem, indicating the optimum grassroots design and the existing network. It can be seen that it would probably not make sense to aim for the optimum grassroots design, since area that has already been paid for would have to be discarded.

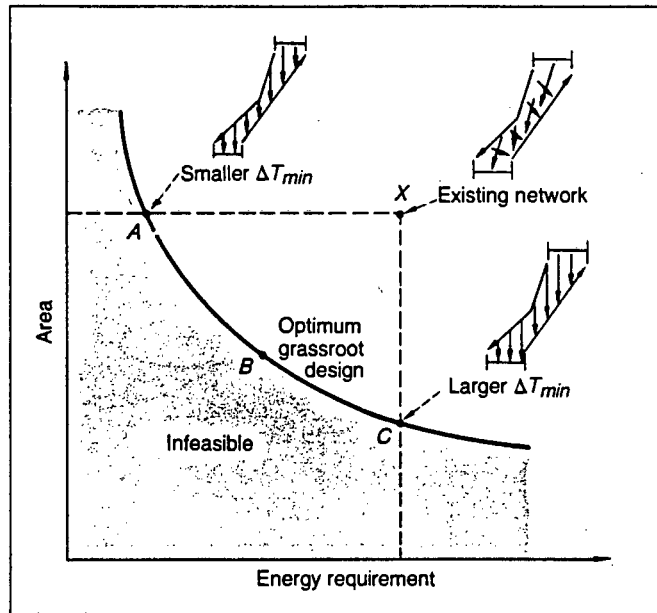


Figure B-5. Energy target vs heat exchange area target<sup>(29)</sup>.

Figure B-6 shows the most likely direction of the optimum retrofit design.

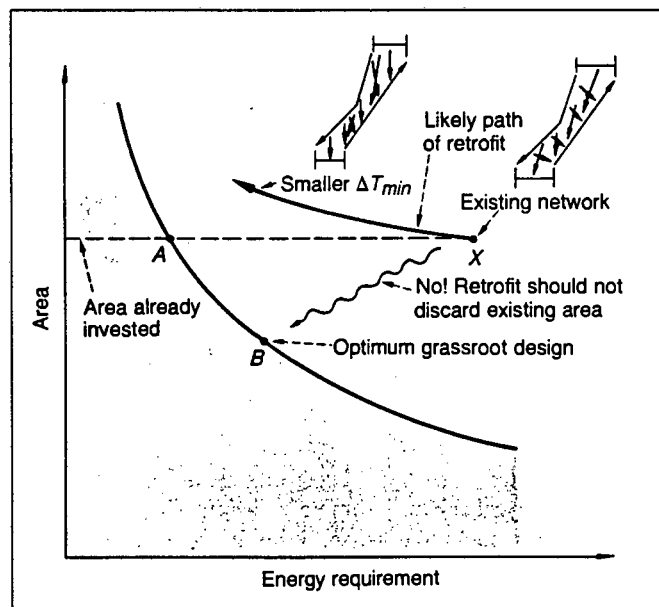


Figure B-6. A retrofit should try to reach A, not B, to take full advantage of existing area.

No rigorous methodology exists to find the optimum retrofit design, but the following procedure can be of valuable assistance<sup>(27)(29)</sup>:

- Perform a heat and material balance, calculate a mean optimum  $\Delta T_{\min}$ , construct the hot and cold composite curves, and identify the pinch point and utility targets.
- Identify and eliminate cross-pinch heat exchangers.
- Complete the network using, where possible, eliminated cross-pinch heat exchangers.
- Evolve improvements by examining the shifting of heat exchangers and points of utilities usage. Examine the economies of each improvement, so the path of optimum retrofit design can be found by iteration.

### Applying pinch technology to batch processes

The dimension of time in batch processes imposes constraints and limitations on energy integration, not present in continuous processes. Two approaches incorporating pinch technology have been used ie the Overall Plant Bottleneck and the Time-Temperature Cascade approaches. It is claimed<sup>(26)</sup> that the Time-Temperature Cascade approach is not rigorous, and can miss some design opportunities. This method is also longwinded and is consequently not considered.

The Overall Plant Bottleneck approach<sup>(26)(30)</sup> is based on the identification of bottlenecks which prevent the plant from reaching its otherwise achievable performance. Time is accounted for by generating two types of models; the 'time average model' (TAM) and the 'time slice model' (TSM). The TAM ignores time by averaging energy values over a chosen period. A pinch analysis is then carried out and minimum utility requirements calculated, which will be the very minimum achievable target.

The TSM divides time into periods when heat flows occur, and a pinch analysis carried out for each time period. Total utility requirements are calculated by summing utility requirements for each time interval, thus giving total minimum utility requirements with no storage. The effects of storage can easily be investigated by matching utility requirements of different time periods, and weighing up the capital cost for storage against the utility savings. Rescheduling can also be investigated by recalculating utility requirements for various revised schedules. The utility requirements calculated by the TAM should be targeted for. It is however important to realise that rescheduling may influence plant capacity, flexibility, process yields etc as well as energy consumption.

## METHODS OF ECONOMIC ANALYSIS

The net cash flow at any time is the difference between earnings and expenditure, and a cash flow diagram, such as that shown in Figure C-1 shows the forecast cumulative net cash flow over the life of a project.

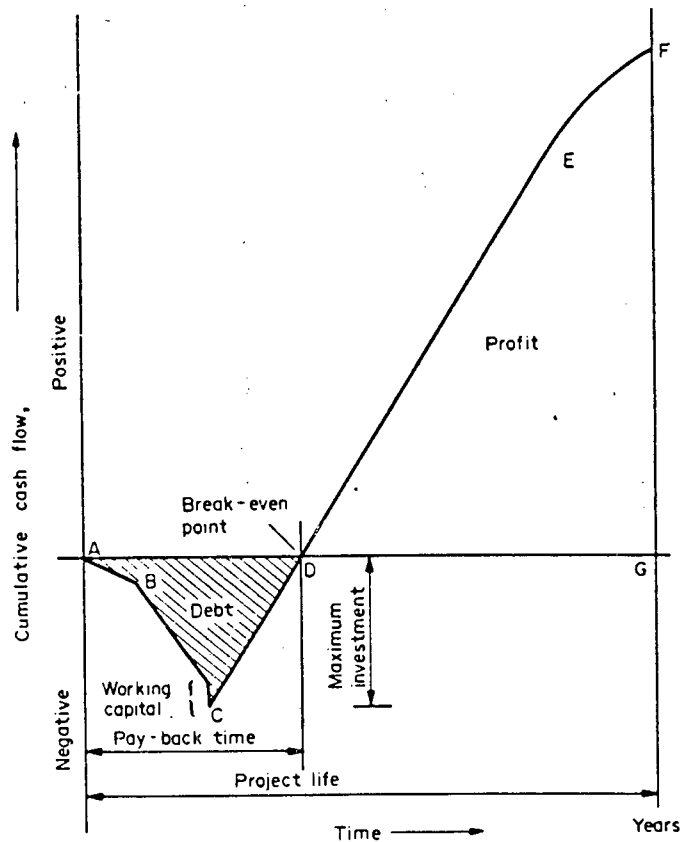


Figure C-1. Project cash-flow diagram<sup>(14)</sup>.

### Capital investment

Investment can be used for the selection of proposals for small projects and for simple choices where the benefits far outweigh the investment.

### Payback time

Payback time is the time required after the start of a project to pay off the initial investment with energy savings, and is often simply calculated by dividing the capital

investment by expected annual energy savings. Payback time ignores interest and escalation costs, expected lives of equipment, costs or savings beyond the payback time, and the return on investment. This method of evaluation is normally acceptable if the pay-back period is short (one to three years).

### Net present value (NPV)

In Figure C-1 the net cash flow is shown at its value in the year in which it occurred, so the figures on the ordinate show the cumulative net future value of a project. The money earned in any year can be reinvested as soon as it is made available to earn a return or interest above inflation, called the discount rate ( $r$ ), which is the earning power of money and differs between companies. The total NPV of a project over the project life ( $t$  years) can be calculated as follows from net future value (NFV) as follows:

$$\text{Total NPV} = \sum_{n=1}^t \text{NFV}/(1+r)^n$$

The NPV should be positive for a project to be accepted.

### Rate of return (RR)

RR provides a measure of the performance of capital. It is the ratio of annual profit to investment, and although it is a simple concept, the calculation of RR is complicated by the fact that the annual profit will not be constant over the system life. The simplest method is to base the RR on the average income over the life of the project and the original investment.

$$\text{RR} = \text{total NFV}/(t \times \text{investment})$$

This simple RR calculation does not take into account the time value of money, and is consequently only used as a rough indication of the profitability of a project.

### Internal rate of return (IRR)

IRR is the discount rate at which the total NPV at the end of a project is zero ie

$$\sum_{n=1}^t \text{NFV}/(1+\text{IRR})^n = 0$$

The IRR is usually found by trial-and-error. A figure of 20 to 30 % can be used as a rough guide for judging proposals. For NPV, RR, and IRR it must be remembered that there will be tax on net savings, and this may also be included in the calculations.

APPENDIX D

PRIMARY ENERGY REQUIREMENTS

Table D-1. Primary energy requirements.

	Apr	May	June	July	Aug	Sept	Mean
PACKAGED (hl)	175630	222106	146528	162070	110947	169900	164530
BREWED (hl)	133009	147627	137636	79496	125065	151635	129078
PRODUCED (hl)	154319	184866	142082	120783	118006	160767	146803
COAL (t)	1067	1124	1044	1012	947	1127	1053
OIL (l)	27774	38734	72483	16277	21364	20627	32876
COAL EQUIV. (t)	1110	1184	1157	1037	980	1159	1104
kg COAL EQUIV./ hl PRODUCED	7.19	6.40	8.14	8.59	8.30	7.21	7.64
ELEC. (Mwh)	1875	1739	1646	1831	1605	1807	1750
(MVA)	3720	3720	3600	3600	3984	4500	3854
kWh/hl PRODUCED	12.15	9.41	11.58	15.16	13.60	11.24	12.19

## STEAM REQUIREMENT CALCULATIONS

---

Since about 80% of the beer produced is LION, calculations were based on requirements for this brand. All pressures given are gauge pressure. Saturated dry steam is assumed at the inlet to all heating areas.

### 1) Steinecker brewhouse

#### Heat losses

Heat loss occurs from the surface of the vessel and the surface of the liquid in the vessel. During rest periods (no heating) these heat losses are taken into account by the temperature drop. However during heating periods these losses must be accounted for. Pensel<sup>(38)</sup> gives typical heat losses during heating and boiling to be 5%, and this was used.

#### Maize cooker

Volume of liquid	160 hl
Density of liquid	1,07 kg/l
Heat capacity of liquid	3,7 kJ/(kg.K)
Latent heat of vapour	2257 kJ/kg
Steam pressure	320 kPag
Latent heat of steam	2127 kJ/kg

Heating program for the maize cooker is:

Mash pumped in	25 min
Rest; final temp 56°C	15 min
Heat to 80°C	20 min
Rest; final temp 78°C	25 min
Heat to 100°C	20 min
Boil (6% boil off)	30 min

$Q_{\text{heat 1}}$

$$= 160 \text{ hl} * 107 \text{ kg/hl} * 3,7 \text{ kJ}/(\text{kg} \cdot ^\circ\text{C}) * (80 - 56)^\circ\text{C} * 1,05 / (20 * 60 \text{ sec})$$

$$= 1330 \text{ kW}$$

$Q_{\text{heat 2}}$

$$= 160 \text{ hl} * 107 \text{ kg/hl} * 3,7 \text{ kJ}/(\text{kg} \cdot ^\circ\text{C}) * (100 - 78)^\circ\text{C} * 1,05 / (20 * 60 \text{ sec})$$

$$= 1220 \text{ kW}$$

$$\begin{aligned}
 Q_{\text{boil}} &= 0,06 * 160 \text{ hl} * 107 \text{ kg/hl} * 2257 \text{ kJ/kg} * 1,05 / (30 * 60 \text{ sec}) \\
 &= 1352 \text{ kW}
 \end{aligned}$$

Mash tun

Volume of liquid	540 hl
Density of liquid	1,06 kg/l
Heat capacity of liquid	3,7 kJ/(kg.K)
Steam pressure	180 kPag
Latent heat of steam	2170 kJ/kg

Heating program for mash tun is:

Mash pumped in	30 min
Rest; final temp @ 45°C	15 min
Maize cooker pump over	20 min
Rest; final temp 62°C	25 min
Heat to 67°C	10 min
Rest; final temp 66°C	30 min
Heat to 72°C	8 min
Rest; final temp 72°C	10 min
Heat to 78°C	8 min

$$\begin{aligned}
 Q_{\text{heat 1}} &= 540 \text{ hl} * 106 \text{ kg/hl} * 3,7 \text{ kJ}/(\text{kg} \cdot ^\circ\text{C}) * (67 - 62^\circ\text{C}) * 1,05 / (10 * 60 \text{ sec}) \\
 &= 1853 \text{ kW}
 \end{aligned}$$

$$\begin{aligned}
 Q_{\text{heat 2}} &= 540 \text{ hl} * 106 \text{ kg/hl} * 3,7 \text{ kJ}/(\text{kg} \cdot ^\circ\text{C}) * (72 - 66^\circ\text{C}) * 1,05 / (8 * 60 \text{ sec}) \\
 &= 2780 \text{ kW}
 \end{aligned}$$

$$\begin{aligned}
 Q_{\text{heat 3}} &= 540 \text{ hl} * 106 \text{ kg/hl} * 3,7 \text{ kJ}/(\text{kg} \cdot ^\circ\text{C}) * (78 - 72^\circ\text{C}) * 1,05 / (8 * 60 \text{ sec}) \\
 &= 2780 \text{ kW}
 \end{aligned}$$

Wort kettle

Liquid volume before heat	710 hl
after boil	660 hl
Adjunct volume added during boil	20 hl
Topping up water volume added	10 hl
Density of liquid before boil	1,04 kg/l
after boil	1,06 kg/l
Density of water at 100°C	0,96 kg/l
Heat capacity of liquid	4,0 kJ/(kg.K)
Latent heat of vapour	2257 kJ/kg
Steam pressure	480 kPag
Latent heat of steam	2089 kJ/kg

Heating program for the wort kettle is:

Pump over @ 74°C	80 min
Heat to 98°C	60 min
Boil	90 min

$$\begin{aligned}
 Q_{\text{heat 1}} &= 710 \text{ hl} * 104 \text{ kg/hl} * 4,0 \text{ kJ}/(\text{kg} \cdot \text{°C}) * (98 - 74\text{°C}) * 1,05 / (60 * 60 \text{ sec}) \\
 &= 2067 \text{ kW}
 \end{aligned}$$

$$\begin{aligned}
 Q_{\text{boil}} &= (710 + 20 + 10 - 660) \text{ hl} * 96 \text{ kg/hl} * 2257 \text{ kJ/kg} * 1,05 / (90 * 60 \text{ sec}) \\
 &= 3370 \text{ kW}
 \end{aligned}$$

Summary

Average steam demand is calculated using 102 brews/month/brewhouse on average.

*Table E-1. Steam requirements in the Steinecker brewhouse.*

	DURATION (min)	HEAT LOAD (kW)	STEAM DEMAND (kg/hr)	AVERAGE STEAM DEMAND (kg/hr)
<u>Maize cooker</u>				
heat 1	20	1330	2251	106
heat 2	20	1220	2065	98
boil	30	1352	2288	162
<u>Mash tun</u>				
heat 1	10	1853	3074	73
heat 2	8	2780	4612	79
heat 3	8	2780	4612	79
<u>Wort kettle</u>				
heat 1	60	2067	3562	505
boil	90	3370	5809	1234

## 2) Huppmann brewhouse

The same assumptions are made as for the Steinecker brewhouse. The Huppmann brewhouse handles slightly larger batches, and some operating conditions are different.

### Maize cooker

Volume of liquid	170 hl
Density of liquid	1,07 kg/l
Heat capacity of liquid	3,7 kJ/(kg.°C)
Latent heat of vapour	2257 kJ/kg
Steam pressure	320 kPag
Latent heat of steam	2127 kJ/kg

Heating program for the maize cooker is:

Mash pumped in	30 min
Rest; final temp 56°C	10 min
Heat to 80°C	14 min
Rest; final temp 78°C	25 min
Heat to 100°C	14 min
Boil (8% boil off)	30 min

#### Mash tun

Volume of liquid	555 hl
Density of liquid	1,06 kg/l
Heat capacity of liquid	3,7 kJ/(kg.°C)
Steam pressure	180 kPag
Latent heat of steam	2170 kJ/kg

Heating program for mash tun is:

Mash pumped in	30 min
Rest @ 45°C	10 min
Maize cooker pump over	10 min
Rest; final temp 62°C	25 min
Heat to 67°C	6 min
Rest; final temp 66°C	30 min
Heat to 72°C	8 min
Rest; final temp 72°C	5 min
Heat to 78°C	8 min

#### Wort kettle

Liquid volume before heat	740 hl
after boil	700 hl
Liquid adjunct added during boil	20 hl
Topping up water volume added	10 hl
Density of liquid before boil	1,04 kg/l
after boil	1,06 kg/l
Density of water at 100°C	0,96 kg/l
Heat capacity of liquid	4,0 kJ/(kg.°C)
Latent heat of vapour	2257 kJ/kg
Steam pressure	480 kPag
Latent heat of steam	2089 kJ/kg

Steam pressure 480 kPag  
 Latent heat of steam 2089 kJ/kg

Heating program for the wort kettle is:

Pump over @ 74°C 80 min  
 Heat to 98°C 60 min  
 Boil 75 min

Summary

Table E-2. Steam requirements in the Huppmann brewhouse.

	DURATION (min)	HEAT LOAD (kW)	STEAM DEMAND (kg/hr)	AVERAGE STEAM DEMAND (kg/hr)
<u>Maize cooker</u>				
heat 1	14	2019	3417	113
heat 2	14	1851	3133	104
boil	30	1791	3031	215
<u>Mash tun</u>				
heat 1	6	3174	5266	75
heat 2	8	2857	4740	90
heat 3	8	2857	4740	90
<u>Wort kettle</u>				
heat	60	2154	3712	525
boil	75	3540	6100	1080

### 3) Packaging hall

#### Line 1 pasteurizer

H&K double deck tunnel pasteurizer

Type BETA P II S/35-250

42 000 0,75 l bottles/hr

Steam pressure 450 kPag

Latent heat of steam 2095 kJ/kg

Energy during

    continuous operation 3 640 000 kJ/hr

    heating up 9 256 710 kJ/hr for 240 minutes

    starting up 9 097 000 kJ/hr for 6 minutes

#### Line 2 pasteurizer

Simonazzi pasteurizer

45 000 0,75 l bottles/hr

Steam pressure 400 kPag

Latent heat of steam 2106 kJ/kg

Energy during

    continuous operation 4 609 000 kJ/hr

    heating up 6 285 000 kJ/hr for 30 minutes

#### Line 3 pasteurizer

B-W single deck vortex pasteurizer

Type 1650 - RC-SD

25 000 0,34 l cans/hr

Steam pressure 400 kPag

Latent heat of steam 2106 kJ/kg

Energy under

    continuous operation 2 055 000 kJ/hr

    heating up 5 885 000 kJ/hr for 120 minutes

    start up 26 536 000 kJ/hr for 10 minutes

#### Line 4 pasteurizer

B-W single deck vortex pasteurizer

Type 1585 - RC-CD

Steam pressure 400 kPag

Latent heat of steam 2106 kJ/kg

Energy under	
continuous operation	3 075 000 kJ/hr
heating up	4 385 000 kJ/hr in 120 minutes
start up	20 218 000 kJ/hr in 10 minutes

Line 1 bottle washer

H&amp;K bottle washer

Type OMEGA LAVANA 40/105 DM 54 (4,7) 2 ET

46 200 0,75 l bottles/hr

Steam pressure	450 kPag
Latent heat of steam	2095 kJ/kg
Energy during	
continuous operation	2 305 000 kJ/hr
heating up	9 255 000 kJ/hr for 240 minutes

Line 2 bottle washer

Simonazzi bottle washer

45 000 0,75 l bottles/hr

Steam pressure	450 kPag
Latent heat of steam	2095 kJ/kg
Energy during	
continuous operation	2 514 000 kJ/hr
heating up	15 713 000 kJ/hr for 360 min from cold 120 minutes for a 2,5 day shutdown 30 minutes for a 12 hour shutdown

Line 4 bottle washer

B-W pinto hydro jet bottle washer

Type 624,4214/14024

Steam pressure	400 kPag
Latent heat of steam	2106 kJ/kg
Energy during	
continuous operation	2 317 000 kJ/hr
heating up	5 518 000 kJ/hr in 120 minutes

The duration that steam is used on each line is given by the number of hours operation at rated capacity. However there are frequent stoppages and sometimes lines are not run at rated capacity. Machine hours is the duration the steam is switched on. Machine

efficiency is average production rate during machine hours as a percentage of the production rate at rated capacity. Assuming that when a line is not undergoing a stoppage it is running at rated capacity, machine hours multiplied by machine efficiency gives the number of standard production hours. The rest of the time the machines are on idle, and it is assumed that the steam consumption is 30 % that at rated capacity. This should account for:

- radiation and convection losses.
- steam requirements during start ups.
- steam sprays being left on during stoppages.

Average machine hours and machine efficiencies are given in Table E-3 for the first half of F92. Heating up occurred as follows:

Line 1 - twice a week; 12 hrs on Monday and 8 hrs on Friday.

Line 2 - about 5 times a week for the four months June - September.

Line 3 - once a week; 12:00 Saturday to 22:00 Sunday.

Line 4 - once a week; 12:00 Saturday to 22:00 Sunday, with the washer operating about every second week.

The bottle washer on line 4 only operates when 375 ml bottles are being filled, but not for 340 ml. The heating up times given by vendors is from cold, but in practice the machines still have some retained heat when heating up starts so times are less. The times given in Table E-3 were those observed.

Table E-3. Energy data for washers and pasteurisers.

	steam demand at rated capacity (kg/hr)	Steam demand during heating up (kg/hr)	Heating up duration (min)	Machine hours/day	Machine eff. (%)
Line 1 pasteurizer	1737	4 418	45	16,9	65
Line 2 pasteurizer	2189	2 984	45	3,2	42
Line 3 pasteurizer	976	2 794	120	9,7	71
Line 4 pasteurizer	1460	2 082	120	13,0	61
Line 1 washer	1100	4 418	90	16,9	65
Line 2 washer	1200	7 500	60	3,2	42
Line 4 washer	1100	2 620	150	6,5	61

Table E-4. Average steam requirements of washers and pasteurisers.

	Actual production (kg/hr)	Idle (kg/hr)	Start-up (kg/hr)	Total (kg/hr)	kg/hl packaged
Line 1 pasteurizer	795	128	39	962	6,7
Line 2 pasteurizer	123	51	45	219	11,2
Line 3 pasteurizer	280	34	45	359	14,7
Line 4 pasteurizer	482	92	32	606	16,5
Line 1 washer	503	82	79	664	4,6
Line 2 washer	67	28	150	245	12,5
Line 4 washer	182	35	202	419	11,4

**4) De-aeration plant**

Average amount of beer brewed	129 000 hl/month
Dilution	0,44 hl/hl brewed beer
Dilution water required	56 760 hl/month
	78,8 hl/hr
De-aerated water for other uses	19,7 hl/hr
Total requirement	98,5 hl/hr
Temperature of preheated water	80°C
Temperature of heated water	106°C
Heat capacity of water	4,19 kJ/(kg.deg C)
Radiation losses	5%

$$\begin{aligned}
 Q &= \text{energy required to heat the water from 80 to } 106^{\circ}\text{C} \\
 &= 9850 \text{ l/hr} * 4,19 \text{ (kJ/l.}^{\circ}\text{C)} * (106 - 80)^{\circ}\text{C} * 1,05 \\
 &= 1\,126\,721 \text{ kJ/hr}
 \end{aligned}$$

Steam pressure	350 kPag
Latent heat of steam	2147 kJ/kg

Average steam demand = 524 kg/hr

**5) Yeast drying**

Yeast moisture content in	80%
out	10%
Yeast inlet temperature	20°C
Average production rate	1000 bags/month (25 kg/bag)
	34,7 kg/hr
Average dry yeast production	31,2 kg/hr
Average water evaporated	121,5 kg/hr
Heat capacity of water	4,19 kJ/(kg.deg C)
Heat capacity of yeast	1,76 kJ/(kg.deg C)
Latent heat of steam	2257 kJ/kg
Radiation losses	30%

$$\begin{aligned}
 Q &= \text{energy to heat yeast from } 20 \text{ to } 100^{\circ}\text{C} + \text{energy to evaporate water} \\
 &= (31,2 * 1,76 * 80 + 0,8 / 0,2 * 31,2 * 4,19 * 80 + 121,5 * 2257) * 1,3 \\
 &= 416\,586 \text{ kJ/kg}
 \end{aligned}$$

Steam pressure	300 kPag
Latent heat of steam	2162 kJ/kg

$$\text{Average steam demand} = 192,7 \text{ kg/hr}$$

Produce 20 bags/shift (8 hrs/shift)

$$\begin{aligned}
 \text{Capacity factor} &= 400 \text{ hrs/month actual production} / 720 \text{ hrs/month} \\
 &= 0,56
 \end{aligned}$$

$$\begin{aligned}
 \text{Steam demand during production} &= 192,7 / 0,56 \\
 &= 344 \text{ kg/hr}
 \end{aligned}$$

## 6) Flash pasteurizer

Drip beer flash pasteurized	330 hl/week
	1,96 hl/hr
Temperature of 'drip' beer in	10°C
out	95°C
Heat capacity of 'drip' beer	3,9 kJ/(kg.deg C)
Radiation losses	10%

$$\begin{aligned}
 Q &= \text{energy required to heat beer from } 10 \text{ to } 95^{\circ}\text{C} \\
 &= 196 * 3,9 * 85 * 1,1 \\
 &= 71\,471 \text{ kJ/hr}
 \end{aligned}$$

Steam pressure	350 kPag
Latent heat of steam	2147 kJ/kg

$$\text{Average steam demand} = 33,3 \text{ kg/hr}$$

Actual 'drip' beer flowrate - 15 hl/hr

$$\begin{aligned}
 \text{Capacity factor} &= 1,96 / 15 \\
 &= 0,13
 \end{aligned}$$

$$\begin{aligned}\text{Steam demand during production} &= 33,3/0,13 \\ &= 256,1 \text{ kg/hr}\end{aligned}$$

### 7) Hot liquor system

Sufficient heat is available in through wort cooling to raise the temperature of the chilled liquor to 85°C. However losses from the tank, especially during brewhouse shutdown, will result in some steam heating being necessary. It was observed that operation of the two heat exchangers is intermittent and thus it is assumed that they operate 20% of the time and the temperature is raised from 80 to 85°C. Tests done by Elgin Engineering showed the hot water flowrate to be 88185 lb/hr per heat exchanger.

$$\begin{aligned}Q &= 2 * 88\ 185 \text{ lb/hr} * 0,45 \text{ kg/lb} * 4,19 \text{ kJ/(kg.}^\circ\text{C)} * (85 - 80^\circ\text{C)} * 0,2 \\ &= 332\ 546 \text{ kJ/hr}\end{aligned}$$

Steam pressure	800 kPag
Latent heat of steam	2029 kJ/kg

$$\text{Steam demand} = 164 \text{ kg/hr}$$

### 8) Cleaning in place (CIP)

There are four independent CIP plants where steam heating is used. All the CIP plants consist of a caustic solution reservoir and a hot water reservoir. Hot water is first circulated, and followed by the caustic, and then hot water is circulated again. Caustic is recycled back to the caustic plant while the hot water is discarded to drain. Both the caustic and hot water reservoirs are maintained continuously at about 85°C. Peak steam demand from all the CIP plants is assumed to be little more than the average demand, because of the independent operation of the four CIP plants.

#### Huppmann brewhouse CIP plant

This CIP plant is used to:

- clean out the Huppmann wort kettle every fourth brew.
- clean out the Huppmann maize cooker every eighth brew.
- caustic brew on all equipment and lines in the Huppmann brewhouse once a week.
- clean the wort line from the wort cooler to the fermenting vessels after every brew.

Hot water comes from the hot liquor tanks which has already been covered, and there are two caustic tanks each of 125 hl capacity. It is assumed that after a CIP a caustic tank must be heated from 80°C to 85°C. This occurs about 9 times a day.

$$Q = 125 \text{ hl} * 100 \text{ kg/hl} * 4,19 \text{ kJ/(kg.}^\circ\text{C)} * (85 - 80)^\circ\text{C} * 0,375 \text{ times/hr}$$

$$= 98\ 200 \text{ kJ/hr}$$

### Fermentation CIP plant

This CIP plant is used to:

- clean out the yeast mains once a day.
- clean out racking lines once a week.

The caustic tank holds 150 hl and the hot water tank 200 hl. It is assumed that for each CIP the caustic tank must be heated from 80 to 85°C and the hot water from 50 to 85°C. CIP occurs once per day.

$$Q = 150 \text{ hl} * 100 \text{ kg/hl} * 4,19 \text{ kJ/(kg.}^\circ\text{C)} * (85 - 80)^\circ\text{C} * 1/24 \text{ times/hr}$$

$$+ 200 \text{ hl} * 100 \text{ kg/hl} * 4,19 \text{ kJ/(kg.}^\circ\text{C)} * (85 - 50)^\circ\text{C} * 1/24 \text{ times/hr}$$

$$= 135\ 300 \text{ kJ/hr}$$

### Filtration CIP

This CIP plant is used to:

- clean the filter once a week.
- clean the draft beer lines once a day.
- clean the cellar to filter mains once a week.
- clean the drip beer mains once a week.
- a separate hot water tank reservoir at 94°C is used to sterilise the filter once a day and 80 hl is used per sterilisation.

The caustic tank holds 125 hl and the hot water tank 250 hl at 92°C. The filter requires larger volumes for cleaning and it was observed that after a CIP the caustic tank had to be heated from 70 to 85°C and the water from 40 to 92°C. After all other CIPs it is assumed the caustic tank must be heated from 80 to 85°C, and the hot water from 70 to 85°C.

$$\begin{aligned}
 Q &= 125 \text{ hl} * 100 \text{ kg/hl} * 4,19 \text{ kJ/(kg.}^\circ\text{C)} * (85 - 75)^\circ\text{C} * 1/7 * 24 \text{ times/hr} \\
 &+ 125 \text{ hl} * 100 \text{ kg/hl} * 4,19 \text{ kJ/(kg.}^\circ\text{C)} * (85 - 80)^\circ\text{C} * 1/24 \text{ times/hr} \\
 &+ 250 \text{ hl} * 100 \text{ kg/hl} * 4,19 \text{ kJ/(kg.}^\circ\text{C)} * (92 - 40)^\circ\text{C} * 1/7 * 24 \text{ times/hr} \\
 &+ 250 \text{ hl} * 100 \text{ kg/hl} * 4,19 \text{ kJ/(kg.}^\circ\text{C)} * (92 - 70)^\circ\text{C} * 1/24 \text{ times/hr} \\
 &+ 80 \text{ hl} * 100 \text{ kg/hl} * 4,19 \text{ kJ/(kg.}^\circ\text{C)} * (94 - 20)^\circ\text{C} * 1/24 \text{ times/hr} \\
 &= 3118 + 10911 + 32423 + 96020 + 103353 \\
 &= 245\,800 \text{ kJ/hr}
 \end{aligned}$$

### Packaging hall CIP

This CIP plant is used to:

- sterilize the fillers.
- clean the bright beer mains.

Lines 2,3, and 4 require 25 l caustic/week and line 1 50 l/week. The dilution of caustic is 1,5% so 83 hl of caustic solution must be heated from 15°C to 80°C. About 200 hl/week of hot water is also required. In total 283 hl/week (170 l/hr).

$$\begin{aligned}
 Q &= 170 \text{ l/hr} * 4,18 \text{ kJ/(l.}^\circ\text{C)} * (80 - 15)^\circ\text{C} \\
 &= 46\,189 \text{ kJ/hr}
 \end{aligned}$$

The total energy requirement of all CIP plants is :

$$Q = 525\,500 \text{ kJ/hr}$$

Steam pressure	800 kPag
Latent heat of steam	2029 kJ/kg

$$\text{Steam demand} = 259 \text{ kg/hr}$$

### 9) CO<sub>2</sub> plant

Steam usage is estimated to be 100 kg/hr on average.

### 10) Hose points

Hose points exists in the yeast room and in the engine room which each have a maximum flow of about 100 kg/hr, but are only utilised periodically. The steam usage is thus negligible.

## 11) Hotwell

Percent condensate returned	40 %
Temperature of condensate	95°C
Temperature of make-up water	20°C
Temperature of feedwater	75°C
Enthalpy of condensate	397 kJ/kg
Enthalpy of make-up water	84 kJ/kg
Enthalpy of boiler feedwater	314 kJ/kg
Energy requirement from steam	105 kJ/kg of boiler feedwater
Feedwater average flowrate	11 100 kg/hr
Energy requirement from steam	1 165 500 kJ/hr
Pressure of steam	900 kPag
Enthalpy of steam in	2776 kJ/kg

$$\begin{aligned} \text{Energy available from steam} &= 2776 \text{ kJ/kg} - 314 \text{ kJ/kg} \\ &= 2462 \text{ kJ/kg} \end{aligned}$$

$$\text{Average steam requirement} = 427 \text{ kg/hr}$$

Peak demand will occur when no condensate is returned ie when the brewhouses are not operating, so peak demand for the hotwell will occur during periods of low demand overall.

## APPENDIX F

### BOILER EFFICIENCY CALCULATIONS

---

#### Hotwell flowrate measurement

Steam pressure	900 kPag
Enthalpy of steam	2776 kJ/kg
Make-up water temperature	75°C
Enthalpy of boiler feedwater	314 kJ/kg
Average hotwell flowrate measured	15 988 kg/hr
Energy required to raise steam	39 362 MJ/hr
Average coal equivalent usage	1 753 kg/hr
Calorific value of coal	28,0 MJ/kg
Average energy of coal equiv.	49 084 MJ/hr

Average boiler efficiency = 80,2%

#### Average steam and coal equivalent requirement

Steam pressure	900 kPag
Enthalpy of steam	2776 kJ/kg
Make-up water temperature	75°C
Enthalpy of boiler feedwater	314 kJ/kg
Average steam requirement	11 108 kg/hr
Energy required to raise steam	27 348 MJ/hr
Average coal equiv. usage	1 526 kg/hr
Calorific value of coal	28,0 MJ/kg
Average energy of coal equiv.	42 728 MJ/hr

Average boiler efficiency = 64,0%

## Boiler operation

### Dry flue gas loss

According to the British standards

$$Q_{\text{loss}} = \frac{0,63 \cdot (T_{\text{flue gas}} [^{\circ}\text{C}] - T_{\text{inlet air}} [^{\circ}\text{C}])}{\% \text{ CO}_2_{\text{flue gas}}}$$

The air inlet temperature was taken to be 25°C, and flue gas temperatures varied between 200 and 250°C, so the average of 225°C was used. The percentage CO<sub>2</sub> in the flue gases is measured once a day on each boiler. An average value was calculated for each day (with a weighting of 0,4 for the two 20t boilers and 0,2 for the 10t boiler) for two months. These values were then decreased by 1% because it was observed that measurements were only recorded at times when the %CO<sub>2</sub> measurements were higher. The range of %CO<sub>2</sub> measurements was thus calculated to be 4% - 10%.

$$Q_{\text{loss}} = 12,6\% - 31,5\%$$

### Unburnt carbon

Some carbon is lost in the grits, but this is usually small enough to neglect. However unburnt carbon in the ash can be a significant loss. Grade A pea coal is used which has an ash content of 12,5%. Three ash samples from different days were sent for analysis and gave 16 to 23% carbon content. Thus the total ash and unburnt carbon content of the coal is about 16%.

$$\begin{aligned} Q_{\text{loss}} &= 0,16 \text{ kg ash/kg coal} \cdot 0,23 \text{ kg carbon/kg ash} \cdot 33,8 \text{ MJ/kg carbon} \\ &= 1,24 \text{ MJ/kg coal} \end{aligned}$$

The calorific value of grade A pea coal is 28 MJ/kg thus giving:

$$Q_{\text{loss}} = 4,4\% \text{ for } 23\% \text{ carbon content in the ash.}$$

$$Q_{\text{loss}} = 3,1\% \text{ for } 16\% \text{ carbon content in the ash.}$$

Moisture loss

There are three sources of moisture:

- 1) Inherent moisture - 0,05 kg/kg coal (for grade A pea coal)
- 2) Surface moisture - 0,03 kg/kg coal (measured by drying the coal and subtracting the inherent moisture)
- 3) Water produced from H<sub>2</sub> - 0,36 kg/kg coal (calculated from the H<sub>2</sub> content of the coal which is 0,04 kg/kg coal)

Total amount of moisture is 0,44 kg/kg coal, and this moisture must be heated from ambient temperature to its evaporating temperature (165°C), be evaporated, and then superheated to the flue gas temperature (225 °C).

$$\begin{aligned}
 Q_{\text{loss}} &= 0,44 \text{ kg moisture/kg coal} * (4,18 \text{ kJ}/(\text{kg}\cdot^{\circ}\text{C})*(165-25) + 2020 \text{ kJ/kg} + 2,0 \text{ kJ}/(\text{kg}\cdot^{\circ}\text{C})) \\
 &\quad * (225-165) \\
 &= 1199 \text{ kJ/kg coal}
 \end{aligned}$$

Dividing this by the calorific value of the coal gives  $Q_{\text{loss}} = 4,3\%$

Blowdown loss

A blowdown of 3% is assumed. About 8 kg steam is produced per kg of coal, so 0,24 kg blowdown occurs per kg of coal. The heat lost in the blowdown is the energy required to heat the blowdown from boiler feed-water temperature (70°C) to the saturated water temperature (180°C).

$$\begin{aligned}
 Q_{\text{loss}} &= 0,24 \text{ kg blowdown/kg coal} * (4,18 \text{ kJ}/(\text{kg}\cdot^{\circ}\text{C})*(180-70)) \\
 &= 110 \text{ kJ/kg coal} \\
 &= 0,4\%
 \end{aligned}$$

## APPENDIX G

### ASSUMPTIONS FOR THE STEAM SANKEY DIAGRAM

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All energy values are calculated relative to water at 18°C. An energy balance over the entire coal, oil, steam systems was not forced.

#### Boilerhouse

- 1099 t/month coal equiv. usage.
- 11 108 kg/hr steam requirement, with individual requirements being those given in Chapter 4.
- 65% boiler efficiency.
- Boiler feed water temperature 70°C.

#### Steam distribution

- 10% distribution loss.
- Flash losses in the brewhouse condensate tanks were calculated assuming an average condensate pressure after the steam traps of 380 kPag and a condensate tank pressure of 80 kPag.

#### Brewhouses

- radiation losses are
  - 5% of the energy requirements during heating and boiling.
  - 2°C/hr during standing times (4 hours/brew).
  - 1°C for each pump over.
- Spent grains are 130 hl/brew, and leave at 76°C. 77% extract gives 2800 kg of solids in the spent grains.
- Hot liquor energy losses are equivalent to the steam energy requirement.
- 120 hl/brew hot water is required for cleaning and rinsing.

#### Packaging Hall

- Energy required by the product in packaging is the difference between the energy in and out of the beer and bottles. Bottles enter at ambient and leave at 29°C. The beer enters at 1°C and leaves at 29°C.
- Radiation losses in packaging are assumed to be 15% of the energy usage of the washers and pasteurisers.
- Energy lost in the condensate is the difference between energy into the packaging hall, and energy required in the product and lost in radiation. Average temperature of the condensate is 42°C.

## APPENDIX H

### ELECTRICITY REQUIREMENTS

All average electricity requirements were calculated from monthly records of kWh consumed, except for refrigeration, air compression, the CO<sub>2</sub> plant, and the water pumps. Their electricity requirements were calculated from actual measurements and various assumptions. Table H-1 gives the quantities of beer brewed, packaged, and produced during the period that measurements were performed on compressors. The measured data for all compressors covered is given in Tables H-2, H-3, and H-4.

*Table H-1. Cumulative quantities of beer brewed, packaged, and produced.*

DATE	DAY	BREWED (hl)	PACKAGED (hl)	PRODUCED (hl)
18/9	0	0	0	0
20/9	2	8950	14570	11760
24/9	6	25260	36700	30980
27/9	9	39470	58686	49078
2/10	14	67370	92206	79788
7/10	19	95790	117258	106524
11/10	23	120410	151661	136035
19/10	31	160393	218248	189320

Table H-2. Ammonia compressor measurements.

HOUR METERS					
DATE	1	2	3	4	5
18/9	22117	30257	179	233	171
20/9	22132	30314	195	234	190
24/9	22272	30380	195	235	190
27/9	22292	30441	224	257	197
2/10	22303	30561	298	359	241
7/10	22303	30672	388	395	338
11/10	22359	30775	459	396	431
19/10	22414	30961	621	438	592
Mean Amps	610	410	550	420	430
Mean kVA	232	156	209	160	163
Mean kW	290	195	261	200	204

CUMULATIVE kWh								
DATE	1	2	3	4	5	6	Total	(kWh/hl)
18/9	0	0	0	0	0	0	0	
20/9	4350	11115	4176	200	3876	4800	28517	2.42
24/9	44950	23985	4176	400	3876	14400	91787	2.96
27/9	50750	35880	11745	4800	5304	21600	130079	2.65
2/10	53940	59280	31059	25200	14280	33600	217359	2.72
7/10	53940	80925	54549	32400	34068	45600	301482	2.83
11/10	70180	101010	73080	32600	53040	55200	385110	2.83
19/10	86130	137280	115362	41000	85884	74400	540056	2.85

Table H-3. CO<sub>2</sub> compressor measurements.

HOUR METERS				
DATE	1	2	3	4
18/9	34040	49592	56945	74268
20/9	34051	49604	56987	74292
24/9	34073	49607	57036	74302
27/9	34083	49607	57040	74306
2/10	34164	49638	57125	74359
7/10	34247	49684	57222	74448
11/10	34327	49738	57298	74493
19/10	34477	49844	57462	74605
Mean Amps	48	65	65	32
Mean kVA	18	25	25	12
Mean kW	23	31	31	15

CUMULATIVE kWh								
DATE	1	2	3	4	5	6	Total	(kWh/h1)
18/9	0	0	0	0	0	0	0	
20/9	253	372	1302	360	3600	3600	9487	0.81
24/9	759	465	2821	510	10800	10800	26155	0.84
27/9	989	465	2945	570	16200	16200	37369	0.76
2/10	2852	1426	5580	1365	25200	25200	61623	0.77
7/10	4761	2852	8587	2700	34200	34200	87300	0.82
11/10	6601	4526	10943	3375	41400	41400	108245	0.80
19/10	10051	7812	16027	5055	55800	55800	150545	0.80

Table H-4. Air compressor measurements.

RUNTIME HOUR METER				
DATE	1	2	3	4
18/9	1400	4024	18274	49814
20/9	1436	4036	18280	49815
24/9	1532	4038	18281	49817
27/9	1600	4065	18285	49826
2/10	1654	4132	18288	49847
7/10	1681	4179	18336	49903
11/10	1778	4181	18340	49923
19/10	1991	4223	18356	50021
RATING (kW)	200	250	130	130
UNLOADED (kW)	40	50	26	26

LOADTIME HOUR METER				
DATE	1	2	3	4
18/9	1016	2643	14944	32739
20/9	1046	2651	14944	32739
24/9	1120	2653	14945	32739
27/9	1184	2653	14946	32740
2/10	1231	2692	14946	32744
7/10	1258	2731	14959	32790
11/10	1352	2770	14961	32820
19/10	1425	2802	14965	32859

CUMULATIVE KWH						
DATE	1	2	3	4	Total	(kWh/hl)
18/9	0	0	0	0	0	
20/9	6240	2200	156	26	8622	0.73
24/9	21920	2700	286	78	24984	0.81
27/9	34880	4050	494	416	39840	0.81
2/10	44560	15200	572	1378	61710	0.77
7/10	49960	25350	3172	7618	86100	0.81
11/10	68880	33250	3484	11258	116872	0.86
19/10	89080	41750	4316	17862	153008	0.81

## Refrigeration

Compressors comprise:

1 x 300 kW screw compressor

4 x 450 kW screw compressors

The compressors can run from 10% to 100% rated capacity depending on the demand. Hour meter readings and the current drawn, was recorded over a month for each compressor. From the average current drawn, the average KVA used could be calculated. Power factor was about 0,8, from which the kWh used could be calculated. The compressors had only recently been commissioned so about half of the time an old compressor was also run. The results are shown below, and give 2,85 kWh/hl produced, which gives 418 300 kWh/month for the average production of 146 800 hl.

Approximately five evaporative condensers were run continuously. Each fan has two 7,5 kW motors for the fans, and one 4 kW motor for cooling water circulation. Total electricity consumption was thus 68 000 kWh/month.

Refrigeration pumps comprise:

### Ammonia pumps

6 x 5,5 kW, which operate 50% of the time.

### Glycol pumps

1 x 7,5 kW

4 x 15 kW

2 x 37 kW

which operate about 90% of the time.

### Chilled water pump

1 x 5,5 kW, which operates 50% of the time.

Thus total electricity consumption by pumps was 105 000 kWh/month.

## CO2 plant

### Dry compressors:

1 x 18,5 kW

1 x 30 kW

1 x 75 kW

### Liquefying compressors:

2 x 45 kW

1 x 75 kW

Hour meter readings and average currents drawn were recorded for all CO2 compressors. The large compressors operated continuously. The data and results are shown below, with electricity consumption being 0,80 kWh/hl produced ie 117 400 kWh/month.

There are also 2 x 6 kW gas reheaters and 2 x 6 kW trace heaters which all operate about 50% of the time ie 9 000 kWh/month.

## Air plant

### Compressors:

2 x 130 kW

1 x 200 kW

1 x 250 kW

The same methods as for refrigeration were used for calculating electricity consumption, and the data and results are shown below. Electricity consumption was 0,81 kWh/hl produced ie 118 900 kWh/month.

Two air dryers use about 20 kW continuously ie 14 000 kWh/month.

## Water pumps

1 x 22 kW

7 x 30 kW

which run about 50% of the time ie 84 000 kWh/month.

## APPENDIX I

### REFRIGERATION LOADS

---

For each load it is assumed that a 5% loss occurs.

#### Wort cooling

The chilled liquor to wort ratio is 1,1:1. An average of 129 078 hl/month is brewed, thus giving a chilled water requirement of 141 986 hl/month (5,478 l/s), which must be chilled from 18°C to 1 °C.

$$Q = 5,478 \text{ l/s} * 4,19 \text{ kJ/(l.}^\circ\text{C)} * (18 - 1)^\circ\text{C} * 1,05 \\ = 410 \text{ kW}$$

#### Fermentation

The average conversion of solids is 13,0 kg/hl which is exothermic releasing 630 kJ/kg of solid converted. 129 078 hl/month (4,98 l/s) are fermented on average. The wort arrives at the fermenting vessels at 11°C and with a chill back leaves at 6°C.

$$Q = 4,98 \text{ l/s} * 0,13 \text{ kg/l} * 630 \text{ kJ/kg} + 4,98 \text{ l/s} * 4,0 \text{ kJ/(l.}^\circ\text{C)} * (11 - 6)^\circ\text{C} * 1,05 \\ = 533 \text{ kW}$$

Because fermentation takes such a long time and there are so many fermenting vessels, the fluctuation in total fermentation cooling load will be small.

#### Chilling between fermenters and storage

Beer is chilled from 6°C to -2°C.

$$Q = 4,98 \text{ l/s} * 4,0 \text{ kJ/(l.}^\circ\text{C)} * (6 - (-2))^\circ\text{C} * 1,05 \\ = 167 \text{ kW}$$

#### Storage

Beer is stored in storage vessels at -2°C for four days, and the only cooling load is to compensate for any heat gain of the beer. It is assumed that the heat gain of the beer during the four days is approximately enough to raise the temperature of the beer by 2oC.

$$Q = 4,98 \text{ l/s} * 4,0 \text{ kJ/(l.}^\circ\text{C)} * 2^\circ\text{C} \\ = 40 \text{ kW}$$

Filtration pre- and post-chillers

Pre-filtration cooling is assumed to be from 1°C to -2°C and for post-filtration from 2°C to -1°C.

$$Q = 4,98 \text{ l/s} * 4,0 \text{ kJ/(l.}^\circ\text{C)} * [(1 - (-2)) + (2 - (-1))] * 1,05$$

$$= 126 \text{ kW}$$

Bright beer tanks

The same assumption as for the storage vessels is made, but the quantity of beer is 1,44 times larger due to the addition of de-aerated water.

$$Q = 58 \text{ kW}$$

De-aeration plant

100 hl/hr (2,78 l/s) water leaves the regeneration section at about 28°C and is cooled to 2°C.

$$Q = 2,78 \text{ l/s} * 4,18 \text{ kJ/(l.}^\circ\text{C)} * (28 - 2)^\circ\text{C} * 1,05$$

$$= 317 \text{ kW}$$

Flash pasteuriser

1,96 hl/hr (0,054 l/s) 'drip beer' is cooled from 20°C to 9°C.

$$Q = 0,054 \text{ l/s} * 4,1 \text{ kJ/(l.}^\circ\text{C)} * (20 - 9)^\circ\text{C} * 1,05$$

$$= 2,6 \text{ kW}$$

However flash pasteurisation is only carried out once a week with an actual flowrate of 15 hl/hr.

$$Q_{\max} = 20 \text{ kW}$$

Yeast and yeast propagation

The temperature reduction of the yeast is from 14°C to 4°C at a daily quantity of about 4400 kg (1,22 kg/s). Yeast propagation consists of a 5hl inoculation vessel, 20 hl sterilising vessel, 20 hl propagation vessel, and 2 150 hl intermediate vessels. The design peak cooling load for yeast propagation is 42 kW, and the average load is assumed to be about 20 kW.

$$Q = 1,22 \text{ kg/s} * 1,76 \text{ kJ}/(\text{kg}\cdot^{\circ}\text{C}) * (14 - 4)^{\circ}\text{C} * 1,05 + 20 \text{ kW} \\ = 43 \text{ kW}$$

#### Hop store

The load is estimated in the design to be 19 kW.

#### Pumping losses

Pumping losses, through heat gain from the friction of pumping is about 95% of the pump energy consumption ie

16 kW for ammonia pumps

121 kW for glycol pumps

3 kW for chilled water pump

#### Piping insulation losses

These were taken to be 11 kW for ammonia piping and 39 kW for glycol piping, in the design of the refrigeration plant.

## APPENDIX J

### FERMENTATION COOLING LOAD PROFILES

During fermentation the yeast converts the sugars to alcohol and carbon dioxide. Fermentation scheduling depends on the measured sugar concentration of the wort. Figure J-1 shows a typical timing diagram of the fermentation cycle.

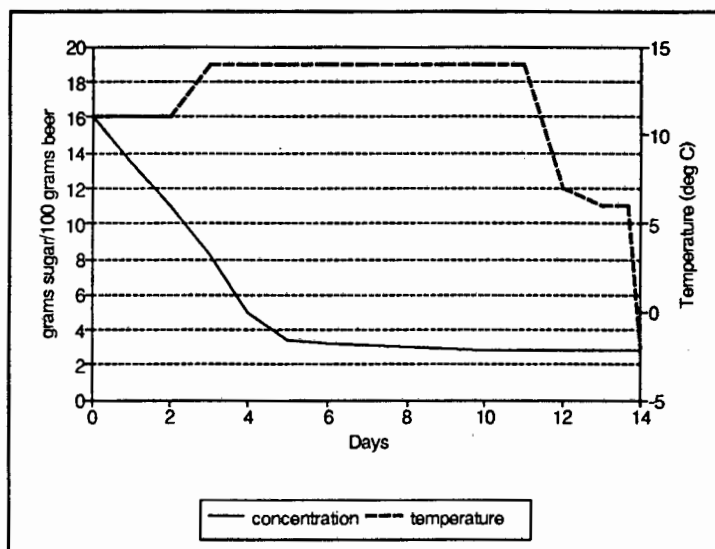


Figure J-1. Timing diagram of the fermentation cycle.

#### Holding the wort at 11°C

The is done for 45 hours.

Sugar converted = 5 g/100g wort

Energy released during fermentation = 630 kJ/kg sugar

Capacity of fermenting vessel (large vessel) = 2640 hl

Cooling load

$$\begin{aligned} &= 630 \text{ kJ/kg sugar} * 5 \text{ kg sugar/hl wort} * 2640 \text{ hl} / (45 \text{ hrs} * 3600 \text{ s/hr}) \\ &= 51,3 \text{ kW} \end{aligned}$$

#### Allowing wort to rise to 14°C

No cooling.

#### Holding the wort at 14°C

For the first 24 hours 3g sugar/100g wort is converted.

Cooling load

$$\begin{aligned} &= 630 \text{ kJ/kg sugar} * 2,5 \text{ kg sugar/hl wort} * 2640 \text{ hl} / (24 \text{ hrs} * 3600 \text{ s/hr}) \\ &= 48,1 \text{ kW} \end{aligned}$$

This was repeated for the duration of the period ie until day 11.

### Chillback

This occurs over 32 hours during which the wort is cooled from 14°C to 6°C.

Cooling load

$$\begin{aligned} &= 2640 \text{ hl} * 100 \text{ kg/hl} * 4,1 \text{ kJ/(kg.°C)} * (14 - 6)^\circ\text{C} / (32 \text{ hrs} * 3600 \text{ s/hr}) \\ &= 75 \text{ kW} \end{aligned}$$

### Cooling between the fermenting vessel and the storage vessel

This takes 7 hours for a 2640 hl batch.

The wort is cooled from 6°C to -2°C.

Cooling load

$$\begin{aligned} &= 2640 \text{ hl} * 100 \text{ kg/hl} * 4,1 \text{ kJ/(kg.°C)} * (6 - (-2))^\circ\text{C} / (7 \text{ hrs} * 3600 \text{ s/hr}) \\ &= 344 \text{ kW} \end{aligned}$$

## APPENDIX K

### DATA USED IN THE PINCH ANALYSIS

Table K-1. Data used in the overall pinch analysis.

	T <sub>in</sub> (°C)	T <sub>out</sub> (°C)	F (kg/s)	C <sub>p</sub> (kJ/kg.K)	FC <sub>p</sub> (kW/K)	POWER (kW)
<b>HEATING REQUIREMENTS</b>						
1 Brewhouse wort	100	9	5.08	4	20.32	1849
2 Fermenting (11°C)	12	11	5.08	31.5	160.0	160
3 Fermenting (14°C)	15	14	5.08	34.6	175.8	176
4 Chill back	14	6	5.08	4	20.32	163
5 Fermenting to storage	6	-2	4.93	4	19.72	158
6 Storage	0	-2	4.93	4	19.72	39
7 Pre-filter	1	-2	4.93	4	19.72	59
8 Post-filter	2	-1	4.93	4	19.72	59
9 Dearation	100	2	2.78	4.19	11.65	1142
10 Bright beer tanks	1	-1	6.96	4.1	28.54	57
11 Pasteurisation	63	27	11.6	2.85	33.06	1190
12 CO <sub>2</sub> condensing	-27	-28	0.23	310	71.30	71
<b>COOLING REQUIREMENTS</b>						
13 Water for maize cook.	18	56	1.1	4.19	4.61	175
14 Water for mashing	18	45	1.85	4.19	7.75	209
15 Water for lautering	18	76	2.7	4.19	11.31	656
16 Water for cleaning	18	84	0.63	4.19	2.64	174
17 Heating in maize	56	99	1.26	3.7	4.66	200
18 Boiling in maize	99	100	0.076	2257	171.5	172
19 Heating in mash tun	45	78	4.25	3.7	15.73	519
20 Heating in kettle	76	99	5.67	4	22.68	522
21 Boiling	99	100	0.63	2257	1421.9	1422
22 Deaeration	18	106	2.78	4.19	11.65	1025
23 Pasteurisation	5	63	11.6	2.85	33.06	1917
24 Heating wet yeast	20	99	0.043	3.71	0.16	13
25 Yeast drying	99	100	0.034	2257	76.74	77
26 CIP water	18	85	0.55	4.19	2.30	154
27 CO <sub>2</sub> vaporisation	-28	-27	0.15	310	46.50	47

Table K-2. Data used in the brewhouse pinch analysis.

	$T_{in}$ (°C)	$T_{out}$ (°C)	F (kg/s)	$C_p$ (kJ/kg.K)	FCp (kW/K)	POWER (kW)
<b>HEATING REQUIREMENTS</b>						
1 Brewhouse wort	100	9	5.08	4	20.32	1849
<b>COOLING REQUIREMENTS</b>						
2 Water for maize cook.	18	56	1.1	4.19	4.61	175
3 Water for mashing	18	45	1.85	4.19	7.75	209
4 Water for lautering	18	76	2.7	4.19	11.31	656
5 Water for cleaning	18	84	0.63	4.19	2.64	174
6 Heating in maize cooker	56	99	1.26	3.7	4.66	200
7 Boiling in maize cooker	99	100	0.076	2257	171.5	172
8 Heating in mash tun	45	78	4.25	3.7	15.73	519
9 Heating in kettle	76	99	5.67	4	22.68	522
10 Boiling	99	100	0.63	2257	1421.9	1422

## APPENDIX L

### TECHNICAL AND ECONOMIC ASSESSMENT CALCULATIONS

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#### L1. Ammonia compressor COP as a function of compressor capacity<sup>(91)</sup>

Capacity (%)	COP
20	1,2
40	2,2
60	2,84
80	3,11
100	3,30

#### L2. Flash steam recovery

Total steam requirement	21,4 ton/hr
Brewhouse steam requirement	7,0 ton/hr
Pressure of sat. water after traps	3,8 kPag
Enthalpy of saturated water	634 kJ/kg
Pressure in condensate tanks	0,8 kPag
Enthalpy of sat. water in condensate tanks	492 kPag
Enthalpy to raise flash steam	2210 kJ/kg
Energy lost to flash steam	
= (634 - 492) kJ/kg * 7000 kg/hr	
= 994 000 kJ/hr	
Heat recovered (60%)	596 000 kJ/hr
Cost of recovered energy	R5137/month
 Costs for spray condensor system:	
Two 100 mm pipe spray condensors	R24 000
Auxillary equipment, installation	R12 000
Total	R36 000
Payback time	7 months

**L3. Vapourisation of CO<sub>2</sub>**

Enthalpy of saturated liquid (-28°C and 1520 kPa)	21 kJ/kg
Enthalpy of vapour (-5°C and 300 kPa)	370 kJ/kg
Produce 3,66 kg CO <sub>2</sub> /hl final beer	
Use about 65% of this in the process	
Average final beer production	72 300 hl/week

Energy required for vaporisation

$$= (370 - 21) \text{ kJ/kg} * 0,65 * 3,66 \text{ kg/hl} * 72\ 300 \text{ hl/week} /$$

$$(7 * 24 * 3600) \text{ s/week}$$

$$= 99,2 \text{ kW}$$

**L4. Compressed air drying**

Overall temperature reduction	15°C
Heat capacity of air at 7 kPag	1,1 kJ/(kg.°C)
Compressed air requirement	8 m <sup>3</sup> /hl
Average flowrate of air	3440 m <sup>3</sup> /hr
Density of free air	1,3 kg/m <sup>3</sup>
Average mass flowrate of air	4472 kg/hr
Energy required to cool air	
= 4472/3600 kg/s * 1,1 kJ/(kg.°C) * 15°C	
= 20,5 kW	

Energy required to condense water

$$= 0,007 \text{ kg water/kg air} * 4472/3600 \text{ kg/s} * 2050 \text{ kJ/kg}$$

$$= 17,8 \text{ kW}$$

**L5. Continuous blowdown**

Continuous blowdown keeps blowdown to a minimum. At present it is likely that blowdown is a third more than required.

Softened water TDS	120 ppm
Maximum boiler TDS	3500 ppm

Percentage blowdown (minimum)	$120/(3500-120) = 3,4\%$
Average steam production	21,4 ton/hr
Average blowdown	0,73 ton/hr
Savings in blowdown	0,24 ton/hr
Enthalpy of blowdown	763 kJ/kg
Enthalpy of make up water	84 kJ/kg
Extra energy saved = $(763 - 84) \text{ kJ/kg} * 240 \text{ kg/hr} = 163\ 000 \text{ kJ/hr}$	
Coal saving due to less blowdown = R1404/month	

#### Costs for all the boilers:

Continuous blowdown equipment	R50 000
Installation etc	R5 000
Total	R55 000
Payback time	3,3 years

#### L6. Blowdown heat recovery

Enthalpy of blowdown at 9 kPag	763 kJ/kg
Enthalpy of water at 2 kPag	562 kJ/kg
Enthalpy to raise steam at 2kPag	2162 kJ/kg
Energy to flash steam	
= $(763 - 562) \text{ kJ/kg} * 730 \text{ kg/hr}$	
= 147 000 kJ/hr	
Energy recovery (80%)	118 000 kJ/hr
Coal saving due to heat recovery	R1017/month
Costs for all the boilers:	
Continuous blowdown equipment	R50 000
Flash vessel	R17 000
(max. inlet flow 2250 kg/hr)	
Auxillary equipment, installation	R8 000
Total	R75 000
Payback time	2,6 years

#### L7. Condensate recovery in the packaging hall

Table L-1 summarizes all assumptions made for packaging steam usages only in areas where indirect steam heating through coils occurs. This excludes the pasteurisers on lines three and four. It was assumed that machine efficiencies on lines one and two will be

75% and 70% on line four, and average operating times on lines one and two will be 16 hours/day, and 12 hours/day on line four.

Table L-1. Packaging indirect steam usages after the expansion.

Line	Quantity packed (hl/month)	Specific steam requirement (kg/hl)	Monthly steam usage (kg)
1	113 400	11	1 247 000
2	121 500	11	1 337 000
4	27 000	11,5	311 000

Assuming an 80% condensate return efficiency and a return temperature of 95°C, the energy saving will be

$$= 2\,316\,000 \text{ kg/month} * 4,18 \text{ kJ}/(\text{kg} \cdot ^\circ\text{C}) * (95 - 20)^\circ\text{C}$$

$$= 726 \text{ GJ/month}$$

$$\text{Cost saving} = 726 \text{ GJ/month} * \text{R}11,97/\text{GJ} = \text{R}8690/\text{month}$$

#### L8. Air compressor energy recovery

Compressor shaft input energy 0,81 kWh/hl beer produced

Shaft power required 235 000 kWh/month

$$= 325 \text{ kW}$$

Compressor capacity available 730 kW

Capacity factor 0,45

Energy recovery in hot water<sup>(92)</sup> 80%

Energy transferred by 220 kW compressor to boiler make-up water

$$= 220 \text{ kW} * 0,8 * 0,45$$

$$= 79,2 \text{ kW} = 205 \text{ GJ/month}$$

#### L9. Conversion from coal to oil

Table L-2 shows the difference in running costs between using coal or fuel oil for the boilers.

Table L-2. Difference between coal and fuel oil running costs.

	Coal	H.F.O
Calorific value	28,0 MJ/kg	42,7 MJ/l
Boiler efficiency	70%	80%
Fuel cost	R0,19/kg	R0,45/l
Energy to raise steam	2462 kJ/kg	2462 kJ/kg
Fuel cost per kg steam	R0,024	R0,032
Boiler utilisation	32%	50%
Maximum boiler capacity	15,6 t/hr	20 t/hr
Kg steam/month	3 594 000	7 200 000
Additional expenditures/month		
Labour	R1200	-
Boiler spares	R1000	-
Cleaning costs	R300	-
Fuel handling		
Cost per kg steam	R0,024	R0,032

### L10. Economiser

Economiser sizing was done using economiser curves shown in Figure L-1.

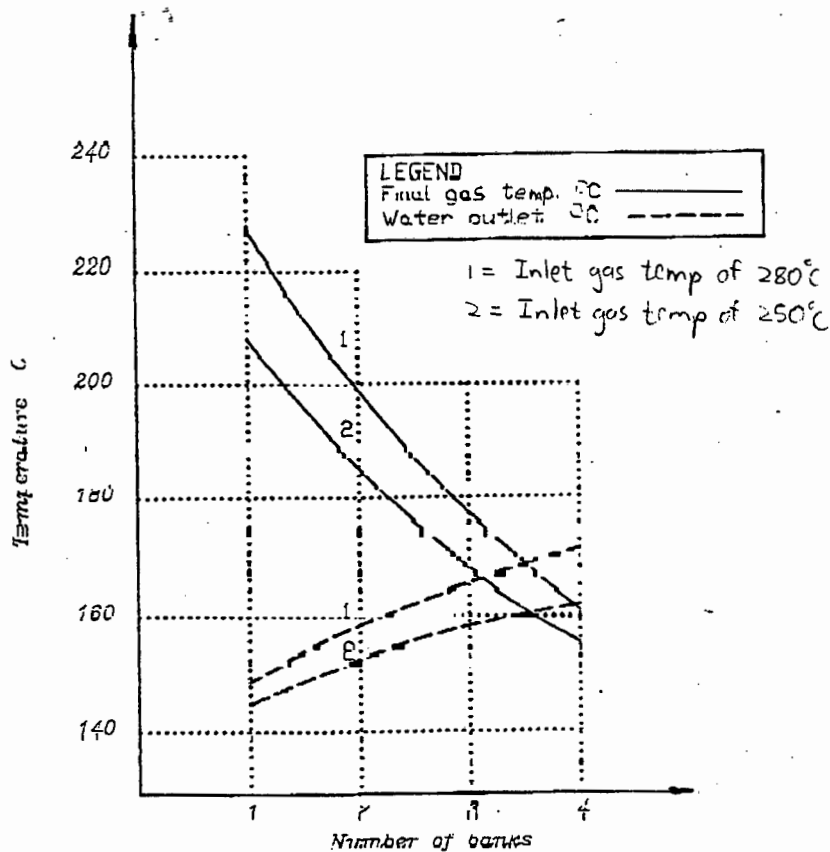


Figure L-1. Economiser curves<sup>(88)</sup>

Average boiler combustion efficiency	70%
Enthalpy of sat. 900 kPag steam	2,776 MJ/kg
Calorific value of coal	28 MJ/kg

With no economiser boiler feedwater temperature = 130°C

Enthalpy of boiler feedwater	0,543 MJ/kg
kg steam/kg coal	8,78
Coal required to produce 5,0 ton/hr steam = 0,570 ton/hr	

With an economiser boiler feedwater temperature = 155°C

Enthalpy of boiler feedwater	0,648 MJ/kg
kg steam/kg coal	9,21
Coal required to produce 5,0 ton/hr steam = 0,543 ton/hr	

Saving by using an economiser

$$= (0,570 - 0,543) \text{ ton coal/hr} * 720 \text{ hr/month} * \text{R}205/\text{ton}$$

$$= \text{R}3\ 985/\text{month}$$

### L11. Accumulator

In phase brewhouse operation at full production is shown in Figures L-2 and L-3:

Average steam demand	7,9 ton/hr
Peak steam demand	14,3 ton/hr
Excess storage required	2,3 tons

Worst case out of phase operation at full production is shown in Figures L-4 and L-5:

Average steam demand	7,9 ton/hr
Peak steam demand	20,6 ton/hr
Excess storage required	10,6 tons

Accumulator capacity of the boilers:

Flash steam is generated when the boiler pressure falls.

Assume initial pressure	900 kPag
Assume final pressure	700 kPag
Quantity of flash steam/ton water	21 kg/m <sup>3</sup>
Water capacity of a 20 ton/hr boiler	35 ton
Assume 4 boilers are on line	
Storage capacity	2,9 ton

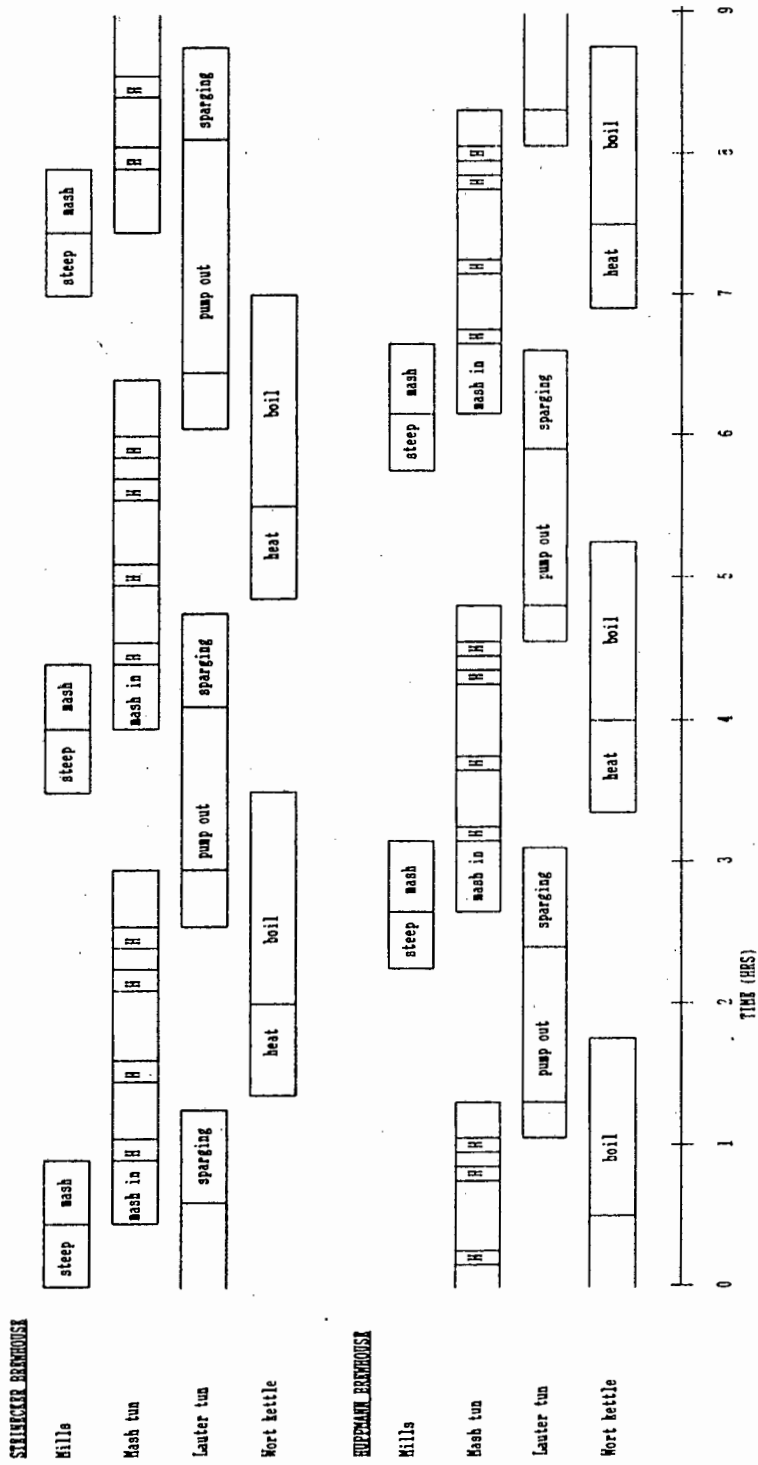


Figure L-2. In phase co-ordination of brewhouse operations.

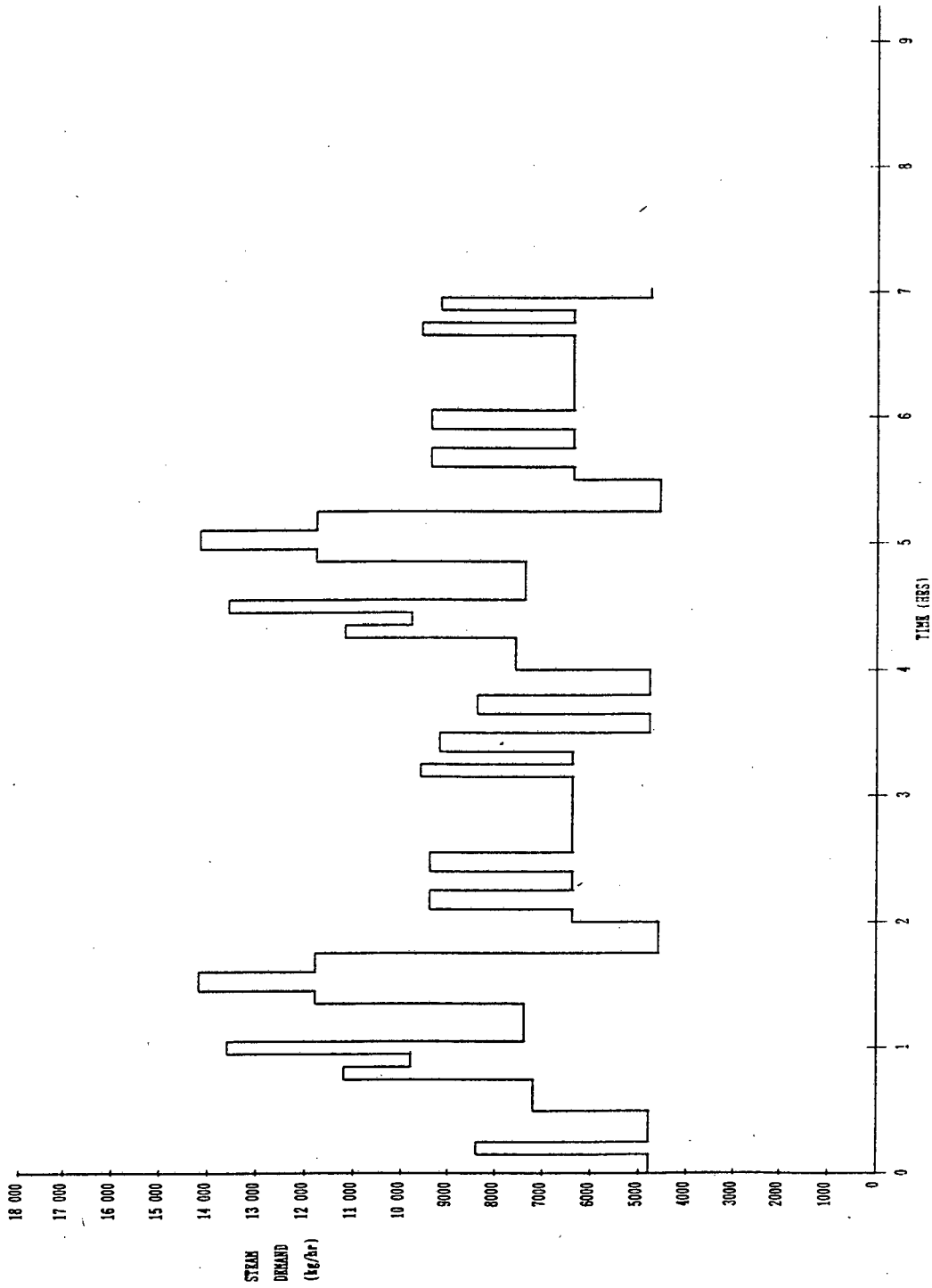


Figure L-3. In phase brewhouse steam profile.

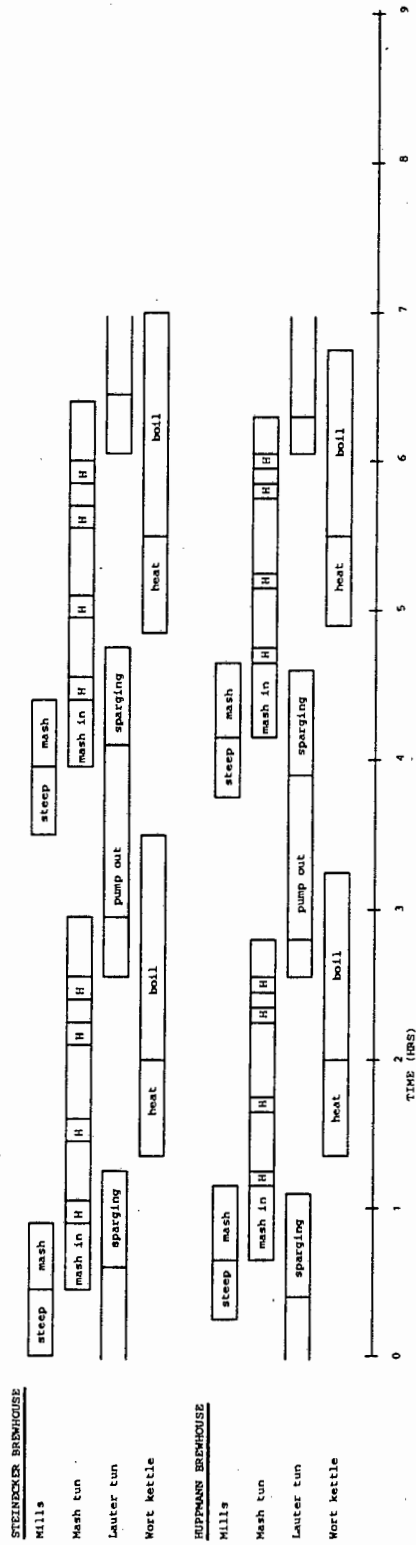


Figure L-4. Worst case brewhouse co-ordination.

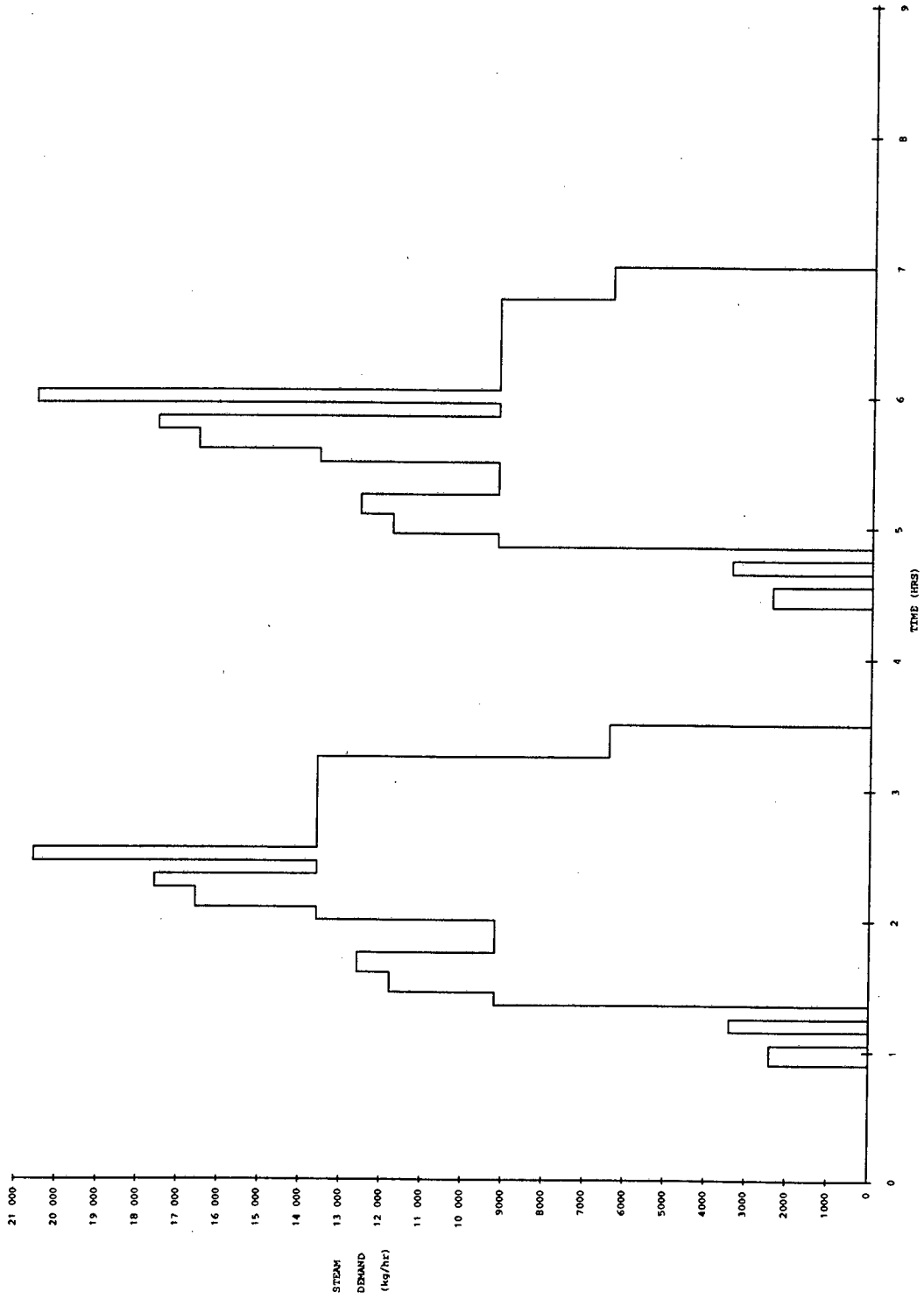


Figure L-5. Worst case brewhouse steam profile.

Thus the accumulator should provide 7,7 tons of storage.

Working pressure of accumulator	800 kPag
Discharge pressure	550 kPag
Quantity of flash steam/ton of water	42 kg/m <sup>3</sup>
Working level in accumulator	80%
Volume of accumulator = 7700 kg/(42 kg/m <sup>3</sup> * 0,8) = 229 m <sup>3</sup>	
Rule of thumb is the maximum discharge rate (kg/hr/m <sup>2</sup> )	
= 2,13 * absolute working pressure (kPa)	
Surface area at 80% level	49 m <sup>2</sup>
Maximum discharge rate	
= 2,12/1000 * 900 kPa * 49 m <sup>2</sup>	
= 93 ton/hr	

#### L12. Wort vapour condensation

Average number of brews/month	166
Total evaporation	10%
Total wort quantity per brew	720 hl
Latent heat of wort	2257 kJ/kg
Energy required in wort boiling	
= 166 brews/month * 720 hl/brew * 0.10 evap. * 2257 kJ/kg * 105 kg/hl	
= 2832 GJ/month	
Overall energy recovery efficiency	70%
Energy recovered	1982 GJ/month
Energy savings/month	R23 725