Investigations into the use of Physical Chemical Techniques for the Treatment and Management of Industrial Effluents with High Organic Content

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INVESTIGATIONS INTO THE USE OF PHYSICAL CHEMICAL TECHNIQUES FOR THE TREATMENT AND MANAGEMENT OF INDUSTRIAL EFFLUENTS WITH HIGH ORGANIC CONTENT

BY

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REPORT TO THE

WATER RESEARCH COMMISSION

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Department of Environment Affairs
The Regional Master Bakers Associations
The Dairy Control Board
The various Regional Milk Distributors & Industries Associations
Association of Balanced Feed Manufacturers
Citrus Board
Deciduous Fruit Board
Fisheries Development Corporation
Federation of Meat Traders
SA Fish Canners Association
SA Oil Expressers Association
SA Sugar Association
Association of Biscuit Manufacturers
SA Chocolate and Sweet Manufacturers
SA Brewing Industry Association
The Sorghum Beer Industry Development Committee

REPORT SUMMARY

0.0 REPORT SUMMARY

0.1 INTRODUCTION

This chapter summarises the industrial survey results and briefly identifies recommended research projects.

0.2 RESULTS

0.2.1 General

The following physical/chemical processes were identified as being worthy of detailed investigation in the treatment of highly organic industrial effluents:-

a. Screening, coagulation and flocculation
b. Sedimentation
c. Dissolved-air flotation
d. Membrane processes
e. Solvent extraction
f. Ion-exchange

The following industries were identified as being suitable for the application of physical/chemical processes in removing the organic component of the effluent and making water of a reusable standard available:-

a. Abattoirs - red meat and poultry
b. Bakeries
c. Breweries - barley and sorghum
d. Dairies - cheese, milk and milk powder
e. Vegetable oil and margarine
f. Soft drinks and carbonated water
g. Yeast

Brief mention is also made of the following industries:-

a. Grain milling
b. Fish processing
c. Fruit and vegetable
d. Pulp and paper
e. Tanneries

Grain milling is a dry industry and therefore of limited interest and the remaining industries are part of existing detailed studies. For these reasons, only brief attention is given to them in this report.

The survey data, collected in 1983, suggest that a total potential saving of 18 400 Ml/a exists in the industries surveyed. This represents about 40% of the total water intake for these industries. This saving can be achieved by in-house management and the application of physical/chemical techniques. However, to be certain that the potential savings can be realised, we recommend that detailed surveys, including visits to several production plants followed by pilot plant trials should be undertaken to confirm the practicability of achieving these savings.

Table 1 gives a summary of water intake and potential savings for the industries considered. Table 2 gives a summary of the specific water intake and specific pollution loads for the industries investigated.

TABLE 0.1

Summary of water intake and potential savings

Industry	Estimated annual water intake	Estimated annual potential savings
Abattoirs	Ml/a	Ml/a
(i) red meat	9 400	4 300
(ii) poultry	3 200	1 500
Breweries		
(i) barley	10 400	4 800
(ii) sorghum	3 100	1 000
Dairies		
(i) cheese	680	460
(ii) milk & milk powder	8 600	4 200
(iii) mixed	680	180
Margarine & Oil	3 150	1 100
Soft Drinks	2 900	560
Yeast	1 160	330
Grand Total	43 270	18 430

TABLE 0.2

Summary of specific water intake and specific pollution load

Industry	Units	Range of SWI	NASWI	Specific pollution load	
				SS	COD
		kl/unit	kl/unit	kg/unit	kg/unit
Abattoirs					
(i) red meat	cattle unit	1,2-18	3	0,6	6,0
(ii) poultry	l/bird & g/bird	15-30	22	10	20
Bakeries	t	0,8-39	5,8	-	-
Breweries					
(i) barley	kl	7,9-10,9	8,6	5,1	23
(ii) sorghum	kl	1,3-5,8	3,0	3,1	28
Dairies					
(i) cheese	t	5,6-140	18	9,5	46
(ii) milk & powder	t	1,6-88	6,6	9,0	28
(iii) mixed	t	0,8-38	4,1	ND	ND
Margarine & Oil	t	2,0-11,5	6,0	0,05	3,8
Soft Drinks	kl	1,1-11,6	3,3	0,2	2,0
Yeast	t	20-35	28	10	100

ND = No data received

0.2.2 Industries

ABATTOIRS - RED MEAT

Various systems for treating effluent from red meat abattoirs have been considered. From literature it is clear that screening followed by dissolved-air flotation (DAF) using a range of flocculants including those specifically designed for protein extraction is presently the best option. This process can reduce the organic load discharged by at least 70% and can yield 1 kg of reusable proteinaceous sludge per kg of COD removed. If water is to be reused after DAF treatment further purification is necessary.

Although likely to be more expensive than DAF treatment, membranes operating on the screened faecal-free component of the industrial effluent could produce potable-quality water for reuse and a concentrate which could be rendered for animal feed. Protein selective ion-exchange resins could also find application.

The majority of the pollution load at red meat abattoirs originates in the blood handling and blood trough washing, and from the paunch contents. Segregation of these effluents and their concentration by membranes could substantially reduce the organic loads discharged.

ABATTOIRS - POULTRY

The strongest effluents from poultry abattoirs originate from the blood handling and cleaning of blood tunnels, the hot scalders, the feather recycle/transportation water and the spin chillers. Segregation of these effluents which represent a small proportion of the total water intake, and their treatment by DAF can substantially reduce pollution loads discharged by these undertakings.

Investigations undertaken overseas have shown the possibility of implementing counter current reuse of spin chiller waters.

Membrane treatment, similar to that proposed for red meat abattoirs, could potentially provide water for reuse.

BAKERIES

Bakeries who manufacture bread only are unlikely to produce strong organic effluents. However where cakes and other confectionery are produced, the potential pollution load from jams and pie fillings removed during baking-pan cleaning can be substantial.

The DAF process applied to the final effluent with the pan wash water dosed into the stream in a ratio of 9 parts final effluent to 1 part pan wash water, can substantially reduce pollution.

BEER - BARLEY

There exists a major potential for water savings in the barley beer industry. Segregation of the effluents from the brewhouse, fermentation cellars and packaging hall is the first step in water management.

The effluents from the brewhouse should be treated to achieve carbohydrate and alcohol removal. The fermentation cellars discharge beer and yeast and treatment by membranes seems potentially to be worth consideration.

The handling of spent grains and trub and their removal from the effluent by wedgewire screens followed by their efficient drying would reduce pollution loads substantially.

Recycle of the pasteuriser and bottle washing waters would reduce the water intake.

BREWERIES - SORGHUM

The malting of sorghum requires considerable watering of the grains during their processing. This process consumes 71% of the total water used in malting. The treatment of the effluent by membranes to remove the SS, COD and TDS would make it suitable for reuse.

The comments under barley beer effluents also apply to sorghum breweries, although DAF treatment of the final effluent could assist pollution reduction.

DAIRIES - CHEESE

The handling of the cheese whey determines the degree of pollution caused during cheese making. Considerable advances have been made with membrane concentration of cheese whey by reverse osmosis or ultrafiltration. Total solids concentration of up to 24% can be achieved with these techniques. The concentrate would be a valuable animal or human feed.

A process for the precipitation of whey has been developed by Binnie & Partners. It involves the selective precipitation of the protein by polyphosphates, followed by removal using DAF.

DAIRIES - MILK & MILK POWDER

Milk losses during bottling account for the pollution load from these dairies; this loss can be as high as 3% of the milk processed. Membrane processes and perhaps DAF in its protein/fat recovery mode, would be worth pursuing.

Recycling of bottle wash water should also be investigated.

Where milk is evaporated, reuse of the evaporative condensates after treatment for organics removal, possibly by activated carbon, would save considerable amounts of water.

VEGETABLE OIL & MARGARINE

The application of DAF to final oil-containing effluents from this industry appears to be the most promising method of reducing pollution. However, owing to acid splitting of these effluents, a considerable concentration of sulphates appears in the final effluent. The application of the "Alwafloc" process employing ferric chloride & lime should be investigated.

GRAIN MILLING

This industry is 'dry' and provided all flour is removed by dry processes, no effluent other than domestic is to be expected.

PULP & PAPER

The only effluent considered is that of SAICCOR in Natal as their spent sulphite liquor contains substantial quantities of ligno sulphonates which if recovered could be used as coagulation agents for removing proteinaceous matter in the abattoir and dairy industries.

Reverse osmosis and ultrafiltration would be required to separate the lignosulphonates and sugars. Two effluents should be considered. The washpit liquor could be concentrated from 5% TDS to 16% TDS using reverse osmosis which would provide copious quantities of reusable hot water. The digester liquors and the concentrate from the wash pit water recovery would then be separated from their accompanying sugars.

SOFT DRINKS AND CARBONATED WATER

Potential exists for substantial pollution discharges during the washing out of fruit concentrates and sugar storage tanks. Membrane treatment would be the only route for recovery of these substances.

Recycle of the bottle wash waters could substantially reduce the water consumption.

YEAST MANUFACTURE

Although the volumes of effluent are low, the pollution loads created by cleaning the heat exchangers for sterilising the molasses and the discharges from the yeast separating centrifuges can only be described as enormous. Ultrafiltration of these streams is probably the only viable route for their disposal.

OTHER PROCESSES

We believe that the Sirotherm desalination process might find application for desalting cooling tower blowdown flows. It could also be used on the can cooling circuits in the canning industry.

Solvent extraction processes have potential as a route for recovering fat from the DAF sludges extracted from abattoir wastewater treatment. They might also find application in the treatment of margarine plant effluents.

Many industrial operations involve the concentration of products such as fruit juices, milk and sugar. At present thermal evaporation processes are used, although the energy requirements of these processes are high compared to membrane systems. Accordingly the combination of membranes as a preconcentration stage prior to evaporation could provide considerable savings in energy.

In other applications where no market exists for the organic matter removed from an effluent, its concentration by membrane techniques could permit that concentrate to be anaerobically digested in ultra high rate sludge blanket type upflow digesters having hydraulic residence times of only a few hours.

0.2.3 Recommended research projects

Our preliminary survey has indicated considerable potential for water savings. It is also of importance to identify why the SWI of industries is so variable from one plant to the next.

Consideration should be given to the manufacture and deployment of pilot dissolved-air flotation plants in several industries to test their potential for water recovery.

A pilot plant capable of operating both ultrafiltration and reverse osmosis processes, should be constructed and deployed in various industries.

We recommend that consideration should be given to undertaking the following research projects:-

NATIONAL WATER & WASTEWATER SURVEY

The objectives of this survey would be to visit every industry to investigate how the water is used in-house and to quantify the reasons for the wide range of SWI.

ABATTOIRS RED MEAT & POULTRY

The investigation of water and effluent management within the industry should be undertaken to determine targets for the overall SWI as well as the SWI for individual processing steps.

The project should include the provision of DAF and membrane pilot plants to investigate the various alternatives to chemical precipitation and recovery of proteins. The membrane units should also determine the feasibility of water recovery by this technique.

BREWERIES - BARLEY & SORGHUM

An investigation of the water and effluent management in the brewing industry is recommended. The performance of DAF and membranes on selected effluents should be quantified.

Targets should be set for the SWI at each process step.

The project should also investigate the reuse of sorghum malting water.

DAIRIES

An investigation to determine the feasibility and economics of DAF and membrane plants in the dairy industry should be undertaken. Attention should be given to the measures needed for treatment of evaporative condensates for reuse.

SOFT DRINKS AND CARBONATED WATER

The techniques for renovating water for bottle washing, which is the main water use, would possibly have been covered by the breweries project. Accordingly the recovery of sugars and drink concentrates by membrane techniques are the only measures requiring research in this industry.

VEGETABLE OIL AND MARGARINE

The water and effluent management in this industry would involve the in-plant operation of DAF using the 'Alwafloc' process as well as other coagulants. The recovery of the high grade fats by solvent extraction also warrants investigation.

YEAST

Although the industry is relatively small, problems exist with the disposal of the highly polluted effluent. The feasibility of membrane separation should be investigated.

To achieve the maximum savings in the shortest time we recommend that the order in which the industries be investigated be as follows:-

a. breweries
b. abattoirs
c. dairies
d. vegetable oil and margarine
e. soft drinks and carbonated waters
f. yeast

CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

1.1 BACKGROUND

Intensive research into water and effluent management in several industries has been instituted by the Water Research Commission. These projects include the fruit and vegetable, fish, meat, hide and textile industries. This approach produced detailed guides to water and effluent management, often including methods for conventional pretreatment of effluent followed by biological degradation.

It has become apparent, however, that certain physical/chemical treatment techniques can successfully be applied in many industries having effluents with high organic concentrations. This can result in the recovery of valuable components in the effluent stream. The revenue generated in this way would offset the costs of installing and operating such a treatment plant. This is not the case for biological treatment which cleans up the effluent but does not result in the recovery of valuable material. A further advantage in physical/chemical treatment is that it can produce water of a reusable quality resulting in a further cost saving as well as a reduction in demand for water.

1.2 OBJECTIVES

The objectives of this study are therefore:-

a. To establish which physical/chemical processes can be used to reduce the organic pollution load of industrial effluents and what costs are involved in implementing these processes.

b. To show how and where these processes can be applied in industry and further to estimate the potential water savings, pollution load reduction and possible reuse of water resulting from these applications.

c. To identify research projects which are required to facilitate the implementation of these processes in the industries considered.

d. To compile a list of references to allow easy access to information presented in this report.

1.3 METHODS

The approach required to meet the objectives of the study is logically divided into five areas. These are a survey, a literature review, process application, data work-up and potential research projects. In practice, it was found that these five areas of work could not be tackled one at a time. A certain amount of overlap was required due to the exploratory nature of the study. Information obtained in one area could prompt further work in another area.

1.3.1 Survey

A questionnaire survey was performed on as large a sample as possible of the industries which were shown to warrant investigation. Information pertaining to water intake, water usage, production, effluent volume, effluent quality and effluent disposal routes was requested. Costs of water and effluent were also sought. Site visits to certain factories were arranged in order to verify information collected in the survey. This also served as a first hand introduction to the types of problems experienced by each industry.

1.3.2 Literature review

The Waterlit and Aqualine databases were searched initially and an update search was performed on a monthly basis for the duration of the study. Papers reporting on the use of physical/chemical effluent treatment techniques as well as those relating to applications of these techniques in specific industries were obtained.

1.3.3 Process applications

The performance of the various processes was examined in relation to the various industries. Potential recovery of useful material as well as potential re-use of water was investigated.

1.3.4 Data work-up

From the survey data received for each industry the following calculations were performed:

a. The specific water intake (SWI) which is the volume of intake water per unit of production was calculated for each factory.

b. A national average specific water intake (NASWI) was then computed for the sample. This is the total water intake for the sample of factories divided by the total reported production.

c. Using the total annual production as given by the Central Statistical Services publication, "Manufacturing Statistics", and the NASWI, the total annual water intake was estimated.

d. Total annual effluent volumes and pollution loads were then estimated in an analogous fashion.

e. Estimates were made of an SWI which could be achieved by each industry through good water management and potential re-use of water. These estimates were based on information obtained from factory visits, the survey data and the literature. Using this SWI, the amount of water which could be saved in each industry considered was calculated.

1.3.5 Potential research projects

Finally, areas requiring further research, before the various processes can be successfully and economically implemented, have been identified.

1.4 REPORT STRUCTURE

Chapter 2 discusses the physical/chemical processes found to warrant investigation and provides information available on the costs of the process. Chapter 3 details the industries found to be suitable for the application of these processes. The survey data are presented here as well as the estimated potential savings in water and reduction in pollution load. Chapter 4 presents the recommended research projects and Chapter 5 gives summaries of the most important papers received and details the literature reviewed.

1.5 REPORT DATA

All data presented in this report is related to the year 1983. Cost data would vary with time in response to economic factors. Less obvious is the fact that production related data, such as water consumption, might also vary with time in response to economic factors as well as environmental factors such as drought. For these reasons, care should be exercised when using and interpreting the data presented in this report.

CHAPTER 2

PROCESSES & COSTS

2.0 PROCESSES & COSTS

2.1 GENERAL

The physical/chemical processes considered in this report have been those selected from literature as being worthy of detailed investigation to treat effluents having high organic concentration.

The processes are:-

a. screening, coagulation & flocculation
b. sedimentation
c. dissolved-air flotation
d. membrane processes
e. solvent extraction
f. ion exchange
g. hybrid processes

These processes are briefly described and where data is available estimated costs have been provided. All costs have been related to the year 1983 unless otherwise specified. In some cases, costs could not be derived as further research is needed.

2.2 SCREENING, COAGULATION & FLOCCULATION

2.2.1 Screening

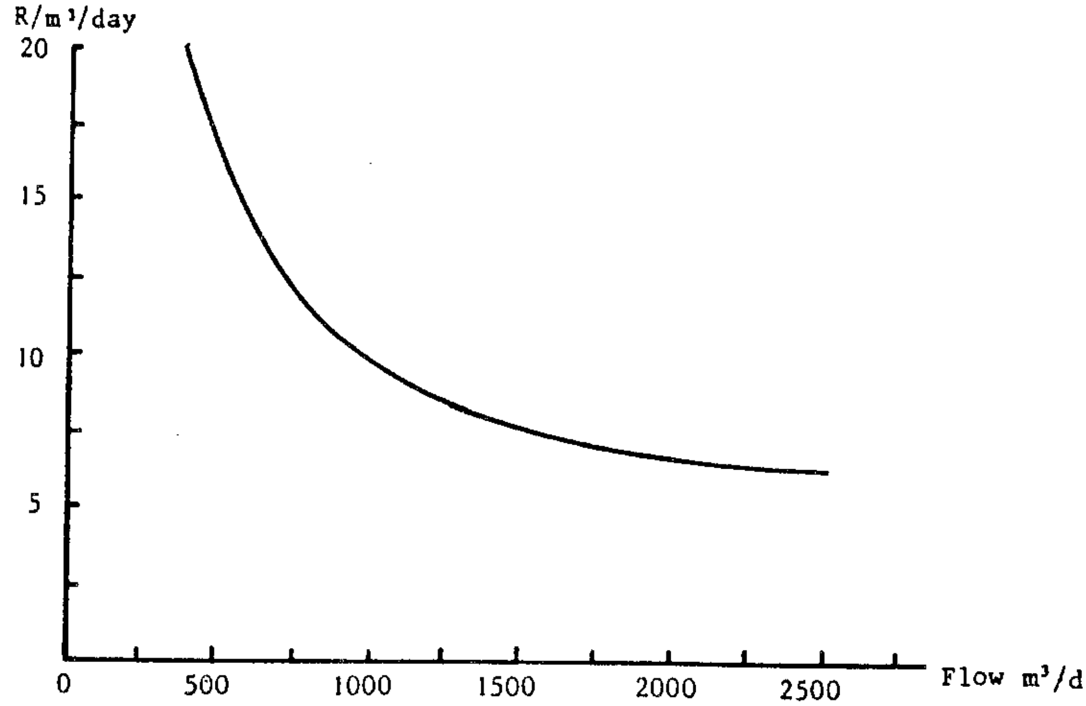
Virtually without exception the first step in treating waste waters should be screening. Static wedgewire screens with aperture opening 0,5 to 3 mm are ideal, having no moving parts and the minimum of maintenance. This type of screen is rated in terms of kl of flow per metre of weir length. Trials are needed to determine the correct length of weir for each effluent.

The costs of this type of screen based on stainless steel 316 S16, are given in Fig. 2.1.

2.2.2 Coagulation & flocculation

After screening, coagulation followed by flocculation is needed prior to removal of the precipitated matter. Coagulation and flocculation are often used in conjunction with sedimentation to enhance the process of settlement. The chemicals used are coagulants and coagulant aids, which are simple water soluble electrolytes, low molecular weight inorganic acids, bases or salts. Iron, aluminium and calcium salts are the most widely used coagulants; including lime $Ca(OH)_2$, alum $Al_2(SO_4)_3$, ferric chloride ($FeCl_3$), ferrous sulphate $Fe_2(SO_4)_3$ and sodium aluminate $NaAlO_2$. The coagulant aids comprise natural or synthetic long chain organic molecules with characteristics of polymers and electrolytes. Polyelectrolytes, bentonite and activated silica are common aids.

Fig. 2.1 Specific capital costs for static screens



The flocculation/coagulation process, if used, must occur in specially configured basins or tanks designed to promote the floc growth, and the chemicals must be rapidly and effectively mixed into the stream prior to commencing the flocculation stage. The pH range at which the optimum coagulation occurs varies depending on the coagulant being used. For the fruit and vegetable industry coagulants, if used, are likely to be alum, ferric chloride or polyelectrolytes. These are described below:-

ALUMINIUM SULPHATE

When added to water the main reaction of aluminium sulphate ($Al_2(SO_4)_3.18H_2O$) or alum is with either the natural alkalinity, such as calcium carbonate, or with added alkalinity such as lime or soda ash, or caustic soda, resulting in the formation of colloidal aluminium hydroxide which then flocculates into large particles like snow flakes. This reaction with the water lowers the pH.

Alum works in the range pH 5,0 - 7,0 as follows:-

(i) $Al_2(SO_4)_3 + 3\ Ca(OH)_2 = 3CaSO_4 + 2Al(OH)_3$
(one part of lime is needed for 3 parts alum)

(ii) $Al_2(SO_4)_3 + 6NaOH = 2Al(OH)_3 + 3Na_2SO_4$
(NaOH dose must be 36% of the alum dose)

(iii) $Al_2(SO_4)_3 + 3Na_2CO_3 + 3H_2O = 2Al(OH)_3 + 3Na_2SO_4 + 3CO_2$
$Al_2(SO_4)_3 + 6Na_2CO_3 + 6H_2O = 2Al(OH)_3 + 3Na_2SO_4 + 6NaHCO_3$
(dose 1 part soda ash to 1 or 2 parts alum)

Alum is made into a 10% solution and dosed with either plunger or diaphragm type metering pumps.

IRON SALTS

Ferric chloride ($FeCl_3$) is very corrosive but performs well with fruit and vegetable effluents. The iron salts work over a wider pH range than the alum and often produce a denser floc particle. The dosing and handling equipment for this liquid must be designed for its use. In South Africa the chemical is sold in liquid form.

$$FeCl_3 + 3Ca(HCO_3)_2 = 3CaCl_2 + 2Fe(OH)_3 + 6CO_2$$

POLYELECTROLYTES

The polyelectrolytes can occur naturally and include sodium alginate which occurs in kelp. Starch and gum-based products also exist.

By far the greatest number of these substances, however, are the synthetic ones comprising derivatives based on polyacrylamide and its co-polymers with polyacrylic acid. These long chain macromolecules have specific electrical charges which enable them to attract charged particles in water. They fall into 3 main groups:-

(a) non-ionic - polyacrylamides; adsorb on particles to modify their state;

(b) anionic - adsorb on particles to modify surface state;

(c) cationic - positively charged chains due to amine presence. These cancel out the negative chargesonparticles.

2.3 SEDIMENTATION

Sedimentation occurs when the effluent is held in a quiescent state or at a velocity low enough for the solid particles to settle. The design parameters include surface area, retention time, tank depth and overflow rate. Filters are inefficient removers of suspended solids and thus are normally preceeded by settlement tanks. They should be installed when turbidities of feed to the filters exceed 10 mg/l. Sedimentation tanks may be circular or rectangular and can have vertical, radial or horizontal flow.

2.3.1 Vertical flow

Fig. 2.2 shows the general arrangement of a vertical flow sedimentation tank. These tanks work well with fruit and vegetable effluents, especially for soil and the heavier solids. The influent is conveyed to the bottom of a 60° hopper-bottomed tank whereupon it commences its vertical flow from the bottom to the top of the tank. As the crossectional area of the tank increases, the velocity of vertical flow reduces allowing the settling velocity of the particles to exceed the vertical velocity of the water. The clarified water passes over the top of the tank through submerged orifices. Owing to the geometry of the tank the particles agglomerate to form a blanket through which all incoming particles must pass. The blanket assists with removal of solids from the water. When the particles become too large to be suspended they fall into the base of the tank to be hydrostatically removed as sludge. Where the particles are very small, there exists the chance that the blanket will rise into the vertical sided portion of the tank. To control the top level of the blanket, a sludge bleed pocket is provided at the top of the blanket. These tanks can be manufactured in circular or rectangular configuration. The design of these tanks is governed by the vertical rise rate in the tank, 1,2 to 4 m/h being the normal range. It is important to allow the inlet pipe to be adjustable so that the correct height above the tank bottom can be established. The cost of settlement tanks of this type is shown in Fig. 2.3

Fig. 2.2 Vertical flow sedimentation tank

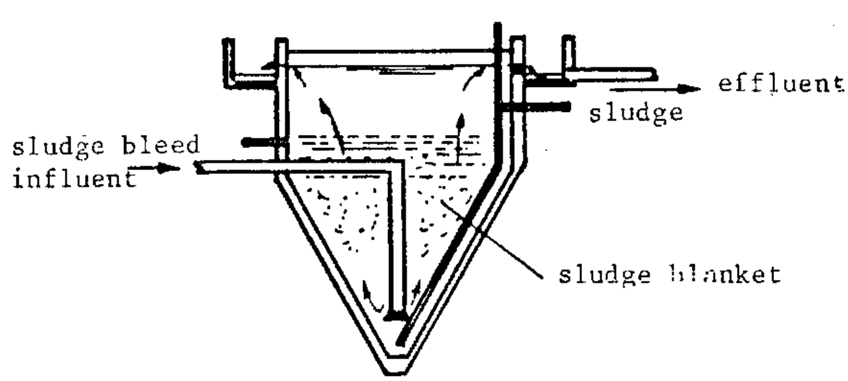


Fig 2.3 Specific capital costs of clarifiers

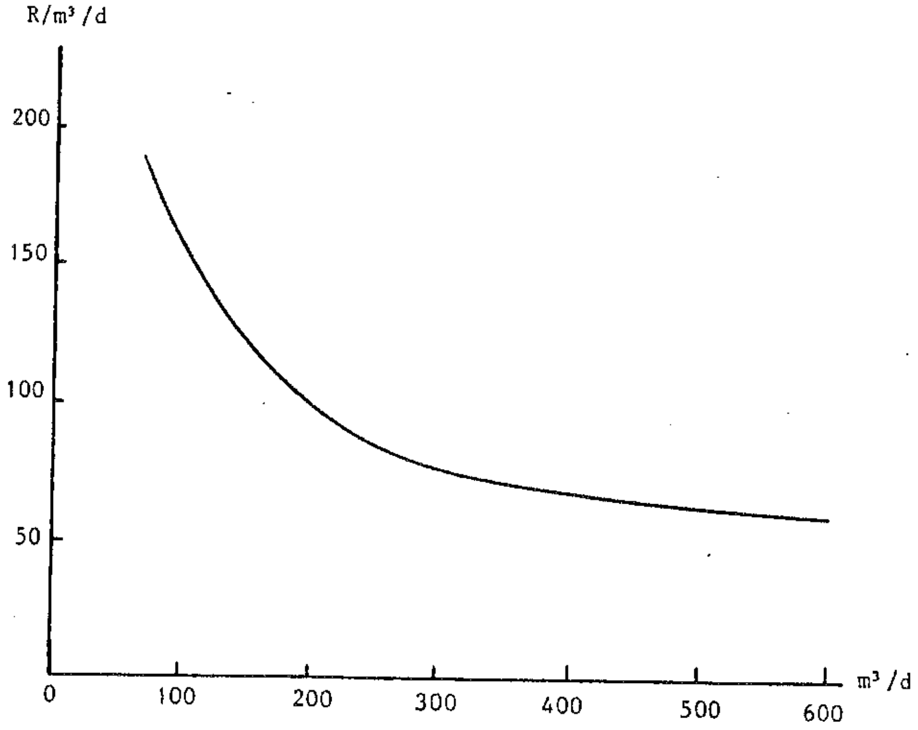


Fig. 2.4 Radial flow sedimentation tank

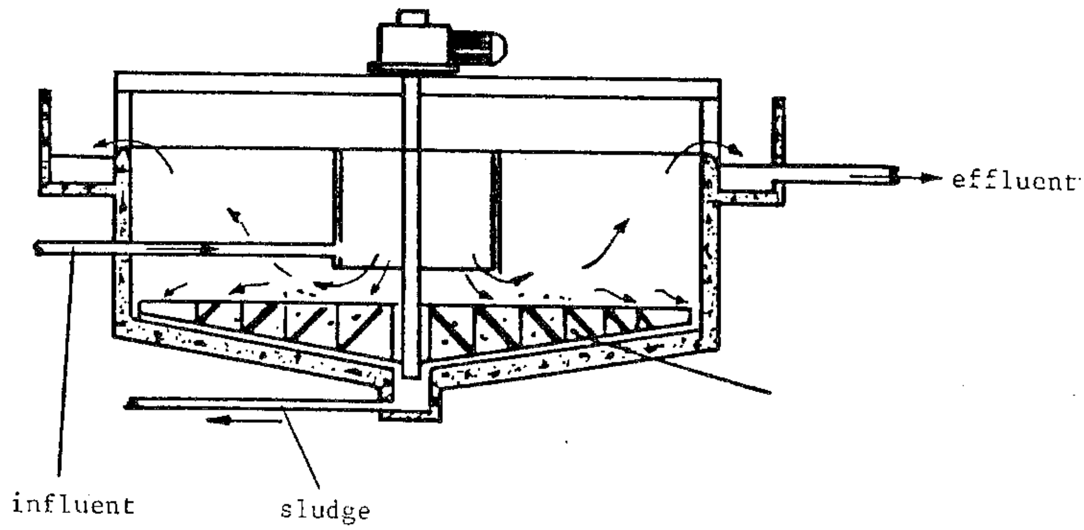
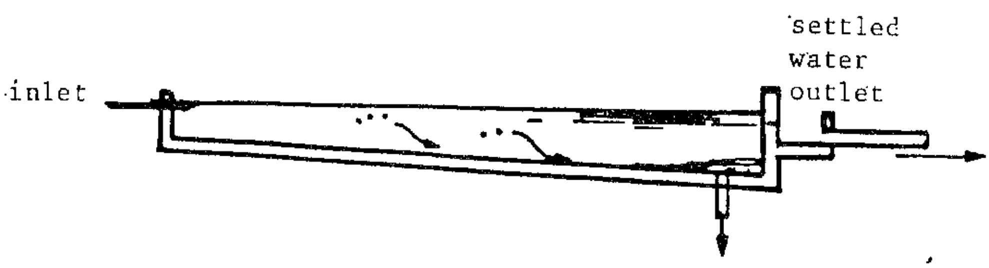


Fig. 2.5 Horizontal flow sedimentation tank



2.3.2 Radial flow

Fig. 2.4 shows the general arrangement of a radial flow sedimentation tank. The flocculated water enters the centre quiescent chamber which allows the heavier particles to sink into the sludge zone from which sludge is scraped into a central pocket for disposal. The water commences a radially vertical rise to exit from the tank over weirs or orifices arranged around the tank.

2.3.3 Horizontal flow

Fig. 2.5 shows the general arrangement of a horizontal flow sedimentation tank. These tanks are often rated by the number of hours retention, but more correctly they should be rated on the flow per unit of surface area on which the sludge can settle. The normal range is from 9 to 18 $kl/m^2/hr$. Once the area of the tanks has been fixed, the depth must be determined. The depth must be considered in relation to the length of the tank, because this ratio will decide the horizontal velocity. If the length of the tank does not exceed 20 times the depth available for the horizontal flow of water, then it will usually be found that the actual depth is not critical.

2.4 DISSOLVED-AIR FLOTATION

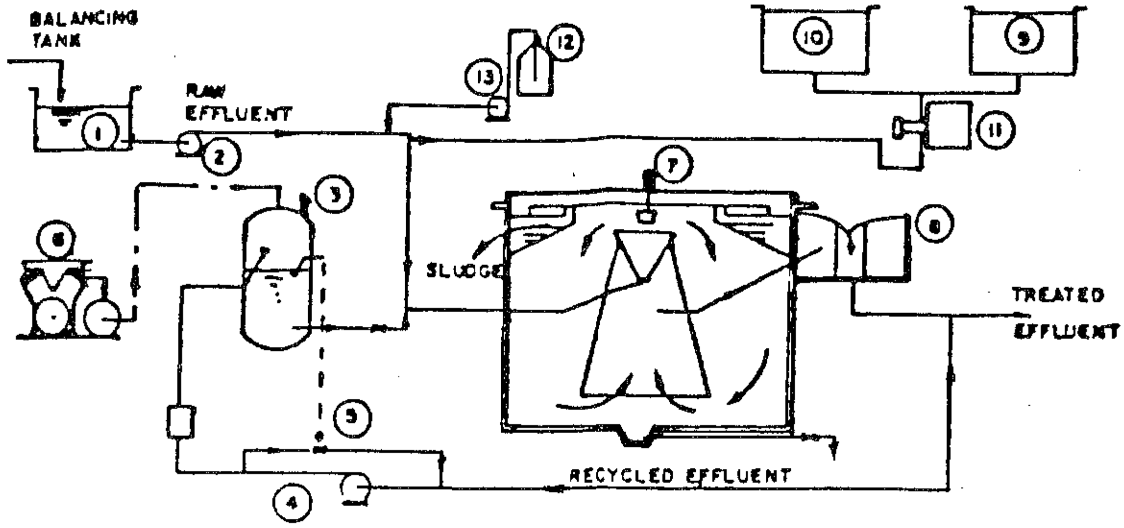
As an alternative to settlement tanks for the removal of gross solids, dissolved-air flotation (DAF) plants can be used. These have been tested in a number of industries but pilot trials will be required.

Referring to the schematic diagram, Fig. 2.6, the effluents from the various parts of the plant are passed to a holding tank (1) which balances the flow and organic strength to near-constant values which permits the plant to be sized to the average flow over 24 hours rather than the peak flow. The effluent is abstracted by supply pump (2) which forwards it to the reaction tank (7). A portion of the flow which can be recycled effluent or clean water is passed from weir box (8) to high-pressure pump (4) which raises it to a saturation pressure of 600 kPa and passes it into the saturator tank (3). The level in tank (3) is maintained by a level control float which operates a by-pass (5) around high pressure pump (4), increasing the flow by-passed if the level in the saturator tank is too high and vice versa if it is too low.

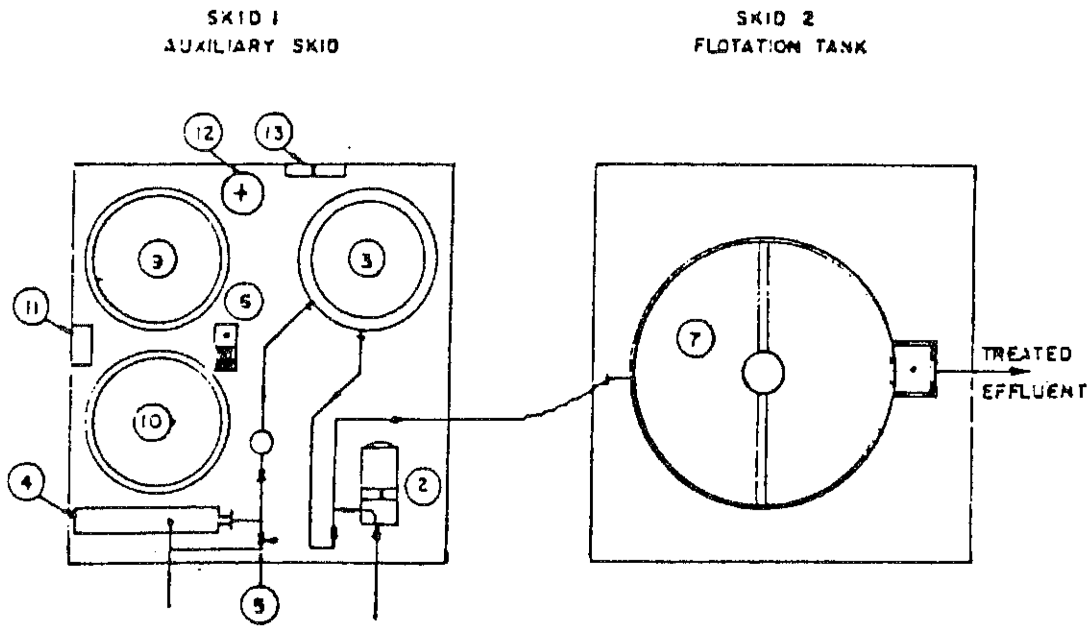
The air-compressor (6) delivers air to the saturator vessel (3) where it dissolves into the water which leaves the vessel to join the main stream from the supply pump before entering the reaction tank (7). On entering the tank where the pressure reduces to atmospheric, the air bubbles come out of solution to form a rising stream which floats the debris to the surface for removal by the rotating scraper.

Once separated the effluent falls to the bottom of the tank passing under a skirt into the outlet pipe which discharges over an adjustable weir to maintain the water level in the tank and then leaves via weir box (8). Facilities are provided for dosing coagulating chemicals - tanks (9) and (10) and pump (11) and for pH correction should this be needed.

Fig. 2.6 Dissolved-air flotation plant



PILOT PLANT LAYOUT

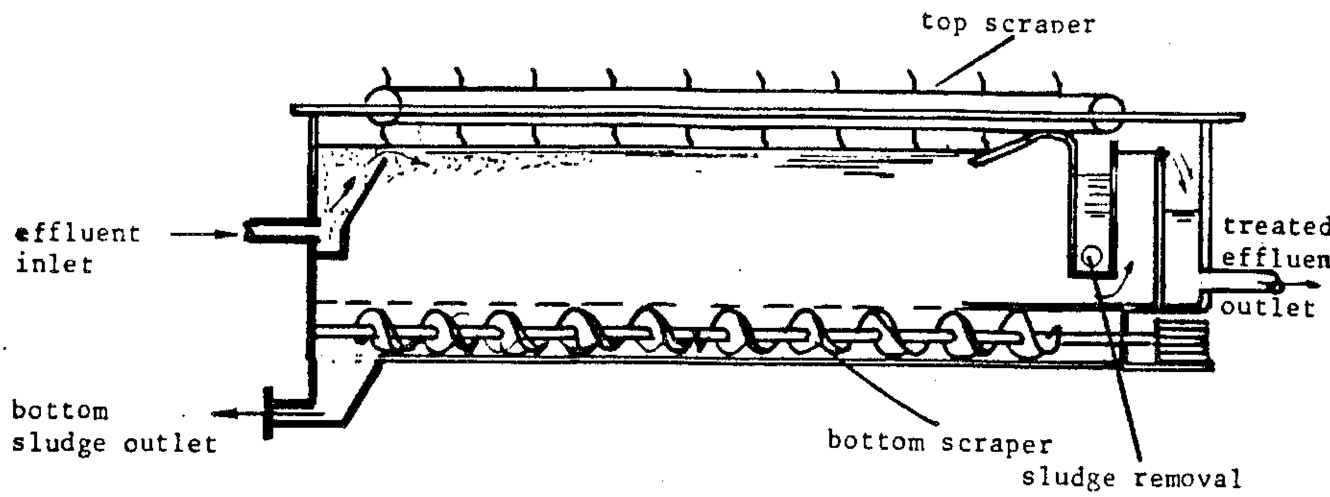


LEGEND

1. RAW EFFLUENT BALANCE TANK
2. RAW WATER SUPPLY PUMP
3. SATURATOR VESSEL
4. HIGH PRESSURE PUMP
5. SATURATOR LEVEL CONTROL VALVE
6. COMPRESSOR / RECEIVER
7. REACTION TANK
8. TREATED WATER OUTLET
9. CHEMICAL TANK 1
10. CHEMICAL TANK 2
11. CHEMICAL DOSE PUMP
12. ACID CARBUOY
13. ACID PUMP

The commercial flotation plants are available in rectangular or circular format, a typical rectangular tank is shown at Fig. 2.7.

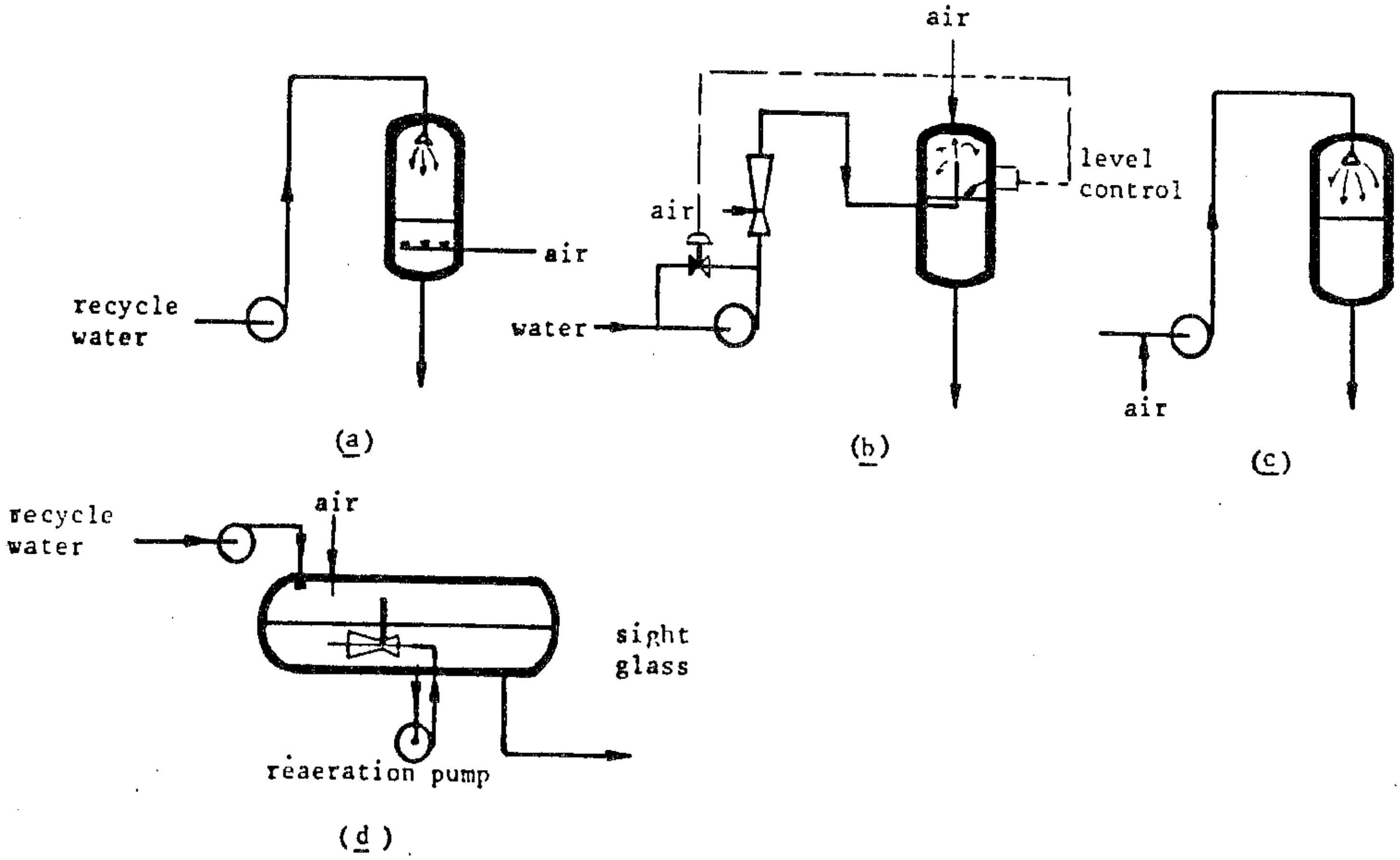
Fig. 2.7 Retangular flotation tank



It must be noted that the design parameters of the flotation systems vary depending on the character of the effluent. The circular units give superior air bubble distribution compared with the rectangular ones, but rectangular units provide a greater time and space for the agglomeration of the solids. The key to successful flotation tank design is the selection of the optimum method of dissolving the air and the pressure at which this operation is performed.

Various methods of inducing the air to dissolve into the recycle flow are in use. Figs. 2.8 (a) to (d) show the recycle pump, the saturator vessel and the methods of dissolution. System (a) employs a top spray film into a vertical saturator which may be packed with Raschig rings to improve the air to water contact. Saturator packing should not be used where high SS concentrations are likely to be experienced in the recycle feed. In the work conducted for this guide no packing was used in the saturator.

Fig. 2.8 (a) to (d) Methods of air dissolution in DAF plants



Type (b) was the type used in compiling this guide where a positive displacement mono-pump fitted with level controlled by-pass delivered the recycle flow into the saturator via a venturi eductor. Type (c) involves the injection of air into the eye of the high pressure pump or if it is a multi stage pump at the 2nd or 3rd stage of the pump. The delivery sprays into the saturator. Type (d) involves the amalgamation of (a) & (b) where the air is supplied to the air cushion and a reaeration pump removes water from the saturator and pumps it through a venturi which draws air from the air cushion.

Type (b) saturators should be sized to retain the recycle flow for 10 minutes and to operate at 80% water level (on the straight). Reaction tanks can be sized for an hydraulic loading of 3 to 5 kl/m^2 tank surface area per hour. It should be noted that if the recycle flow is taken from effluent rather than feed, the designed hydraulic loading must include the saturator recycle flow.

Fig. 2.9 Degree of air saturation of water with increasing pressure

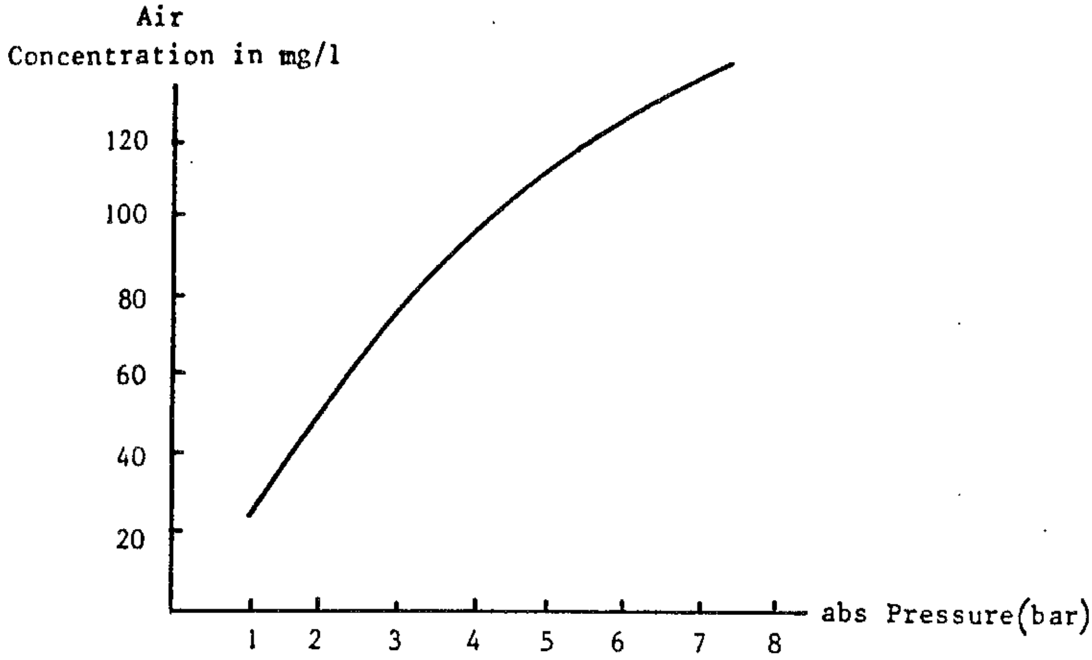
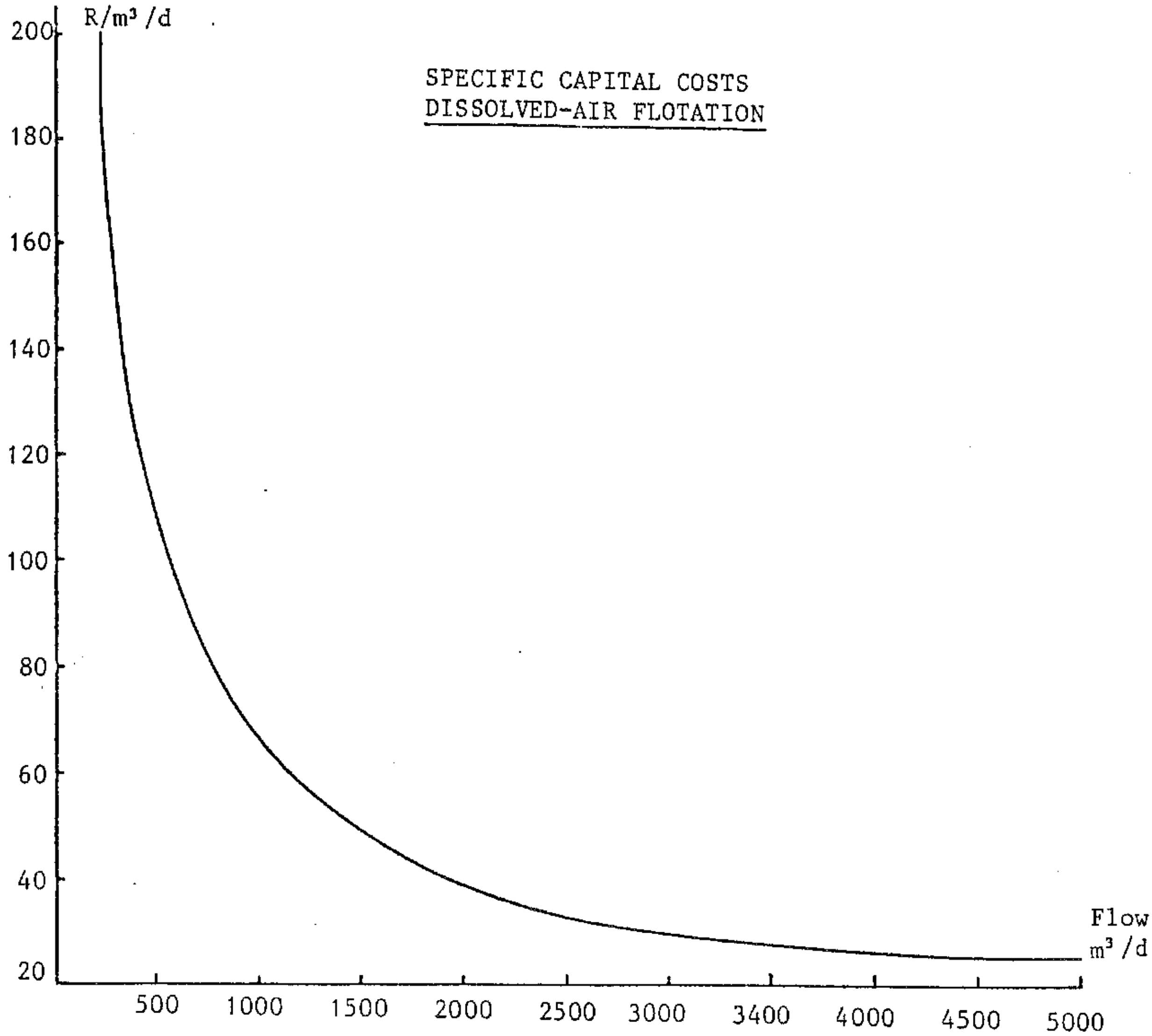


Fig. 2.9 shows the degree of air saturation of water for different pressuration pressures. Facilities must be provided to remove sludge from both the top and the bottom of the tank. The costs (1984) of dissolved-air flotation plants are shown at Fig. 2.10. Where chemical flocculation is desirable, a suitably designed flocculator should be provided upstream of the flotation tank.

Fig. 2.10 Specific capital costs (1984) for dissolved-air flotation



2.5 MEMBRANE PROCESSES

2.5.1 Introduction

Membrane technology is advancing so rapidly that it is nearing a level of economic effectiveness. The processes are divided into two categories, ultrafiltration and reverse osmosis.

2.5.2 Ultrafiltration

As its name implies, ultrafiltration (UF), is a method of mechanical separation of suspended solids from a liquid and is similar in principle to filtration through screens or beds of porous media. A major difference is that, whereas conventional filtration processes are not capable of removing suspended particles finer than about 0,001 mm, e.g. colloids, UF operates in the macro-molecular size range and can therefore be used to separate large organic molecules from liquid suspensions or even from solutions. Since many food industry wastes and products contain large organic molecules, UF offers a convenient and efficient way of carrying out separations such as the recovery of cheese whey, separating and concentrating blood plasma in abattoir wastes, and many other diverse applications. It may be regarded as an ultra-fine sieving technique.

Separations are achieved by using ultra-thin synthetic or natural product-derived membranes in which are present a very large number of very fine "holes". The size of the holes can be tailored to match the molecular dimensions of the range of organic compounds which it is desired to remove from the effluent.

The way in which these UF membranes are assembled into a commercial system is basically similar to the description following which deals with tubular and flat plate type reverse osmosis systems.

2.5.3 Reverse osmosis

Reverse osmosis (RO) is superficially similar to UF in that it also makes use of ultra-thin synthetic or natural membranes to separate valuable and non-valuable materials which may co-exist in a liquid product or effluent. However, the mechanism of separation is quite different and the types of material which can be recovered differ markedly.

Whereas UF is basically a mechanical separation, RO relies upon the diffusion of water molecules through a semi-permeable membrane by a sequence of phenomena such as adsorption, permeation and desorption. RO membranes have therefore a much "tighter" structure than those of UF. True "holes" as such are not present in the membrane. Even so, RO membranes can, like UF membranes, be tailored to suit the class and molecular sizes which it is desired to separate from water. In this case, however, the molecules are dissolved in the water, rather than in suspension as in UF, so that the products of an RO unit operating on a feed solution are a more concentrated solution, on the one hand, and a relatively solute-free water (the permeate) on the other. Typical applications include the production of potable water from saline solutions (desalination) and the concentration of weak solutions to stronger solutions as in the concentration of sugar and fruit juices.

A simple diagram of the RO process is shown in Fig. 2.11. The upper figure shows the process of normal osmosis in which at left, a semi-permeable membrane is shown separating vessels initially containing equal volumes of a concentrated solution and pure water. Under normal osmosis, water flows from the left hand reservoir to the right hand reservoir, diluting the concentrated solution.

This process continues until the flow of water ceases, at which point the head of the solution exceeds that of the water by a difference called the osmotic pressure of the particular solution.

If, now, a hydraulic pressure, greater than the osmotic pressure, is applied to the solution, as shown in the lower part of Fig. 3.11 the osmotic flow is reversed. Nearly pure water will pass through the membrane from right to left, concentrating the solution and separating pure water from the solution. This is the process of reverse osmosis.

2.5.4 Commercial application of RO

The elements of a commercial system for utilising RO to separate a solution into water and a concentrate are shown in Fig. 2.12. All that is needed is a pump to pass the saline solution into a flow module containing an RO membrane with a pressure let-down valve for the concentrate, and an exit, on the opposite side of the membrane compartment, for the fresh water. Provided the hydraulic pressure, P, generated at the pump discharge exceeds the osmotic pressure of the saline solution some degree of separation and concentration will occur.

In practice it may be necessary to pretreat the feed solution to make it physically and chemically compatible with the material of the membrane. Some degree of post-treatment of the permeate may also be needed. Pretreatment normally entails the removal of gross suspended solids which may be present in the feed, possibly adjustment of the pH to prevent alkaline scale deposition on the membrane and to ensure chemical compatability and, occasionally, dechlorination and/or the removal of dissolved oxidants. Each application must be treated on its own merits but, in general, pre-treatment should be designed to be a minimum by experienced choice of membrane type and separation process. Post-treatment may not be needed and is usually confined to simple recarbonation of the product (freshwater) and, possibly, chlorination.

Fig. 2.11 Principles of osmosis and reverse osmosis

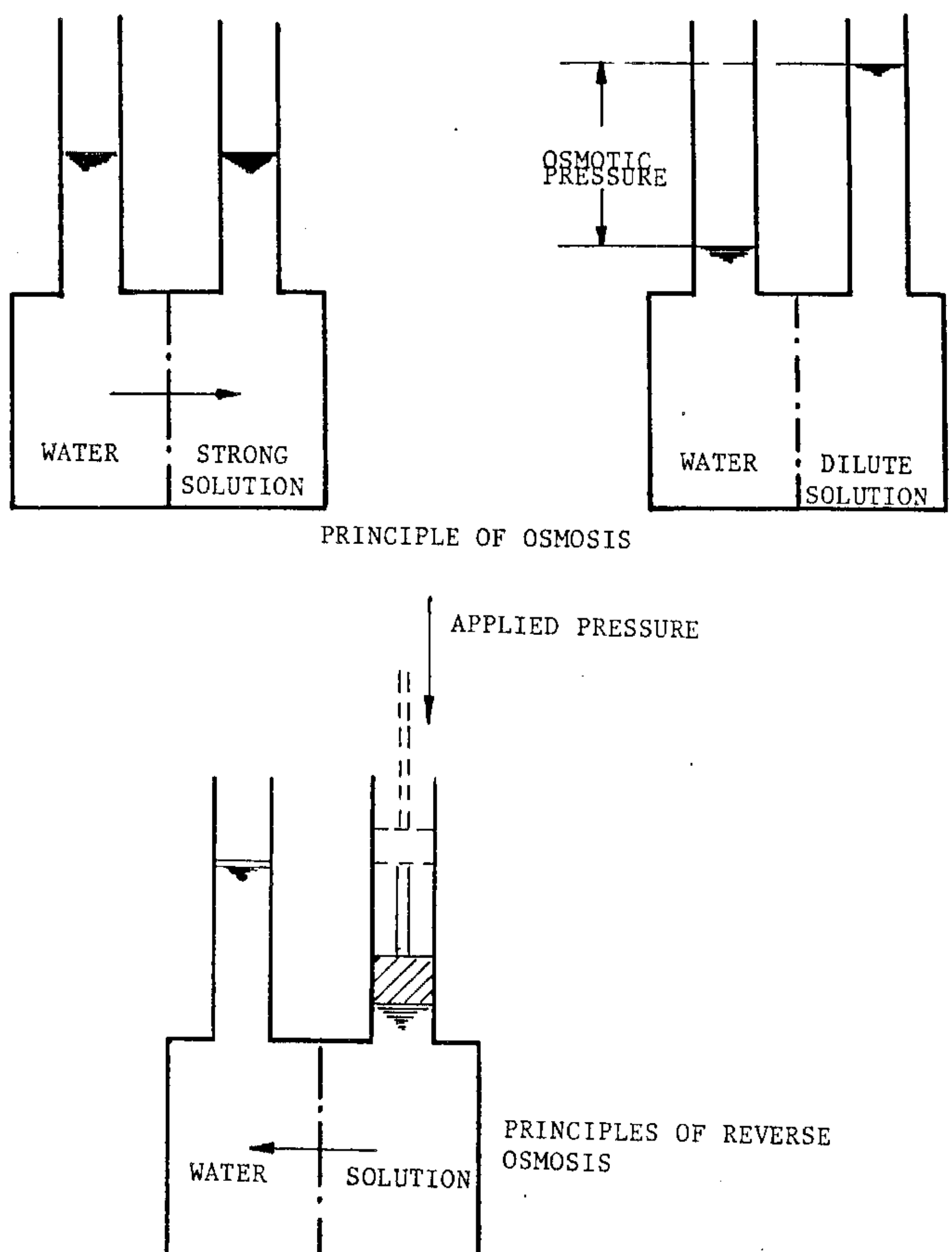
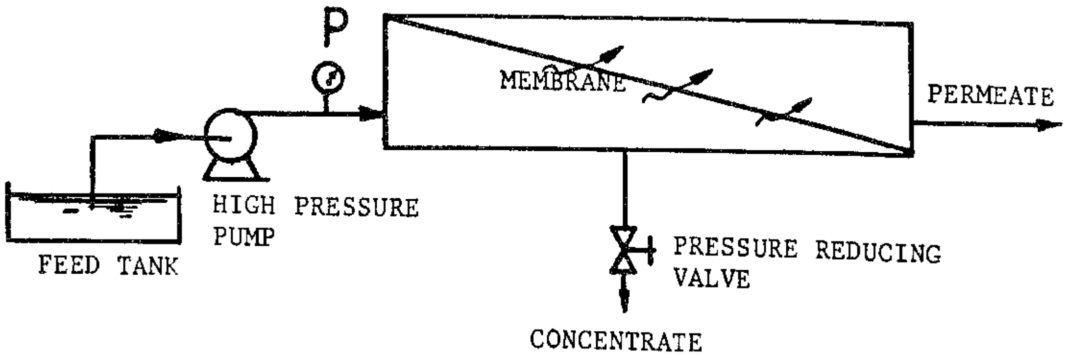


Fig 2.12 Elements of a commercial reverse osmosis system



2.5.5 Types of RO membrane systems

There are several basic types of RO systems, characterized by the geometry of the membrane and the hardware in which it is assembled. Each type has advantages and disadvantages for specific applications, but generally, the commercial objective is to achieve the greatest output of permeate for the smallest cost of hardware. This may be achieved in part by maximizing the amount of membrane surface area in the module volume, but ultimately, the objective must be to separate and concentrate the feed at minimum total capital and operating costs.

TUBULAR MEMBRANES

The simplest type of RO system is the permeable tubular membrane, shown in Fig. 2.13. Feed solution is pumped under pressure through a sufficient number of tubes in parallel to achieve the desired output of freshwater, which permeates through the tube walls, and the concentrate is discharged from the ends of the tubes. From the engineering viewpoint the problem of design is to produce a permeable tube which can withstand the hydraulic pressure needed to pass the freshwater against the osmotic pressure, usually in the range of 2 000 to 6 000 kPa. A typical means of achieving this objective is shown in the lower left diagram of the figure in which the RO membrane is shown placed within a perforated rigid support tube spearated by an intermediate porous packing. The rigid tube withstands the hydraulic pressure and the freshwater produced passes through the porous support and exits through the holes in the rigid tube, to be collected externally.

FLAT PLATE MEMBRANES

A second type of RO membrane of particular interest for food industry applications, is the flat plate configuration, shown in the top diagram of Fig. 2.14. In principle this type is similar to the plate and frame type filter press, with alternate perforated spacers and flat RO membranes assembled into a unit having internal passages for supplying the feedwater and removing the concentrate, and being clamped together by a hydraulic press. Product water leaves the press at the edges of the membranes and can be collected in troughs or plastic pipes attached to the spacers.

SPIRAL WRAP

Spiral wrap reverse osmosis units, as their name implies, are fabricated from a layer of membrane sheet, with fine permeate collection grooves on its rear, a mesh netting and a backing sheet. These are layered on top of each other, joined at the top and rolled with the permeate collection grooves attached to a central pipe, to form the elements. The fluid is then admitted at the end of the roll passing along the passages formed by the mesh, the permeate passes through the membrane sheet and runs down the grooves into the central collection pipe. A number of elements are mounted into a pressure vessel to form the module. Spiral wrap elements are manufactured in 63 mm, 102 mm, 152 mm and 203 mm dia units.

It is apparent that a large membrane area can be packed into the minimum of space with this configuration, thus the cost per unit membrane area is the lowest of all the configurations.

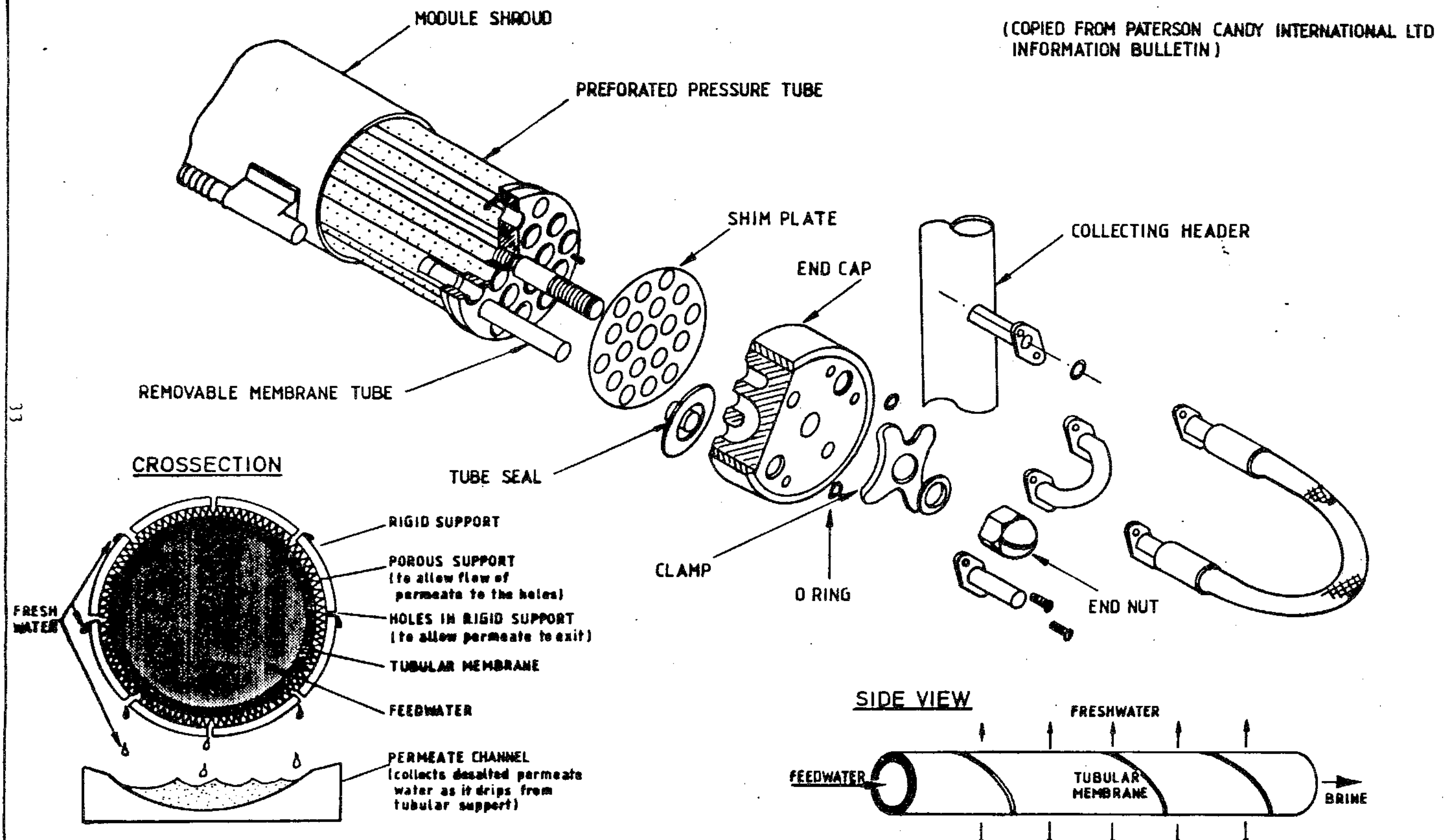
However owing to the small concentrate passages, it is unlikely that this type would be suitable for raw effluents carrying a high concentration of suspended solids. It is feasible however that this type of unit would find application in recovering water from effluents which have been pretreated by DAF, thereby obtaining reusable water at the lowest cost.

2.5.6 Energy requirements of UF and RO separation processes

For UF applications all that is needed is for the feed to be pumped through the UF device at sufficient pressure, usually in the range of 200 to 1 000 kPa, to overcome the frictional losses. For this purpose pumping energy of about 2 to 4 kWh per kl of feed is required.

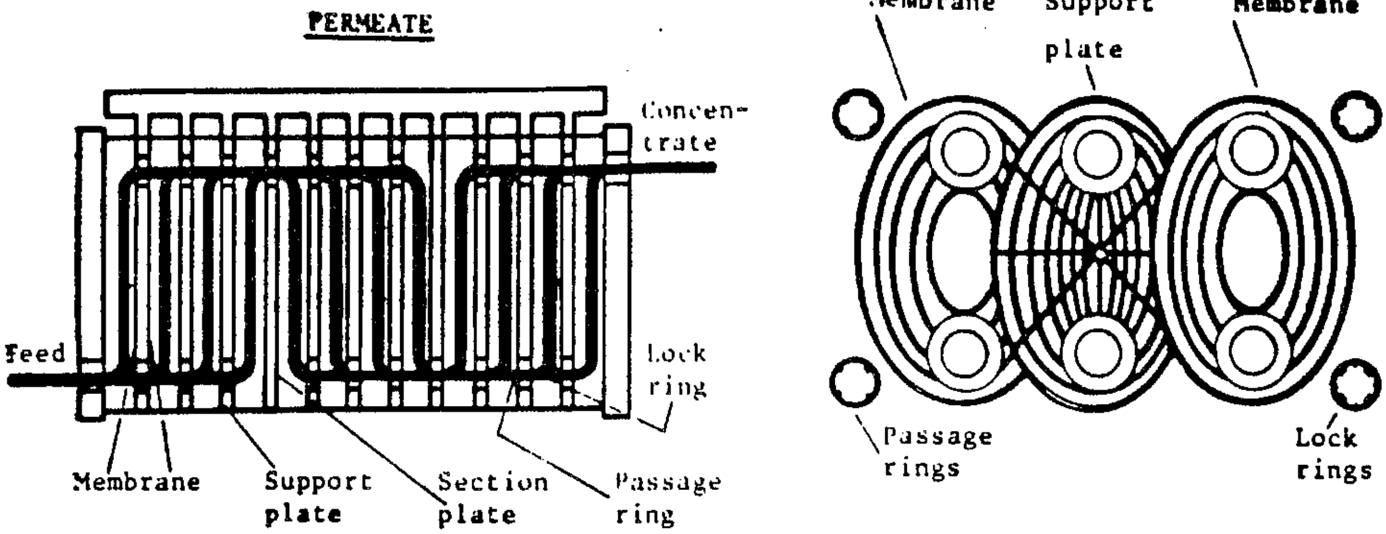
Fig. 2.13

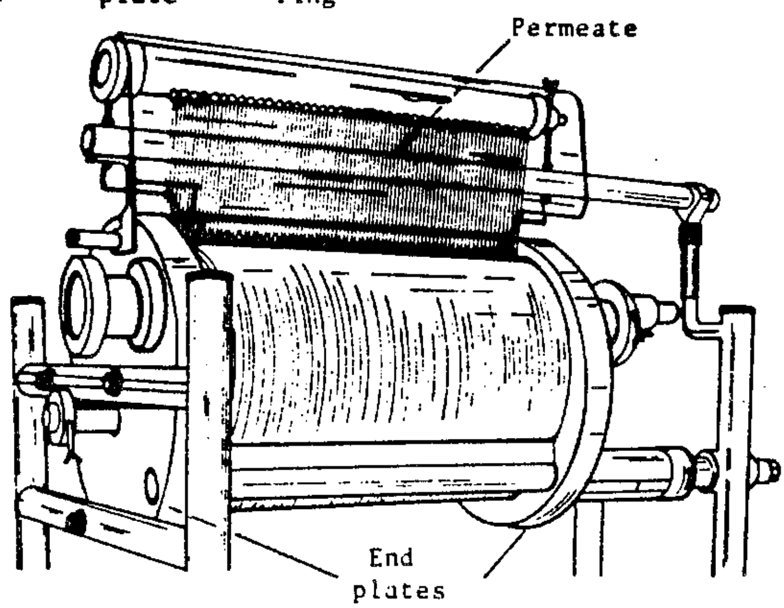
TUBULAR SYSTEM



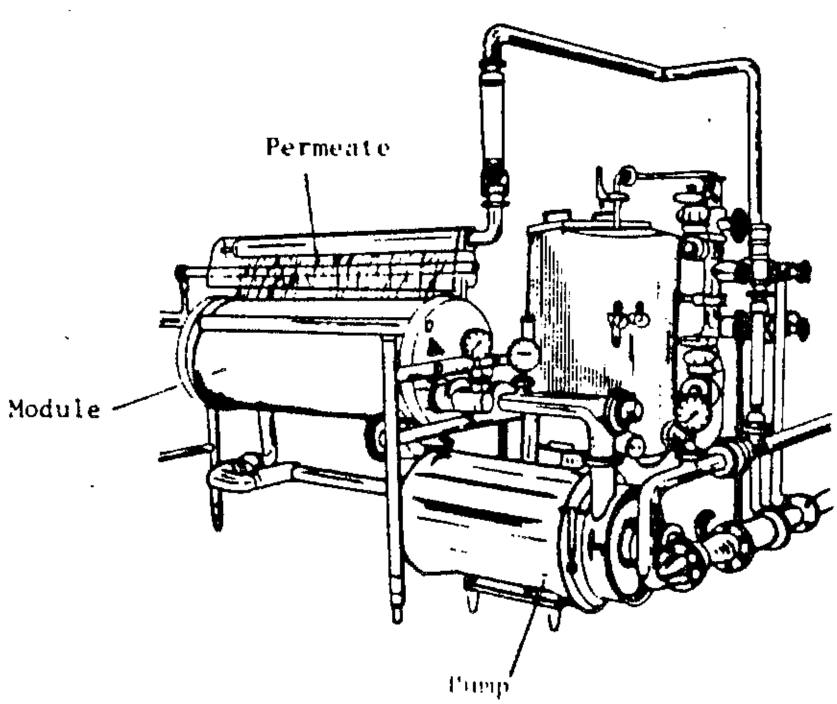
CONSTRUCTION OF A TUBULAR MEMBRANE

Fig. 2.14





TYPICAL MODULE



TYPICAL PLANT

In the case of RO systems, as well as overcoming frictional resistance, sufficient hydraulic head is needed to provide an adequate driving force to cause permeate to flow against the osmotic pressure. Feed pressures for RO systems are therefore normally in the range of 2 - 6 MPa, depending on the concentration of solute which is desired, and energy demands are correspondingly greater than for UF. Typical figures, corresponding to the above pressure range, are of the order of 7 to 10 kWh/kl of feed.

Compared with other methods of concentrating solutions such as evaporation, RO is much more energy-efficient. The relative specific energy demands depend upon a number of factors such as the degree of concentration required, the number of evaporator effects with which the RO system is being compared and the type of solute being separated. Typically, for concentrating a solution to twice its initial strength (i.e. recovery of half of the feed as re-useable water) the primary energy demands of RO are from one third to one tenth those of evaporation processes. However, because of increasing osmotic pressure with solute concentration, RO cannot completely replace evaporation for very high concentration processes (say over 25% dissolved solids).

2.5.7 Application of membrane processes

Membrane separation processes offer considerable advantages in the fruit and vegetable processing industry for the following reasons:-

a. They permit valuable waste food substances to be recovered from effluents, thereby reducing the cost of treating the effluent by conventional biological means, whether in the factory itself or in central treatment works.

b. By using RO, large volumes of clean water can be recovered for reuse in the factory instead of being discharged to drain. The RO process removes not only the dissolved solids but effectively removes bacteria, pathogens and viruses from the permeate. The re-usable water is therefore virtually sterile. Where it is possible to operate the RO equipment at elevated temperature (60 to 80°C) the entire separation process - both concentrate and permeate- can be operated under sterile conditions.

c. The use of RO for the initial stages of concentration of sugar solutions and fruit juices in a new factory will reduce the energy demands for concentration several-fold compared with the alternative method of evaporation, especially if the process can be run during off peak electricity demand periods.

d. In existing factories, the substitution of RO for evaporation in the earlier stages of concentration of these products, (eg up to 20% of dissolved solids) can extend the output of their existing works at minimum cost without need for additional boiler capacity.

Applications for UF/RO can be considered for the treatment and recovery of byproducts from all of the effluents originating in the industries under review.

Perhaps the most important aspects of investigatory pilot work required before these processes can be implemented commercially, are the determination of the ease and efficiency of cleaning to restore the rate of permeability (flux) when it declines, and the degree of pretreatment (if any) of the effluent before admitting it to the membrane.

Detailed costs of RO and UF treatment are shown in Appendices 1.1 to 1.5. The costs of treated water in cents/m^3 of feed for different membrane permeabilities and interest rates (a), together with the breakdown of costs (b) have been given. The costs are shown for plate & frame and tubular units fitted with non-cellulosic membranes which we consider should be used for effluent treatment owing to their wide pH tolerance (pH2-13) and temperature variation (up to 70°C). The tubular and plate & frame configurations are considered well suited to effluent treatment as they can accept high concentrations of total solids (up to 40%).

2.6 SOLVENT EXTRACTION

This process is likely to provide promise in treating fatty effluents from abattoirs and edible oil refining operations.

In essence the process involves the use of a low boiling point liquid which is a solvent for the compound to be removed from the waste water, but must also be immiscible with water.

The solvent is mixed into the effluent where it dissolves the target compound thereby removing it from the water, is separated from the compound by heating the recovered solvent-compound complex in a low temperature boiler. The solvent is condensed and reused.

Costs of the process cannot be developed without pilot plant studies.

2.7 ION EXCHANGE

The principles of ion-exchange are well known and will not be repeated here. However two processes are of interest in the context of this report:-

a. Protein extraction
b. Sirotherm process

2.7.1 Protein extraction

In New Zealand, regenerated cellulose resins of a porous structure have been developed for removal of protein from dilute solutions. Regeneration is by alkaline solution.

2.7.2 Sirotherm process

This process was developed in Australia in about 1978 and is still under development. The process is interesting as regeneration is achieved using hot water only.

APPLICATIONS OF THE SIROTHERM PROCESS

The major advantage of Sirotherm ion exchange resins are that unlike conventional ion exchange resins they can be regenerated very simply with hot water. This saves the cost of chemicals and solves environmental pollution problems. Sirotherm resins can demineralize water containing up to 2 000 - 3 000 mg/l total dissolved solids, and can produce water containing less than 500 mg/l (drinking water) or less than 200 mg/l if high quality water is required. In the latter case, they can be used advantageously in conjunction with conventional resins, which serve as the final stage in the process.

As the heat consumption is low and low-grade energy (low pressure steam) is sufficient, the Sirotherm process is very competitive in comparison with membrane processes such as reverse osmosis and electrodialysis in the 500 - 3 000 mg/l raw water salinity range.

The main applications of the Sirotherm process are:-

- Partial demineralization of brackish waters;
- Production of feed water for high-pressure boilers, in conjunction with a finishing stage using conventional exchange resins;
- Reduction of water salinity in cooling tower circuits, thus reducing the extent of blowdowns;
- Production of irrigation water for arid areas.

BASIS OF THE PROCESS

Sirotherm resins contain weak acid and weak base functions in the same bead. The process is based on the effect of temperature on the equilibrium reaction.

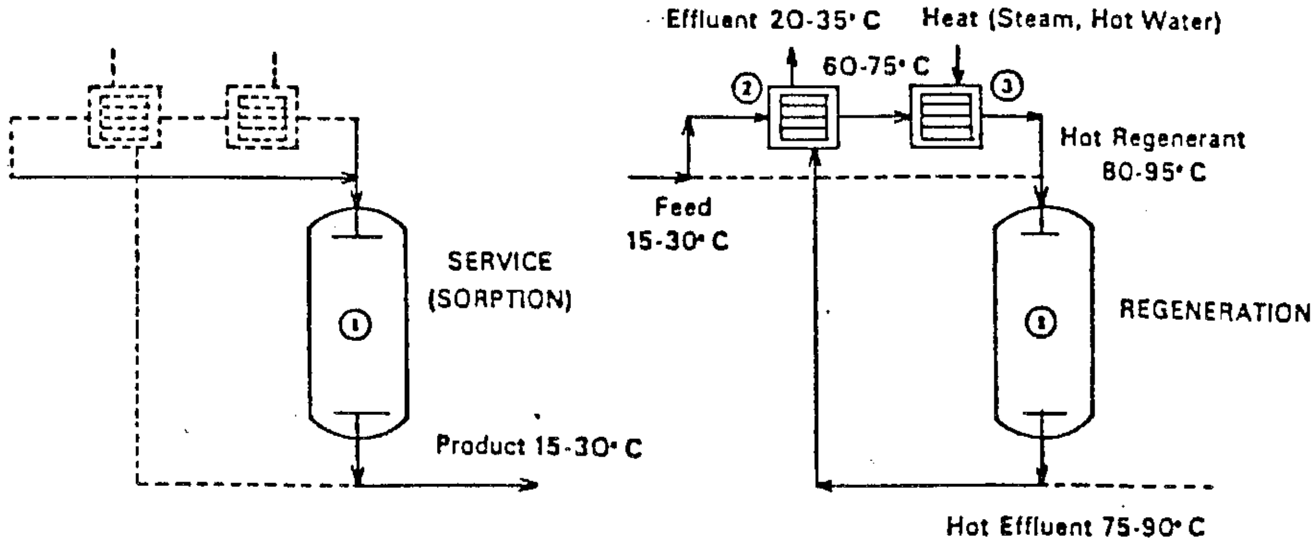
$$R^1CO_2H + R^2NR_2 + Na^+ + Cl^- \underset{\text{Hot}}{\overset{\text{Cold}}{\rightleftharpoons}} R^2NR_2H^+Cl^- + R^1CO_2^-Na^+$$

Salts are thus fixed at ambient temperature when the transfer of the H^+ ion from acid to base creates charged ion-exchange sites. When the temperature is raised from 25 to 85°C, there is an appreciable increase in ionization of the water; the concentration of H^+ and OH^- ions is increased thirty fold. The acid and basic regenerants are thus provided by the water.

PRINCIPLES OF A SIROTHERM PLANT

If the Sirotherm process is to be used to demineralize water containing, for example, 1 000 mg/l total dissolved solids, the water is passed through a bed of Sirotherm resin at a temperature of about 20°C with a flow rate of 15 bv (bv= bed volumes)/h. This will produce 10 to 25 bv of water containing 200 to 500 mg/l salts. The resin bed can then be regenerated by 3 to 5 bv raw water heated to 80-90°C; the effluent from the regeneration process will contain 3 000 to 5 000 mg/l salts. The simplest type of installation is shown in Fig. 2.15.

Fig. 2.15 Simple 'Sirotherm' flowsheet



The main components are:-

- A fixed column containing Sirotherm resin;

- A heat exchanger to recover heat from the hot effluent produced by the regeneration stage;

- A heating system to offset heat losses. There is a wide range of possible heating sources : hot water, steam, solar heating or low grade waste heat from cooling tower circuits.

PRETREATMENT OF RAW WATER

Clarification and filtration

As with conventional ion exchange resins and membrane systems, suspended solids must be removed by the usual clarification and filtration techniques. Carbonate removal by means of lime can be used to remove some or all of the divalent salts, which simplifies the arrangement of the following Sirotherm units. If the raw water still contains some suspended solids, the Sirotherm resins must be backwashed by the methods used on conventional ion exchange resins.

Organic matter

Like other ion exchangers, Sirotherm resins are subject to fouling by organic matter. Low molecular weight material is normally fixed and then eluted during the regeneration cycle, but there is a risk of fouling by organic matter of high molecular weight, with the consequent gradual reduction in operating capacity. If the organic matter content is too high, it can be reduced by conventional processes (carbonate removal by lime, use of a strong base resin as scavenger). If the fouling process has already begun, the original properties of a Sirotherm resin can be restored by a treatment with caustic soda/brine of the kind used on anion resins.

Oxygen

Like other anion exchangers, Sirotherm resins are liable to oxidation at high temperatures. This brings about chemical deterioration of the resin and an irreversible reduction in operating capacity. To give a long operating life the oxygen content must be reduced, and this can be achieved quite simply by treating with sodium bisulphite when the raw water contains oxygen.

2.8 HYBRID PROCESSES

In many applications of physical/chemical treatment, a use of the separated organic matter as a byproduct will be found. However in some cases the separated material will require disposal and it is in this application that hybrid processes might be developed.

Conventional anaerobic digestion plants tend to have long hydraulic residence times which leads to large and expensive containing structures being required. Accordingly if the organics can be concentrated, the digestion process can be accelerated.

We consider therefore that consideration should be given to membrane techniques to concentrate the organic matter, thereby recovering the water for reuse, with the concentrates being passed to high-rate perhaps sludge blanket type digesters, where the hydraulic residence time is greatly reduced.

2.9 PROCESS ECONOMICS

We have prepared a brief estimate of the running costs involved in operating a DAF plant, a tubular membrane plant and a DAF plant followed by a spiral wrap RO plant recovering water for reuse.

It should be noted that for the tubular RO plant which receives raw screened abattoir effluent, we have used a flux of 40 l/m^2h. For the case of spiral wrap RO, we have taken the same flux, although it is highly likely that the flux could be far higher when the RO plant receives pretreated water.

At 30% annual capital charges, we find the cost of water treated is as follows:-

Process	R/m^3	
DAF	1,06	Appendix 1.6
Tubular RO	2,60	Appendix 1.7
DAF followed by spiral RO	1,68	Appendix 1.8

CHAPTER 3

RESULTS OF INDUSTRIAL SURVEY

3.0 RESULTS OF INDUSTRIAL SURVEY

3.1 GENERAL

This chapter briefly introduces the production process performed by each industry. The major areas of water use and effluent generation are outlined and an estimate of the effluent strength is given where available.

The summarised survey results are then presented. These include the NASWI, water intake, effluent output and values for SS and COD on a yearly basis. Potential savings through water management are quantified.

The application of physical/chemical treatment processes is then discussed. Potential savings arising from the application of these processes have been calculated. Posible areas for reuse of treated water are mentioned where applicable.

3.2 ABATTOIRS - RED MEAT

3.2.1 Industry and process description

Over 500 abattoirs are registered in South Africa, although only about 24 process more than 100 animals per day. The units of production at an abattoir are expressed in terms of cattle units, defined as 1 cow, bull, ox or horse, 3 calves, 5 pigs and 15 sheep or goats. Abattoirs are classified as follows:-

Class	Size in cattle units per day	Number of establishments
A	greater than 100	24
B	51 - 100	25
C	15 - 50	72
D	4 - 15	168
E	less than 4	226

Ten of the abattoirs are operated by the South African Abattoir Corporation (SAAC), 263 are privately owned and 242 are operated by Municipalities. Appendix 1.9 shows the layout of a typical red meat abattoir.

The animals are kept in a lair prior to entering the stunning area where they are stunned and lifted by hind leg onto an overhead conveyor on which they remain throughout the processing. They are "sticked" to allow the blood to run into the blood trough, from which the blood is passed to the rendering plant for conversion into blood meal.

Even though the blood is collected, a considerable quantity of spillage occurs to the drain system and during plant washdown. The semi congealed blood is also washed into the drain. The blooding results in the largest single pollution load.

The carcasses continue to pass along the conveyor into an electrical stimulation area, the heads are removed, followed by hide pulling, evisceration, carcass splitting, final washing, grading and sub processing.

The viscera pass to the offal handling areas where the rumen is pierced and opened. It is in this area that the second largest pollution load occurs.

The various offals and offcuts are washed which adds to the pollution load.

The effluents discharged by abattoirs are strongly organic comprising of proteins, fats and paunch contents from the main processing areas and manure mixed with straw from the lairs.

Typical ranges of concentration of effluents arising from mixed red meat abattoirs are shown below:-

Parameter	Units	Range
pH value	-	6,0 - 7,5
Suspended solids (SS)	mg/l	600 - 2 000
Chemical Oxygen Demand (COD)	mg/l	2 000 - 4 000 *
5 day - Biochemical Oxygen Demand (BOD_5)	mg/l	800 - 3 000
Oils and Fats	mg/l	200 - 1 000
Total Kjeldahl Nitrogen (TKN)	mg/l	200 - 500

* spillage of blood can cause this value to reach 20 000 mg/l

3.2.2 Survey results

The survey response and key data are given below:-

Industry	:	**Abattoirs - red meat**
Survey Response	:	**29 Factories (43% annual production)**
Total Production	:	3 143 000 cu/a
SWI range	:	1,2 - 18 kl/cu
NASWI	:	3,0 kl/cu
Total water intake	:	9 400 Ml/a
Total effluent generated	:	7 700 Ml/a
SS	:	1 900 t/a
COD	:	18 700 t/a
If NASWI reduced to	:	2,0 kl/cu
Potential savings are	:	3 100 Ml/a

3.2.3 Effluent treatment

As the organics in the effluent are protein or fat based, the recovery of these proteins and fats for reuse as animal feed represents the correct pretreatment practice as a revenue can accrue from the sale of or reuse of the sludge. On the other hand if a biological process is used this degrades the useful materials and effluent treatment has a net negative cash flow.

If all abattoirs undertook treatment of their effluents by dissolved-air flotation operating on the protein extraction principle, the following amounts of reusable protein would be recovered, thereby reducing the pollution loads:-

Parameter	Amount (t/a)	Removal (%)	Savings in pollution (t/a)	Yield of re-usable solids (t/a)
SS	1 900	50	950	
COD	18 700	70	13 100	13100

It is anticipated that a 70% reduction in organic load can be achieved using DAF and that about 1 kg of sludge will be recovered per kg of COD removed. The removal of TKN will be similar.

The dissolved-air flotation process would yield further volumes of water for potential reuse in lairage washing amounting to a further saving of 12% or another 1 300 Ml/a; the total potential saving approaches 4 300 Ml/a.

The literature reports that sodium hexametaphosphate (HMP), ferric chloride, sodium lignosulphonate (LSA) and aluminium sulphate with polyelectrolytes can be effective for treatment of abattoir effluents. However, it is necessary to determine the safety of reusing the sludges if chemicals other than LSA or HMP are used.

Secondary treatment with lime flocculation is also proposed in literature and this is also worthy of further pilot work.

Although not reported in the literature, we consider that ultrafiltration and reverse osmosis using tubular, non-cellulosic membranes could be superior to DAF as no chemical dosing plant is required and the quality of the treated water would likely be suitable for reuse. The sludges produced would be suitable for reuse. Application of ultrafiltration to paunch contents fluids should also be investigated as this fluid represents a significant proportion of the organic load.

3.3 ABATTOIRS - POULTRY

3.3.1 Industry and process description

Appendix 1.10 shows the layout of a typical poultry abattoir. Modern poultry (broiler) abattoirs process up to 60 000 birds per day. The birds are placed onto overhead conveyors with their feet in shackles. They pass into a stunning trough, followed by neck slitting and bleeding over a blood trough. The blood is pumped or blown pneumatically into storage tanks for rendering into animal feeds.

The birds pass into a spray or dip type scalder and then through automatic pluckers consisting of a number of rotating rubber fingers which remove the feathers without damaging the skin.

The feathers are washed away into flumes from which they are pumped to dewatering screens prior to rendering.

The birds, still on the original shackles are conveyed to neck pullers for removal of the head and then pass over a hock cutter which removed the feet, allowing the birds to fall onto a chute which passes them into a separate room for the "clean" processes including evisceration.

The birds are placed onto overhead conveyors, the vents are cut and the birds pass into automatic evisceration machines with the gizzards, giblets and other useful parts being harvested for sale. The remaining offal is used for pet food manufacture.

The birds are washed and if destined for freezing they pass into a spin chiller in which they are immersed in chilled recycled water prior to blast freezing.

The major effluents from poultry processing arise from the scalders, the feather transport recycle water, the cleaning of blood tunnels, and spin chiller overflows. If hydraulic transport of the giblets and inedible offal is practised this stream is also highly polluted. In many abattoirs pneumatic or vacuum systems are used.

The typical concentration of mixed poultry abattoir effluents is:-

Parameter	Units	Range
COD	mg/l	2 000 - 5 000
SS	mg/l	500 - 1 000
TKN	mg/l	200 - 300

3.3.2 Survey results

The survey response and key data are given below:-

Industry	:	**Abattoirs - poultry**	
Survey Response	:	**11 Factories (100% annual production)**	
Total Production	:	146 x 10^6	birds/a
SWI range	:	15 - 30	l/b
NASWI	:	22	l/b
Total water intake	:	3 200	Ml/a
Total effluent generated	:	2 700	Ml/a
SS	:	1 500	t/a
COD	:	2 900	t/a
OA	:	250	t/a
If NASWI reduced to	:	15	l/b
Potential savings are	:	1 100	Ml/a

3.3.3 Effluent treatment

The dissolved-air flotation process is again one of the favoured processes for treating poultry abattoir waste waters, using HMP, LSA or ferric chloride. Secondary treatment with lime prior to discharge is also reported to be successful.

Work is reported on counter current reuse of chiller water. One reference to using ultra filtration on final effluent gave interesting organic rejection results but the fluxes were not reported. Accordingly we believe that the application of DAF membranes could have a major impact on the treatment of poultry abattoir effluent.

The introduction of effluent treatment techniques could result in a further 12% reduction in water intake. Thus the total potential saving approaches 1 500 Ml/a.

3.4 BAKERIES

3.4.1 Industry and process description

Bakeries producing bread create very little effluent and if correctly managed, the potential contaminants such as flour and grease can be swept away, prior to washing of equipment, thereby eliminating much of the organic load.

However where bakeries also make confectionery items such as cakes, tarts and pies, the potential pollution loads can be high owing to the washing of baking pans, which contain spilt jams and pie fillings. It has been practice in the past to use phosphate-based cleaners which produce effluent of high phosphate concentration. New non-phosphate cleaners can reduce phosphate concentration by 53%.

3.4.2 Survey results

The survey response and key data are given below:-

Industry	:	**Bakeries**
Survey Response	:	**24 Factories (11% annual production)**
Total Production	:	$3{,}8 \times 10^6$ t/a
SWI range	:	0,8 - 39 kl/t
NASWI	:	5,8 kl/t

3.4.3 Effluent treatment

DAF process is again the leading process warranting investigation.

3.5 BREWERIES - BARLEY

3.5.1 Industry and process description

Appendix 1.11 gives the layout of a typical barley brewery.

BREWHOUSE

The brewhouse is the first major process area where starch is converted to fermentable sugars suitable for the production of beer. Any unwanted fractions are extracted, separated and disposed of. The process is a batch one comprising the operations described below:-

Steep tanks

Hydration of the dry malt is achieved by steeping it in vats for approximately 20 minutes after which the steep water is pumped to the drain. The steeped malt is then gravitated to grinding mills.

Mills

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 in the lauter tun. After milling the malt is passed either to the maize cooker or the mash tun. The steeping vats and mills are rinsed with water which is discharged to drain.

Maize cooker

Although barley provides the predominant source of the raw starch material for beer production, other forms of starch material, known as adjuncts, are used in lesser quantities. In South Africa the main adjunct is maize, which is used in the majority of the beers produced, with sugar being used to a lesser extent.

Unlike malt, maize requires boiling to gelatinise the starches so that they can be attacked readily by the fermentation enzymes. This operation which takes place in the maize cooker involves raising the temperature of the malt-maize mixture in stages to boiling point where it is held, generally for about 30 minutes. At the end of this period the malt-maize mixture is pumped to the mash tun and the maize cooker is rinsed with water which is then discharged to drain.

Mash tun

Mashing is the basis of the beer making process. It is at this stage that the barley malt and adjunct starch are converted into a fermentable extract suitable for the production of beer. Enzymes present in the malt regulate and control the starch to sugar conversion reaction by dissolving the protein film surrounding the starch sac and converting the starch to maltose.

The malt-maize mixture is fed to the mash tun and additional malt is added to obtain the correct malt content. After conversion of all starch to sugar, the mash is raised to 78 °C and held for a period of time. After a total period lasting approximately 4 hours the mash is pumped to the lauter tun. The mash tun is then rinsed and the rinse water led to drain.

Lauter tun

Following mashing, the fermentable sugars which are in solution in the mash must be extracted from the dissolved portion. This operation is carried out in the lauter tun where the sugar solution, or wort, is filtered through the spent grains under gravity, following which the remaining wort is flushed through the bed by sparging. The wort and sparge water are pumped to the wort kettle while the spent grains are conveyed to storage bins. The lauter tun is then rinsed and the remnants of spent grain and rinse water are led to drain.

Wort kettle

In the wort kettle, hops are added to the wort and the mixture is boiled for approximately 90 minutes before cooling. The boiling of wort with hops precipitates the soluble proteinaceous material, known as trub, which settles out during the cooling process, together with any fine grain particles which were carried over from the lauter tun. At the end of a cycle the wort is pumped via a heat exchanger to the fermentation cellar; the trub is pumped to storage and the wort kettle is rinsed with water which is then led to drain.

Yeast production

After propagation of the yeast to the required volume it is pitched into a fermentation vessel with the incoming wort. At the end of the fermentation cycle the yeast is drawn off; that required for the next brew is repitched while the excess is wasted. After several generations (approximately 7) the entire yeast crop is wasted. As different brews require different yeast cultures, storing of the yeast can become difficult, resulting in the sudden discharge of yeast batches to drain.

Tank sterilisation in the brewhouse

In addition to the rinsing of the tanks which takes place after every brew all of the vessels are sterilised weekly. This is done by preparing a caustic "brew" which is then pumped through the system; this caustic brew may be used more than once before being discharged to drain.

FERMENTATION CELLAR

After brewing and yeast addition, the cold wort is passed to the fermentation cellar where the wort sugars are fermented to alcohol. This operation, which takes place in large fermentation vats generally sized to hold either one or two brews, varies in duration depending upon factors such as the type of beer being made, and speed of fermentation, but on average takes approximately ten days. Towards the end of that period, the temperature in the fermentation vats is lowered to reduce yeast activity allowing the yeast to settle to the bottom of the vat from where it is withdrawn and discharged to storage bins. The beer is then pumped to storage tanks and the fermentation vats are cleaned before the addition of the next brew. This cleaning process is extremely thorough, comprising several rinses and washing with caustic and detergent. Wash and rinse waters are led to drain.

STORAGE AND FILTRATION CELLAR

The beer is kept in the storage tanks for up to seven days for maturation to take place. At the end of this period more yeast has settled out and these "tank bottoms" must be removed before the beer can be pumped to the filtration plant; the tank bottoms are in most cases wasted directly to drain.

At this stage the pipeline from the storage tanks through the filters to the bright beer tanks is flushed and a pre-coat of kieselguhr applied to the filters. The beer is then pumped through the pipeline, being "chased" through with water which is led to drain. The storage tank is then rinsed and the rinse water discharged to drain while the filter is stripped of the pre-coat and cleaned. The kieselguhr is removed from the brewery, generally in containers, while the rinse water is led to drain.

BRIGHT BEER STORAGE TANKS

Once the beer has been filtered it is pumped to the bright beer cellars for storage before it passes to the bottling hall. These bright beer storage tanks are rinsed and sterilised after each filling cycle.

BOTTLING HALL

The bottling hall is a major water user, due mainly to the high water requirement for cleaning. Water used depends upon whether the beer containers are bottles, of which there are two types - returnable and non-returnable, or cans.

Returnable bottles

The returnable bottles have the highest cleaning water requirement. Upon their return to the brewery the bottles contain in addition to small quantities of beer, a number of pollutants ranging from petrol to pesticides, depending upon the use to which the bottles have been subjected. Removal of these pollutants requires a thorough multistage cleaning operation to ensure complete sterilisation, which results in a high water usage. In addition all traces of the labels and label glue must be removed.

Non-returnable bottles and cans

The non-returnable bottles and cans simply require to be cleaned of any dirt which has been accumulated between the manufacture of the bottles and cans and their arrival at the brewery. This is a simpler cleaning procedure than for returnable bottles and hence the cleaning water requirement is not as great. The washing/rinsing machines are fed constantly with a supply of fresh water and are periodically drained and refilled.

Filling and pasteurisation

After cleaning, the procedure for filling the bottles and cans with beer is virtually the same. The containers are passed to the filling machines, where they are filled with beer and where carbon dioxide is injected. To avoid the creation of an air space which could affect beer quality the bottles are slightly over-filled, with the excess beer generally running onto the floor. The bottles and cans are then capped, sealed and pass to the pasteuriser machines where the beer is heated in hot water to a temperature of 60 - 65°C for a period of 10 - 15 minutes, following which they are cooled and conveyed to the packaging area for packing and despatch. The pasteurisers are supplied continuously with fresh water and are drained periodically and refilled.

GENERAL CLEANING

In all process areas the floors are cleaned down thoroughly at the end of each brew or shift. Additional floor washing is carried out as and when required during normal operations.

The typical range of effluent quality discharged by a brewery is given in the table below.

Parameter	Units	Range
Suspended solids (SS)	mg/l	600 - 700
Oxygen Absorbed (OA)	mg/l	300 - 450
Chemical Oxygen Demand (COD)	mg/l	2 500 - 3 000
Biochemical Oxygen Demand (BOD_5)	mg/l	1 500 - 1 800
Total Dissolved Solids (TDS)	mg/l	1 000 - 1 800

3.5.2 Survey results

The survey response and key data are listed below:-

Industry	:	**Breweries - barley**
Survey Response	:	**12 Factories (100% annual production)**
Total Production	:	1 200 Ml/a
SWI range	:	7,9 - 10,9 kl/kl
NASWI	:	8,6 kl/kl
Total water intake	:	10 400 Ml/a
Total effluent generated	:	7 600 Ml/a
SS	:	6 100 t/a
COD	:	28 400 t/a
If NASWI reduced to	:	4,0 kl/kl
Potential savings are	:	4 800 Ml/a

Appendix 1.12 shows how the water is distributed through a typical brewery whose water : beer ratio is 9,0. It also shows that 30% of the water is used in the brewhouse which expells 49% of the total COD & SS in the final effluent, that 15% goes to the fermentation cellars which expell 36% of the COD & SS and that 38% of the water enters the packing hall which expells 14% of the COD & SS.

Appendix 1.13 shows a revised distribution of water for a brewery which has implemented water savings to a water to beer ratio of 4,85 : 1. Further measures such as close monitoring of filling, high pressure spray cleaning and limiting floor washing can reduce this figure to 4,0 kl water/kl beer.

3.5.3 Effluent treatment

It is apparent that physical/chemical treatment of the brew house and fermentation cellar effluents can substantially reduce the organic load from the brewery and that water management by recycling bottlewash and pasteurising water and by reusing surplus water from wort cooling in the CIP systems, can substantially reduce water intake.

A study of the contaminants in the various brewery effluent streams indicates that the brewhouse discharges organics including cellulose, carbohydrates, proteins, polypeptides, spent grain, wort and trub. The fermentation cellar discharges beer, yeast and trub and the storage & filtration cellars discharge beer, yeast, haze particles, detergent and spent kieselguhr. The bottling hall discharges beer, beer residues, caustic soda and glues from the labels. The organic load in these streams can be reduced by physical/chemical treatment such as DAF or microscreens.

The effluent stream leaving the fermentation cellars has 0,1% alcohol present which could be recovered using spiral wrap reverse osmosis. Similarly alcohol is present in the packaging hall effluents owing to spillage at the filling lines.

Recovery and drying of spent yeasts from the yeast laden stream also produces a major reduction in organic load.

3.6 BREWERIES - SORGHUM

3.6.1 Industry and process description

For the purposes of this process description, the sorghum beer industry will be divided into malting and beer production.

MALTING

The malting of sorghum for beer production is generally performed by malting companies who specialise in the preparation of this ingredient.

Referring to Appendix 1.14 the grain seed is steeped in water and formaldehyde for 3 to 4 hours in 15 ton steeping silos followed by a rinse. It is then discharged into the bins - stage 1 below the silos. These bins have false perforated floors, to permit hot air to be blown through the grain bed. After 14 hours resting period, water is sprayed over the grain from hosepipes and there after discharged to the drain every 9 hours for a total period of 24 hours.

The grain is then transferred manually into the stage 2 bins where it resides for a further 24 hours having a spray of water every 9 hours. Similarly after transfer to stage 3, water is sprayed at the same frequency for another 24 hours.

At the fourth stage no water is added for the 24 hour resting period. After transfer to the drying bins, hot air is added at 55°C for 24 hours. The process is completed by extracting the grains and blowing then into silos for later bagging and sale.

About 71% of the total water used in the sorghum malting process is for spraying, 24% is used as boiler feed make-up and the balance for domestic and washing down.

The effluents which are discharged have the following analysis:-

Parameter	Units	Amount
TDS	mg/l	1 200
COD	mg/l	1 100
BOD_5	mg/l	700

The processing of 900 t sorghum consumes 3 600 kl of water giving a specific water intake of 4 kl/t.

BEER PRODUCTION

Preparation of the "sour"

Refering to Appendix 1.15, water is mixed with ground sorghum malt and wheat bran and left at 50°C for 8 to 16 hours, in a vessel known as a "lactic acid generator". The batch composition is approximately as shown below:

Water.......................... 16 000 litres
Sorghum malt.................... 2 200 kg
Wheat bran...................... 440 kg

During this phase of the manufacture, the sugars are transformed into lactic acid. The acidity of the sour is measured in brewer's degrees (B°) by means of a titrated solution of sodium hydroxide. Usually, the final sour has an acidity of 7 to 9 B°.

Cooking of the mixture of malt and maize grits

In the mixer, 4 000 litres of water and 1 650 kg of maize grits are added to the sour. The mixture is then transferred to a closed cooking vessel, provided with an internal coil through which steam is passed. During the cooking of the mixture, which lasts about one hour at a pressure of 0,5 bar, the lactic acid of the sour solubilizes the starch in the maize grits.

Cooling of the mixture and addition of more malt

Cold water is then passed through the internal coil of the cooker to lower the temperature to 80°C when a second dose of malt (150 kg) is added. This malt will break the starch chains thereby reducing the viscosity of the mixture. After 1,5 hrs more cold water is passed through the coil until the temperature drops to 60°C.

Conversion of the starch

The mixture is transferred to the "converter" vessel, and a third dose of malt (450 kg) is added. This malt acts to convert the starch into sugars.

Addition of yeast and straining

The temperature of the converted mixture is further reduced to 30°C. 10 litres are taken out, mixed with 3 kg of yeast and returned to the converter. The mixture is then strained by passage through a centrifuge and passed to the fermenters. The separated solids, which have a fairly high protein content, are sold as animal feed.

Fermentation

The fermenters are kept at 30°C for about 78 hours where a vigorous top fermenting yeast is used, which gives appreciable quantities of carbon dioxide, which is lost to the atmosphere. A temperature rise that has to be controlled by means of a cooling coil also occurs at this stage. A layer of foam which soon covers the beer tends to overflow and to run down along the external wall of the fermenter, mainly when it is too full and the temperature and other conditions are not carefully controlled. It has been calculated that important quantities of vitamins are then lost with the foam - 90% of the thiamin, 10% of the nicotinic acid and 10% of the riblofavin. Several systems to avoid excessive foaming have been proposed (for instance, the use of stirrers, above the surface of the beer, for breaking the foam). However the newer, closed fermenters, working under a pressure of 0,5 bar, avoid this problem.

Dispatch of the beer

The beer is now ready to be dispatched to the consumers. Part of it leaves the brewery in tank cars, part is packaged in different types of containers, either made of paper lined with polyethylene or totally made of polyethylene. As the beer keeps fermenting after leaving the brewery, provision must be made for venting the carbon dioxide produced. For this reason, all the plastic containers have small holes in their caps. In the paper containers, the heat sealed seam is left interrupted in its middle zone. It is difficult to keep the sorghum beer for long without deterioration in its quality. Even under good conditions, the shelf life of the packaged beer does not exceed one week.

The effluents generated are about 47% of the water intake and comprise malt, grits, sour mash, beer, detergents and disinfectants. Most breweries pass their effluent to the municipal sewer.

The effluents are characterised by the following range of analyses.

Parameter	Units	Range
SS	mg/l	500 - 2 000
COD	mg/l	4 000 - 11 000
OA	mg/l	200 - 550
TDS	mg/l	700 - 3 000
pH	-	3,5 - 6,0

3.6.2 Survey results

The survey response and key data are listed below:-

Industry	:	**Breweries - sorghum**
Survey Response	:	**29 Factories (100% annual production)**
Total Production	:	1 040 Ml/a
SWI range	:	1,3 - 5,8 kl/kl
NASWI	:	3,0 kl/kl
Total water intake	:	3 100 Ml/a
Total effluent generated	:	1 400 Ml/a
SS	:	3 200 t/a
COD	:	29 000 t/a
If NASWI reduced to	:	2,0 kl/kl
Potential savings are	:	1 000 Ml/a

The following table summarises the distribution of water in a sorghum brewery:-

	%Total water intake
brewhouse	53
fermentation	13
packaging	12
boilers and cooling	10
domestic	12

About 34% of the intake water enters the beer and about 47% is due to washdown and cleaning.

The following table summarises effluent concentration ranges found in the survey:-

Parameter	Units	Range
pH		4 - 5
COD	mg/l	1 400 - 4 500
SS	mg/l	2 000
OA	mg/l	175 - 225

3.6.3 Effluent treatment

If, for a sorghum malting effluent, the COD and TDS could be removed and SS were removed to 1 micron, the water that is sprayed onto the grain could be reused. We consider this an ideal application for ultrafiltration or reverse osmosis using plate and frame or tubular configuration.

As far as sorghum brewing effluent is concerned, segregation of the effluent and screening by wedge-wire screens followed by DAF would be a first stage treatment. Work to determine the effectiveness of DAF should be undertaken.

3.7 DAIRIES - CHEESE

3.7.1 Industry and process description

The dairy industry in South Africa is primarily concerned with the production of milk, cheese, butter, condensed milk and milk powder. Smaller quantities of milk are processed to produce skim-milk, cream, cottage cheese and yoghurt.

Cheese is manufactured by adding a bacterial starter to raw milk and, as acidity develops, rennet is added to assist the formation of curds. The curd is recovered leaving the whey which has a very high potential polluting load. The whey contains a proportion of all the major components of milk.

The effluents arising from cheese factories vary in their organic strength depending on the route of disposal adopted for the whey. About 70% of the whey produced is used directly as pig feed or discarded; only 30% is processed to whey powder.

3.7.2 Survey results

The survey response and key data are given below:-

Industry	:	**Dairies - cheese**	
Survey Response	:	**14 Factories (43% annual production)**	
Total Production	:	38 700	t/a
SWI range	:	5,6 - 140	kl/t
NASWI	:	18	kl/t
Total water intake	:	680	Ml/a
Total effluent generated	:	480	Ml/a
SS	:	370	t/a
COD	:	1 800	t/a
OA	:	0,23	t/a
If NASWI reduced to	:	5,6	kl/t
Potential savings are	:	460	Ml/a

Although a wide variation exists, about 50% of the water enters the process, 38% to steam raising and the balance of 12% to domestic consumption.

One plant manufactures dry whey powder and this generates evaporative condensate which is reused in their boiler plant while another irrigates its cheese whey directly onto land.

3.7.3 Effluent treatment

Appendix 1.16 shows possible effluent treatment routes. Between 22 and 24% TS concentration can be achieved using reverse osmosis ZF99 tubular membranes on various types of whey.

Appendix 2 provides a paper on the methods of whey recovery by Binnie & Partners. The economics of HMP and DAF treatment followed by residual phosphate removal in a clarification stage compare favourably with ultrafiltration/RO and although the economic calculations are out dated, we believe that this chemical process warrants further investigation.

3.8 DAIRIES - MILK & MILK POWDER

4.8.1 Survey results

The survey response and key data are given below:-

Industry	**:**	**Dairies - milk & milk powder**	
Survey Response	**:**	**18 Factories (Fresh milk)**	
Total Production	:	615 600	t/a
SWI range	:	1,6 - 88	kl/t
NASWI	:	6,6	kl/t
Total water intake	:	4 100	Ml/a
Total effluent generated	:	3 100	Ml/a
SS	:	5 500	t/a
COD	:	17 200	t/a
If NASWI reduced to	:	3,0	kl/t
Potential savings are	:	2 200	Ml/a

Examination of the plants operating solely on milk suggests that the value for SWI could be reduced to at least 3,0 kl/t, thereby realising a saving of 2 200 Ml/a. A similar amount of savings could be expected from the industrial milk production.

The total milk production statistics provided by the National Dairy Board are summarised below:-

	t/a	
Fresh milk (controlled areas)	615 600	
Industrial milk	685 656	1 301 256

Applying the SWI of 6,6 kl/t the annual water usage amounts to 4 100 Ml/a for fresh milk, and 4 500 Ml/a for industrial milk. The total amounts to 8 600 Ml/a.

An average 68% of the water intake is consumed in the processing and 26% is boiler water. The effluents generated carry 9 kg SS/t, 27,8 kg COD/t and 2,89 kg OA/t. The concentration of SS & COD in the effluents range from 400 - 800 mg/l and 1 200 to 4 000 mg/l respectively.

Where powdered milk is manufactured, the evaporative condensates which are generated, can be reused after further treatment to remove any entrained organics.

Membrane processes could also be considered for recovery of milk solids and preconcentration by reverse osmosis followed by evaporation might be economically justified.

At dairies handling fresh milk, reuse of the pasteuriser and bottle washing water requires investigation.

3.9 DAIRIES - MIXED

3.9.1 Survey results

The data presented here are for those factories which process a wide rang of products. The survey response and key data are presented below:-

Industry	:	**Dairies - mixed**	
Survey Response	:	**11 Factories**	
Total Production	:	166 760	t/a
SWI range	:	0,8 - 38	kl/t
NASWI	:	4,1	kl/t
Total water intake	:	680	Ml/a
If NASWI reduced to	:	3,0	kl/t
Potential savings are	:	180	Ml/a

3.9.2 Effluent treatment

Comments previously made refer equally to mixed dairies and it is interesting to note that most of these dairies would consider water reuse.

We conclude that this industry should be surveyed in detail as a large potential for water savings appears to exist.

3.10 VEGETABLE OIL & MARGARINE

3.10.1 In South Africa sunflower seed and maize germ are the main oils used in the manufacture of margarine. After basic preparation and refining of the oils various alternative processes are performed depending on the type of end product desired. A general commentary is given on the processes of extraction, refining, modification and additives.

EXTRACTION

The fat used in the manufacture of margarine is originally found stored in the cells of animal and vegetable tissue. Therefore, the first stage in the preparation of the raw material is the extraction of the fat from this tissue. Two methods are used to separate the oil from the other components of the cells. Either mechanical pressing in an expeller press to yield oil or extraction of the oil in a suitable solvent which is subsequently boiled off. A combination of both methods is often used.

REFINING

The raw oil obtained by extraction is not suitable for human consumption. It contains many impurities, such as remains of seeds and kernels, phospholipids, free fatty acids, colouring agents as well as metabolic products which would give rise to unpleasant odours and tastes in the margarine. The refining process cleans the oils and removes these impurities. Appendix 1.17 & 1.18 show schematically the degumming, neutralization and bleaching processes

Degumming

There are certain gummy substances (primarily phospholipids such as lecithin in soyabean and rapeseed oils) in raw oil which must be removed completely or they will be broken down at high temperatures during deodorization and give rise to bad-tasting substances. During degumming, the oil is heated to 60 - 80°C and 2 - 5% water or a weak solution of phosphoric or citric acid is added. The emulsion is then agitated for 20 - 30 minutes. The gummy substances absorb the water, swell and precipitate out. The water phase containing the gummy substances is then separated from the oil in a separator and the gummy substances are dried, rinsed and processed further to produce various lecithin preparations.

Neutralization

The free fatty acids in the oil are metabolic products from the seeds and fruits and must be removed. This is usually accomplished by neutralizing using a caustic soda solution with a concentration of 4 - 15% depending on the oil to be treated. The oil is heated to 80 - 90°C and blended carefully in specially designed mixers so that the lye and the free fatty acids quickly come into intimate contact and react with each other. This brings about the formation of a solution of soap in water which is called the "soapstock". This soapstock is separated from the fat in a separator and treated with sulphuric acid to recover some of the fatty acids through cleavage of the soap. If separation takes place in a hermetic separator, the oil is treated gently and there is no air in the system which might lead to the formation of foam or cause oxidation. After separation, the oil is rinsed with hot water and separated again to remove all remaining alkali.

Bleaching

The lye treatment has already removed free fatty acids and some of the colouring agents. The colouring agents in raw oil are either natural pigments or breakdown products from previous treatment. They are unfit for use in food products and must be removed. This is accomplished by bringing the colouring agents into intimate contact with certain substances which have a great capacity to absorb the pigments in oil. The substances normally used for this purpose are fuller's earth, activated fuller's earth or, in certain cases, activated charcoal.

The absorptive medium is added to the oil, which has been dried from water by heating in a vacuum, at a temperature of 60 - 80°C under reduced pressure to minimize oxidation risks.

After bleaching, the oil is filtered and the pigment containing absorptive medium is caught by the filter and the colourless oil proceeds to the next stage in processing. It is essential to keep air contact to a minimum to avoid the risk of oxidation.

Deodorizing

The oil still contains very small amounts of the fat-soluble substances which give the oil its characteristic odour and flavour. The final product should be tasteless and odourless and it is therefore necessary to remove these substances. This is accomplished by means of steam distillation - deodorizing. In the deodorizing process superheated steam (between 190 and 210°C) is forced through the oil. This treatment is carried out under high vacuum (2 - 8 mm Hg). During deodorizing, certain substances are broken down and the volatile products are removed. The choice of temperature is determined by the equipment and the time available to produce a neutral-tasting oil. As a rule, the deodorizing process takes 2 - 5 hours, depending on the oil in question and the degree of tastelessness desired. The deodorizing process also removes any remaining free fatty acids.

MODIFICATION

The margarine manufacturer also has other processes at his disposal to alter the physical properties of the fat materials - hardening, interesterification and fractionation.

Hardening changes the unsaturated fatty acid content of the oil, thereby altering its melting point. Interesterification changes the positions of the fatty acids within one glyceride molecule or among different glyceride molecules, which has an effect on the plastic properties of the fat. Fractionation divides a fat into a high-melting and a low-melting fraction. Appendix 1.19 gives the flow sheet for this process. By using these three processes and combinations of these three processes, it is possible to create fat products which are tailor-made for special purposes.

Hardening - hydrogenation

The physical properties of oils (melting point, plasticity etc.) are determined by their chemical composition, especially the ratio between glycerides composed of solid, saturated fatty acids and glycerides composed of liquid, unsaturated fatty acids. The chemical difference in composition between saturated and unsaturated fatty acids is very small. The only difference between oleic acid, which is liquid at 20°C, and stearic acid, which melts at 72°, is that oleic acid has two hydrogen atoms less.

In the process of hardening of oleic acid, the double bond is broken and two hydrogen atoms are bound to the carbon atoms on either side of the previous double bond; oleic acid has been converted to stearic acid. The hardening of an oil thus entails converting a fatty acid of low melting point to one with a suitable melting point and consistency for the manufacture of margarine.

The fats used in margarine production consist of mixtures of various triglycerides, i.e. triglycerides which contain one or more unsaturated fatty acids in addition to saturated fatty acids. Hardening of polyunsaturated fatty acids can proceed in two different ways. If the hydrogenation of the bonds in the fatty acids takes place sequentially, the process is called "selective". If all bonds are hydrogenated simultaneously, the process is called "non-selective". Hydrogenation makes liquid oils more or less solid depending on how long the process is continued, i.e. how many unsaturated fatty acid radicals are saturated. This makes it possible to obtain "tailor-made" raw material for margarine manufacture. Another significant result of hardening is that marine oils (whale and fish oil) which contain large amounts of unsaturated fatty acids and are therefore unstable (easily oxidized) can be hydrogenated and used for margarine production.

The degree of hardness is expressed either as the melting point of an oil, the amount of the solid phase at various temperatures or as the amount of hydrogen consumed in hydrogenation.

Hardening is accomplished by bringing the oil into intimate contact with hydrogen gas at suitable temperature and pressure in the presence of a catalyst - 0,2 to 1,0% finely divided nickel. The oil is heated up to 140 - 200°C in an enclosed vessel which contains hydrogen gas under pressure. The contact between the gas and the oil is brought about by means of vigorous agitation or by passing small bubbles of hydrogen gas through the oil.

Interesterification

Interesterification is a relatively new method for changing the physical properties of a fat, especially its melting point. The properties of a fat are determined by the positions of the fatty acids in the molecule as well as the ratio of saturated to unsaturated fatty acids discussed above. If, for example, it is determined that a fat consists of tristearin and triolein which is in many ways an unsuitable composition, it would be very advantageous if the fatty acids in the molecules could be regrouped.

This process has recently been made available for industrial production, and although the glycerides in natural fats are much more complicated than those in the example, their consistency can be improved considerably.

Interesterification is accomplished with the help of catalysts at moderate temperature in about an hour. The fat must first be carefully neutralized. Interesterification should proceed under vacuum to keep the fat dry while a stream of nitrogen gas bubbles through the mixture. After interesterification, the mixture is cooled to approximately 90°C and the catalyst and soap traces are removed by washing with warm water or are broken down with an acid such as phosphoric acid. The fat is then deodorized and bleached.

Fractionation

The fat to be fractionated is cooled under controlled conditions to crystallize the high melting parts of the fat. The crystallized fat is mixed with an aqueous solution containing a wetting agent. During mixing, the crystals are wetted by the wetting agent and go into the aqueous solution as a suspension, while the liquid oil remains as a separate phase. This mixture is then separated in a centrifugal separator. Fractionation and a combination of fractionation and interesterification offer interesting possibilities to produce new tailor-made products.

ADDITIVES

In addition to fats and oils, the fatty phase consists of a number of fat-soluble substances, including colouring agents, flavouring agents and emulsifiers, as well as vitamins A and D.

Emulsifiers

Margarine is an emulsion of water in oil, in which the water with milk solids dissolved in it is distributed throughout the fat phase in the form of microscopically small droplets. Oil and water cannot be mixed, but they can be made to form an emulsion if they are subjected to vigorous mechanical treatment. If the emulsion is allowed to stand a while, it separates into oil and water again. To stabilize the emulsion during margarine manufacture, some type of emulsion stabilizer must be added which will:-

a) facilitate the formation of a fluid emulsion of the two phases

b) stabilize the emulsion formed

c) produce a uniform distribution of the various constituents

d) improve the frying properties of the solidified emulsion

Many attempts have been made to improve the emulsion stability of saltless, milk-containing margarine. The additives recommended for this purpose often have the disadvantage that they consist of poorly defined mixtures, the physiological effect of which is far from established. Their use is therefore forbidden in most countries and the choice of emulsifier is limited to lecithin, mono - and di-glycerides and milk proteins. Egg-yolk is used in some cases. It is however, expensive, difficult to sterilize and has a strong characteristic taste.

Colouring agents

The colour of margarine is obtained either by using naturally coloured oils, such as palm oil, or by adding colouring agents. The colouring agents are usually mixtures of different carotenoids or pure B-carotene.

3.10.2 Survey results

The survey response and key data are given below:-

Industry	:	**Vegetable oil and margarine**	
Survey Response	:	**10 Factories (72% annual production)**	
Total Production	:	522 000	t/a
SWI range	:	2,0 - 11,5	kl/t
NASWI	:	6,0	kl/t
Total water intake	:	3 150	Ml/a
Total effluent generated	:	950	Ml/a
SS	:	26	t/a
COD	:	2 000	t/a
FATS	:	630	t/a
If NASWI reduced to	:	4,0	kl/t
Potential savings are	:	1 100	Ml/a

It was found that 50 - 65% of the water is used in the processing and 30 - 50% in the boiler plant.

Appendix 1.20 shows the quality of various effluents taken by us at an Australian margarine plant.

3.10.3 Effluent treatment

The literature review revealed that DAF is the preferred treatment for these effluents and that the coagulants such as ferric chloride and lime are preferred.

The "Alwafloc" process invented by Alwatech Oslo was designed for this type of effluent. In the process the feed is dosed with ferric chloride at a rate which injects 100 mg/l as Fe^{3+} into the flow. After a 20 second delay, lime is added to restore the pH to 6. The iron and calcium ions form a complex with the fat, which is then removed by DAF. The DAF 2 pilot plant provided under the meat contract is equipped with the delay/dosing cylones to enable this process to be operated.

3.11 GRAIN MILLING

This industry is a dry industry and only uses water for dampening the grain prior to milling. It was found that the majority of water used is domestic. Further invesigation is thus not justified.

3.12 FISH PROCESSING

This industry is part of an existing study.

3.13 FRUIT & VEGETABLE

This industry is also part of an existing study.

3.14 PULP & PAPER

This industry is part of an existing study.

The effluent at the SAICCOR cellulose pulping mill is mentioned because it is rich in lignosulphonates which reside in the black liquor presently being discharged into the ocean.

We consider that a project employing the UF and RO techniques would be worthwhile because if UF was operated on the digestor liquor (21,6% TDS) the sugars and lignins could, we believe, be segregated. Furthermore, the washpit liquors could be concentrated by RO up to at least 16-20% TDS recovering clean hot water for reuse in the plant and providing a concentrate which could be added to the digestor liquor for lignosulphonate recovery.

The lignosulphonates would be particularly useful for precipitating proteins and fats in many other industries.

3.15 SOFT DRINKS & CARBONATED WATER

3.15.1 Industry and process description

Appendix 1.21 shows a schematic representation of a soft drink processing plant.

Sugar stored in silos is admitted to stirred stainless steel mixing tanks and made up to 54°BRIX before being filtered and stored in the syrup room tanks, where the flavouring concentrate is added.

The concentrate syrup with flavouring is now passed to a storage tank connected to a triple-headed pump which extracts simultaneously, deaired, dealkalised water, pumps it through a CO_2 addition tank and delivers the carbonated water through one head mixing with the concentrate from the other head at the filling line.

Dirty bottles at the rate of 200/min for 1 litre bottles and 280/min for 500 or 340 ml ones, are passed through a bottlewasher where they are cleaned in 3% NaOH solution at 60°C. The bottles are then rinsed before entering the filling line.

All water used for the soft drinks is passed through dealkalisation to reduce the alkalinity from 85 - 110 mg/l to 40 - 50 mg/l as $CaCO_3$. Ferrous sulphate is used to achieve dealkalisation. The water is also softened in a base exchange softener and filtered through sand filters before use.

The syrup concentrate tanks are cleaned after every batch and the potential for highly organic effluent to be discharged during cleaning is high.

3.15.2 Survey results

The survey response and key data are prsented below:-

Industry	:	**Softdrinks and carbonated waters**	
Survey Response	:	**19 Factories (100% annual production)**	
Total Production	:	1 167 700	t/a
SWI range	:	1,1 - 11,6	kl/t
NASWI	:	3,3	kl/t
Total water intake	:	2 900	Ml/a
Total effluent generated	:	2 000	Ml/a
If NASWI reduced to	:	2,0	kl/t
Potential savings are	:	560	Ml/a

Only one factory declared a high COD i.e. 4 300 mg COD/l; all others returned data showing about 40-100 mg/l COD. We believe this is because samples were not collected during the washing of concentrate vessels.

3.15.3 Effluent treatment

We find that the effluents generally carry little organic matter when the discharge is balanced over the working day. However, potential exists to discharge concentrated sugars during the washing down of vessels. Possible COD loads in spilt juices/squashes can exceed 40 000 mg COD/l.

We believe that ultra filtration and RO could recover substantial amounts of sugars & concentrates from the first rinse waters from syrup storage tanks.

Consideration should be given to recovery and recycling of bottle washing water which could result in all factories achieving an SWI of 2,0 kl/t.

3.16 TANNERIES

This industry is part of an existing survey.

Data was obtained from LIRI on 10 tanneries which revealed that they processed 552 850 hides per month consuming 69 300 kl of water. Accordingly the NASWI is 125 l/hide. The variation in SWI was 72-250 l/hide.

3.17 YEAST

3.17.1 Industry and process desription

Yeast is manufactured from molasses as shown in Appendix 1.22. The molasses is drained in channels under the railway tankers and pumped into a storage tank in readiness for use. It is then pumped through plate & frame heat exchangers to raise its temperature to 125°C for sterilisation. As the molasses in South Africa has 14% ash & other impurities, a considerable amount of scale is deposited in the heat exchangers which have to be cleaned frequently.

Water is added after it has received breakpoint chlorination, in a ratio 1 part water to 1 part molasses. The mixture is pumped into the fermenter vessel in which air, NH_3, diammonium phosphate and trace elements such as Zinc are added. This 300 m^3 vessel is cooled during the exothermic reaction which takes 17 hours. After fermentation, the mixture is pumped through 3 centrifuges.

The cream of yeast from the centrifuges is then passed through a cooler to reduce its temperature to 10°C, from which it continues to cream storage tanks followed by a filter press and extrusion machine.

3.17.2 Survey results

Key data and survey response is as follows:-

Industry	:	**Yeast**
Survey Response	:	**6 Factories (100% annual production)**

Total Production	:	41 360	t/a
SWI range	:	20 - 35	kl/t
NASWI	:	28	kl/t
Total water intake	:	1 160	Ml/a
Total effluent generated	:	1 040	Ml/a
SS	:	410	t/a
COD	:	4 100	t/a
OA	:	950	t/a
If NASWI reduced to	:	20	kl/t
Potential savings are	:	330	Ml/a

Our survey covered the production of 41 360 t/a of yeast, however the central statistics give far less as the annual production. We assume that this arises because some of the yeast companies are owned by their associated bakery and perhaps therefore pass their production internally.

The organic pollution load is high i.e. COD 100 kg/t yeast. We estimate that all yeast operations could perform with an SWI of 20 kl/t. We visited a factory to confirm this.

3.17.3 Effluent treatment

The sources of pollution are the cleaning of the molasses troughs, heat exchangers and the centrifuge blowdown. At one yeast factory visited, the blowdown from the centrifuge was costing R50 000 per month owing to its high organic strength.

A sample of the effluent from the centrifuge blowdown was taken for analysis and found to have the following characteristics:-

Parameter	Units	Amount
COD Total	mg/l	53 600
COD Filt.	mg/l	22 000
Conductivity	mS/m	25 000
pH	-	5,5

The application of ultrafiltration to this low volume flow requires investigation owing to the immense potential saving in disposal charges.

3.18 CHEMICALS

We mention here work performed by us on the recovery of acetic and other mixed aliphatic acids from the Sasol effluent.

We found that using a spiral wrap PBIL reverse osmosis membrane we could recover mixed fatty acids in the Sasol final effluent, and concentrate them from 0,5% to 11% concentration. It was discovered that the acetic acid dimerises and hence permits its recovery to such a high percentage concentration.

CHAPTER 4

RECOMMENDED RESEARCH PROJECTS

4.0 RECOMMENDED RESEARCH PROJECTS

4.1 INTRODUCTION

This investigation has revealed a number of useful areas in which pilot plant work might be undertaken to investigate water and effluent management using physical/chemical techniques as the first step in water rennovation for reuse.

This chapter presents recommendations arising from this report.

4.2 NATIONAL WATER & WASTEWATER SURVEY

The wide variation in SWI between factories processing the same commodity suggests that little if any knowledge about the in plant use of water exists. Accordingly it is proposed that a detailed survey be undertaken and that each industrial water consuming industry be visited and an assessment made of the following items:-

a. the volume or mass of raw materials used;
b. the water intake;
c. the production quantities;
d. the quality & quantity of effluents;
e. the distribution of flow in the plants.

If such a survey was undertaken, it would generate data to enable target values of water intake and pollution loads to be placed on all manufacturing operations which use water.

This information would be most useful to enable realistic assessment of water needed during times of shortage.

4.3 ABATTOIRS - RED MEAT & POULTRY

Our study has revealed that only about half of the water intake to an abattoir comes into contact with the actual product. Accordingly potential for reusing at least half of the abattoir water intake exists, depending on the quality of the reclaimed water.

The processes, most likely to produce water of a quality suited for reclamation are dissolved-air flotation and membrane plants.

We propose the construction of a DAF pilot plant similar to that built for the fishing industry, but incorporating the necessary measures to test various flocculation processes. Among the flocculants to be tested, we propose ferric chloride, lime, lignosulphonates and aluminium sulphate.

The membrane plant should, we propose, be of tubular configuration, capable of being retubed with either RO or UF membranes.

Potential areas for reusing reclaimed water are the lairages at red meat abattoirs and cooling towers, refrigeration circuits and washing down in both industries.

The project should also include a survey of some of the major abattoirs to establish the target water intake for each processing step.

4.4 BREWERIES - BARLEY

The water : beer ratios vary from 7,9 to 10,3 whereas the theoretically achievable value is nearest 3,0. Accordingly a detailed investigation is proposed to identify for each unit process step, the target minimum water intake. This would involve the detailed in plant survey of at least one modern and one older brewery.

Each one of the effluent streams need characterising to determine the contaminants, followed by pilot plant trials to establish if the useful elements such as alcohol and proteins could be recovered as a method of rennovating the water.

Particular attention should be given to the removal of spent grains and yeast from the effluent and to methods of their drying.

The project would require pilot wedge wire screens, hydrocylones dissolved-air flotation and membrane test rigs.

Potential areas for using rennovated water are the cooling tower circuits, the pasteuriser water, and the bottle washing plant.

4.5 BREWERIES - SORGHUM

The water to beer ratio varies from 1,3 - 5,8 and a detailed survey and test program similar to that proposed for barley beer is required.

In addition the sorghum malting process, carried out mainly by independent organisations uses large volumes of water to wet the grains during sprouting. Reuse of this water is feasible provided the suspended solids and COD are reduced. A membrane plant possibly operating as ultrafiltration should be tested.

4.6 DAIRIES

As with other projects a survey is needed initially to determine the water use at each part of the various processes performed by dairies.

The major areas for consideration in dairies are cheese whey concentration, recovery of milk solids and milk evaporator plant condensate reuse.

The bottle washing water recycle would also be a major potential process for water reuse.

4.7 SOFT DRINKS AND CARBONATED WATER

This industry has the potential for high organic effluent discharge from cleaning out of sugar syrup and juice concentrate tanks. Accordingly experiments with membrane rigs are proposed.

The only other area for major reuse would be the recycling of bottle washing water.

4.8 VEGETABLE OIL AND MARGARINE

This industry could be rapidly surveyed owing to the limited number of processing plants.

The major areas of research needed are the refinery part of the process and involve the formulation of a disposal method for the soapstocks. Current practice is to acid split them but this produces a second grade fat and adds greatly to the sulphate concentration discharged.

Dissolved-air flotation trials are needed using various flocculants & chemicals to determine the best treatment route. Membranes in the ultra-filtration mode also warrant investigation.

4.9 YEAST

Although little scope exists for reusing water at the yeast manufacturing operations, the effluents discharged have a very high organic load. Membrane pilot trials are warranted to recover the spent yeast in the centrifuge blow down circuit.

CHAPTER 5

LITERATURE REVIEW

5.0 LITERATURE REVIEW

5.1 INTRODUCTION

The Waterlit and Aqualine databases were searched initially and an update search was performed on a monthly basis for the duration of the study. Papers reporting on the issue of physical/chemical effluent treatment techniques as well as those relating to applications of these techniques to effluents having high organic contents were obtained.

From the many hundreds of abstracts received, the papers shown in Section 5.3 were ordered. The papers are arranged according to subject matter and in alphabetic order of author's names. A detailed description is given of selected papers and these have been arranged according to the appropriate industries and listed in Section 5.2.

5.2 DETAILED REVIEW OF SELECTED PAPERS

5.2.1 Abattoirs

1. Berry L S, Lafayette P F & Woodard F E

   Sand Filtration & Activated Carbon Treatment of Poultry Process Water.

   Several plant operations in poultry processing can reuse wastewater, provided sufficient SS & dissolved organics removal.

   The US National Pollutant Discharge Elimination System allowed 0,4 kg BOD_5/1 000 kg broilers and 0,62 kg SS/1 000 kg broilers (0,71 g BOD_5/bird & 1,05g SS/bird).

   The majority of the SS & COD loads originate in the bleeding area, scalding tank overflow, flume for eviscerated products and the chillers.

   DAF plant effluent was sand filtered through a bed of 65% 20/30 mesh and 35% 30/40 mesh sand having effective size 2,9 and non uniformity coefficient 1,9. The sand filter was followed by passage of the filtrate over a bed of activated carbon (a/c). The columns were arranged in upflow mode with four 6,35 cm dia. plexiglass columns in series. The combined bed depth was 3,6 m. The upflow rate was 163 l/min/m^2 giving a 4 - 10% bed expansion. The carbon was of 8 x 30 mesh.

   Both the filters and a/c were tried on final DAF effluent and a spin chiller effluent.

The sand filter loading giving the best SS removal was 4,9 kl/m^2h. The bed life between backwashing varied substantially depending on the concentration of SS in the feed.

The a/c fed with an influent of TOC 70 mg/l produced an effluent of TOC 10 mg/l. No brand of a/c reduced the TOC further suggesting that a proportion could not be adsorbed.

The performance of the process is shown below:

Stream	SS mg/l	Removal %	TOC mg/l	Removal %
raw chiller effluent	1 240	-	122	-
after coagulation & DAF	35	97	78	36
after sand filtration	18	49	78	-
after activated carbon	9	50	30	61
Total % removal		99+		75

2. Butler D G

Product Recovery from Meat Works Wastes

Two processes of coagulation by acidification, followed by dissolved/air flotation described. Acidification of effluent to pH 4 followed by DAF removed 52 - 80% of the COD and 80% SS. A similar process followed by lime addition to pH 7 followed by settlement, called the Grant-Robins process, produced improved results. Recycle rates for DAF much above 20% do not improve process.

3. Grant R A

Protein Recovery as an Effluent Treatment Process

Ion exchange resins based on crosslinked regenerated cellulose having a highly porous structure into which the proteins can diffuse have protein uptake capacities of 0,5 g protein per g resin. Flow rates up to 2,0 $kl/m^2/hr$ are possible with protein concentrations up to 1 000 mg/l. The resin treatment follows DAF at pH 3 to 5. Regeneration is by alkaline brine solution and the protein is recovered from the spent regeneration solution by neutralising with lime, heat coagulated at 90°C and decanted. Dried samples of recovered protein from abattoir waters showed a true protein content of 68%.

4. Hamza A, Galal S & Lillard H S

Case Study of Water Rennovation and Reuse in an Egyptian Poultry Processing Plant

Previous work by Lillard showed that chiller water which had been rennovated by diatomaceous earth filtration and chlorination could be reused to flume necks, without detrimental effects. Carawan et al found that flushing gizzards with water recovered from the chiller did not effect the wholesomeness of the gizzards and Roberts showed that chiller water could be recycled via diatomaceous earth filters and that the filtrate had lower bacterial levels than the chiller water.

At the Alexandria Poultry Processing Plant, a multiple reuse scheme was implemented where the compressor cooling water was chlorinated and used as make up to the chillers. It was then passed to the prechiller and the washer which was fitted with a closed loop recycle filter and chlorinator (20 mg/l). Finally the water entered the scalding tank.

The work showed that the bacterial counts on the final carcasses were lower with the reuse system than with the normal open circuit one. The system saves 54% of the normal make-up volume to these processes.

5. Hopwood A P

Recovery of Protein and Fat from Food Industry Wastewaters

Lignosulphonates which occur in spent sulphite lye from the sulphite cellulose industry production process were first established as protein precipitators in 1960.

When lignosulphonate is in solution, there is, owing to the ionization of the sulphonate groups, a net negative charge on the molecule; with increased acidity this charge is not lost until the pH falls below pH 1. Owing to the amine groups, protein molecules carry a net positive charge when the pH is below the isoelectric range. Accordingly pH 3 is used in practise. A solution of sodium lignosulphonate is dosed into the feed water at 300-1 000 mg/l depending on the strength of the wastewater and fed to a DAF plant operating at 15 - 25% recycle. Where the recycle flow rejoins the main stream, sulphuric acid is dosed.

Recovered sludges are heat coagulated at pH 9 and 95°C before being dewatered in a decanter which gives better than 50% TS. During the neutralisation/coagulation process about 30 - 50% of the lignosulphonates are released into the aqueous phase for recycle back to the wastewater feed thereby reducing the chemical dose.

The sludges are reused as animal feed as lignosulphonates are EEC approved feed additives. The average performance of the plant is 76% COD, 78% SS and 75% Total N removal.

6. Jeffus H M & Mitchell D T

Grease & Oil Product Recovery from Dissolved Air Flotation Skimmings of Poultry Processing Wastewater

The recovery of grease from effluents has been tried using acid splitting, chlorination, solvent extraction and electroflotation. The dewater investigation of recovered sludges from dissolved air flotation found solvent extraction to be the most exciting. The solvent used had to be already proven safe for use with food products. Hexane and trichlorotrifluoroethane (freon) were selected as they have relatively low boiling points and are immiscible with water. The required volume of solvent was found to be:-

Vol of solvent per volume of scum	**Grease & oil recovered as % total**	
	Hexane	**Freon**
0,25	7	-
0,50	22	-
0,75	21	25
1	-	62
2	69	76
3	73	78
4	74	76

A pilot plant capable of processing 4,5 l scum per hour was established. Approximately 76% of the grease was recovered as edible fat. The characteristics of the fat were:-

Characteristic	**% of recovered fat**
moisture	1,9
insoluble impurities	0,25
unsaponified matter	0,93
free fatty acids	15,6
total fatty acids	97,0
linoleic acid	21,9

The temperature for boiling off the solvents is 47 - 50°C.

7. Litchfield J H

Meat Fish and Poultry Processing Wastes (1981)

Electroflotation for removing fat & oil from beef abattoir wastewater consisted of cells operating at 8 V, 3 000 A and 12 V, 25 000 A respectively and at pH 4,0 - 4,5. Adding 300 mg/l sulphuric acid 2 mg/l anionic polyelectrolyte and 160 mg/l NaOH gave an effluent of pH 6,5, 209 mg/l BOD_5, 58 mg/l SS and 75 mg/l hexane extractables. The skim volume was 0,4% of the effluent volume and contained 10 - 25% solids.

Utilisation of paunch contents was investigated by separating the liquid fraction from the fibrous residue by centrifugation and subjecting the liquid to ultrafiltration. The membrane area was 0,55 m^2. COD reductions between 77 to 86% were achieved and the resulting concentrate had total solids (w/w) and crude protein contents of 6,2 and 35,5%. The amino acid spectrum indicated that the recovered protein concentrate could be fed to pigs.

Shih & Icozinlc investigated ultrafiltration of poultry processing wastewater in a 0,113 m^3 laboratory rig having 0,2 m^2 of membranes. The TS, COD, ash, TKN & protein contents of the permeate were 240, 313, 48, 14 & 37 mg/l respectively. The respective reductions in TS, COD, ash, TKN & Protein were 85%, 95%, 65%, 86% & 94% respectively. The dried protein concentrate was 30 - 35% true protein, 24 - 25% fat and had amino acid profiles similar to soya bean meal.

8. Litchfield J H

Meat, Fish and Poultry Processing Wastes (1982)

Studies in Hungary demonstrated that ferrous sulphate, magnesium chloride and aluminium sulphate in combination as coagulants gave improved removal of organic materials over that obtained with magnesium and calcium chloride. In addition cellulose activated with inorganic salts and lignites treated with sulphuric acid was effective in reducing the organic contents of meat processing wastewaters. At Brest in USSR, sulphite liquor at an optimal dose of 400 mg/l was more effective than alum in recovering dissolved protein from abattoir wastewaters.

9. McNaughton G S & Wakelin W S

The Treatment of Meat Works Wastes by Ion-Exchange

An ion exchange resin manufactured from regenerated cellulose is suitable for extracting soluble proteins from meat works wastewaters. The process should be used after DAF to make the water suitable for tertiary treatment and reuse. Laboratory test results using DAF effluent showed the following results:-

Parameter	Units	Column input	Column output
TS	mg/l	700	470
Total organics	mg/l	250	70
Protein	mg/l	200	20
COD	mg/l	300	60

Resin is regenerated by alkaline brine for 40 resin uptake cycles before revitalisation is needed with stronger industrial chemicals. A life of 3 - 4 years is predicted. As the resin is protein selective, the recovered protein is reusable as animal feed.

10. Murray D S

Preliminary Operating Results of a Slaughterhouse Pretreatment System

An abattoir killing 6 300 pigs per day used a DAF plant to treat its wastewater. The statistics for the abattoir were:-

Parameter	Units	Average	Range
Flow	m^3/d	1 135	189-1 993
pH	-	-	6,1-6,9
COD	mg/l	7 510	2 877-10 635
BOD_5	mg/l	3 575	1 360- 5 300
Total Solids	mg/l	3 482	1 318- 5 100
SS	mg/l	2 540	910- 3 850
Total Volatile Solids	mg/l	2 938	992- 4 256
Suspended Volatile Solids	mg/l	2 398	820- 3 550
Oils & Grease	mg/l	1 427	412- 3 256

The DAF was designed for a solids loading ratio of 6,36 kg $SS/m^2/h$ with a hydraulic loading of $2,3 kl/m^2h$. Using ferric chloride at pH 6,5 the COD removal was 40 - 70%, grease removal was 95% and the SS 45 - 90%. A 10 mg/l dose of polyelectrolyte was necessary. The sludges passed a decanter to separate water, grease and extraneous solids. The grease goes to inedible tallow, centrate is returned to flotation and solids to rendering plant.

11. Ramirez E R, Johnson D L & Clemens O A

Direct Comparison in Physiochemical Treatment of Packinghouse Wastewater between Dissolved Air and Electroflotation

For normal effluents no difference in performance between DAF and electroflotation was found but where slaughterhouses dehair their hides the electrocoagulation followed by electroflotation was superior.

12. Zimmerman & Jacquez

Poultry Waste Pretreatment Through Dissolved Air Flotation Coupled with Lime Polymer Conditioning

The object of this work was to determine if chemical conditioning coupled with DAF could be applied as pretreatment to poultry abattoir wastewater where further processing of the meat occurs. Lime was selected as the primary chemical used in conjunction with a cationic polymer.

The DAF design had the following characteristics:-

air to solids ratio		0,006
pressure	(kPa)	590
recycle ratio		35 - 50%
chemicals : alum	(mg/l)	15 - 30
: lime	(mg/l)	100 - 500
: polymer	(mg/l)	0,1 - 20

Conclusions were that the solubility of the lime and the softening precipitates had a major effect on the fat removal when compared to runs performed with alum and polyelectrolytes.

Flocculation time was very important and 20 minutes was found optimal. Finally selected dose rates were 250 mg/l lime and 1 mg/l polyelectrolyte. Lime doses above 500 mg/l reduced the performance.

5.2.2 Bakeries

1. Lee A W & Ettelt G A

Dual Polymer Treatment of Variety Bakery Products Wastewater

The washing of baking pans produces a high strength, high pH, hot (80°C) detergent water containing large quantities of solids and emulsified fats.

As coagulation of pan wash water required considerable chemical dosing and generated voluminous, difficult to separate sludges, the effluent was collected separately and metered into the remaining effluent in a ratio 1 : 9 to even out its effects. The blended wastewater was pumped to a floc tank where 3 000 mg/l of cyanamid 507C highly charged cationic polyelectrolyte is added, followed by 10 mg/l of anionic cyanamid 835A flocculant.

The flocculated water is passed to dissolved-air flotation plant having an hydraulic loading of 6,0 kl/m^2 h. The flow rate to the plant was 16 kl/h with a recycle flow via an ejector fed with air at 250 kPa of 22 kl/h.

Average performance data given is:-

Untreated waste				Treated waste			
pH	BOD_5	SS	HS$^{(a)}$	pH	BOD_5	SS	HS
7,0	4700	11070	6620	6,4$^{(b)}$	1924	219	76

(a) hexane solubles
(b) pH depressed by chemical dosing

2. Pavilicius A M

"Having your Cake and Treating it too" : A Case History of the Treatment of Bakery Wastes

The characterisation of bakery effluent quality is determined by the products. A plant making bread and similar dry baking operations would have flour and grease as its major contaminants, whereas a plant making cakes and pastries would have an effluent containing high concentrations of COD, BOD, oil, grease and solids. The major contaminants originate from greases, oils, flour, sugar fruit fillings, product emulsifiers and cleaners.

The primary source of effluent is the pan washer where baking trays are cleaned with strong detergents which tend to emulsify the fats.

A dissolved-air flotation plant is used. The chemical dosing regime to the flocculator used Nalco oil in water emulsion breakers (cationic polyelectrolytes) followed by an anionic polymer as a flocculant. The doses vary depending on the product being manufactured. This treatment was successful in removing 93% TOC, 90% COD and 98% SS.

5.2.3 Breweries and Soft Drinks

1. Ghosh & Henry

Stabilization and Gasification of Soft Drink Manufacturing Waste by Conventional and Two Phase Anaerobic Digestion.

About 58% of effluents from soft drink plants originate from process duties, 12% from coolers and condensers, 17% from boilers and other related operations and 13% from sanitary facilities.

At a modern soft drink canning plant which produces 15 types of drinks, reverse osmosis is used to concentrate the dilute waste. Concentrate is passed to biological oxidation remote from the site.

The dilute waste and the RO concentrates had the following characteristics:-

Parameter	Raw waste		RO concentrate		
	Batch 1	Batch 2	Batch 1	Batch 2	Batch 3
Total solids (%)	3,89	2,09	15,25	25,65	10,41
Volatile solids (%)	99,2	98,6	99,9	99,2	99,2
Energy (Btu/gal)	2 770	1 490	10 860	18 260	7 410

The total analysis of batch 3 (RO concentrate).

Parameter	Units	Value
Total solids (TS)	wt%	10,4
Volatile solids	wt%TS	99,2
Total SS	mg/l	225
Volatile SS	mg/l	142
Elemental analysis		
Carbon	wt%TS	51,6
Hydrogen	wt%TS	5,36
Nitrogen	wt%TS	< 0,5
Sulphur	wt%TS	0,07
Potassium	wt%TS	0,03
Calcium	wt%TS	0,10
Magnesium	wt%TS	0,004
Heating value (dry)	Btu/lb	8 533
COD total	mg/l	133 400
COD filtered	mg/l	127 227
Ammoniacal N	mg/l	1
Glucose	mg/l	20 900
Volatile acids as acetic	mg/l	1 600
Ethanol	mg/l	5 900
pH	-	2,5

2. Sidwick J M

Brewery and Soft Drinks Plant Effluents

The basic ingredients of soft drinks are water, sugar, flavours, acid, colourants and if the product is carbonated, carbon dioxide. The following analysis is given for various products:-

Drink	pH	BOD_5 mg/l	Total Solids mg/l
tomato juice	4,1	25 000	66 860
pineapple juice	3,15	65 000	183 900
orange squash	2,5	205 000	-
lemon squash	2,4	175 000	-
limeade	2,95	42 000	56 800
lemonade	2,95	43 000	62 440
brown ale	4,30	69 300	39 620
amber ale	4,05	51 282	23 900

The main sources of effluent in soft drink manufacture are:-

	Process step	Sources & character
a.	water treatment	softener sludges, filter wash water and regeneration chemicals (spent brine)
b.	bottle washer	washwaters with detergent, caustic, phosphates etc
c.	syrup mixing	spillages with sugar acid & colour
d.	filler	spillages with syrup
e.	floor & equipment wash	remnants of concentrates & sugars

A survey of 3 soft drink manufacturing plants gave the analyses of mixed effluent and the bottle washing plant as shown in the table below:-

	pH	BOD_5 mg/l	COD mg/l	SS mg/l	TDS (110°C) mg/l	TDS (500°C) mg/l	Am N mg/l	Tot N mg/l	Tot P mg/l	Detergents mg/l
Factory A										
mixed	10,5-11,9	520	980	63	1260	520	6,3	7,5	0,1	0,5
bottling	10,8-11,7	240	448	40	1090	650	0,5	1,7	0,5	0,5
Factory B										
mixed	11,6-12,6	460	979	13	1500	740	< 6	7,6	0,3	3,1
Factory C										
mixed	10,6	320	685	17	850	280	1,0	2,1	2,5	2,8
bottling	9,7-10,3	134	474	13	640	180	0,3	3,2	1,3	0,4

3. Reverse Osmosis Concentration of Tomato Juice

Two major tomato processing companies have each installed RO plants to concentrate tomato juice from 4,5° Brix to 8,5° Brix. One plant operates at 42 kl/h and the other at 27 kl/h. The plants use tubular ZF 99 membranes.

The production of tomato juice, ketchup or concentrate, in a range of concentration levels of 7-8,5° Brix, 11-14° Brix, and 28-30° Brix is carried out typically in the following process stages:-

washing--> sorting--> chopping--> heat break--> pulper--> finisher--> juice tank--> forced circulation evaporation--> paste tank--> sterilising & canning.

Modern evaporators have the following steam efficiencies:-

2 effects - 0,55 kg/kg water removed
3 effects - 0,36 kg/kg water removed
4 effects - 0,28 kg/kg water removed

About 50% of processing costs (including labour) for the production of 8-8,5° Brix tomato juice are associated with evaporation. In the case of ketchup or concentrate paste, the evaporation step accounts for 60% of the total processing cost.

In the case of 25 kl/h of 4,5° Brix juice being concentrated to 8,5° the water removed is calculated. Using RO at this stage of the concentration is shown to be economic.

5.2.4 Dairies

1. Degremont Handbook

   Effluent quality from dairies differ depending on origin & processes performed.

   a. Pasteurisation and bottling operations produce wash waters containing dilute milk and alkaline solutions.

   b. Cheese dairies and casein factories produce serum rich in lactose but poor in proteins, while butter dairies produce butter milk which is rich in lactose and proteins but low in fats.

   The pollution discharged can be estimated as follows:-

   a. preparation & processing of milk :
      150g BOD_5 per 100 l of milk treated per day;

   b. butter or cheese :
      add a further 5 kg BOD_5 per 100 kg of butter or cheese produced;

   c. condensed milk :
      add 500 g BOD_5 per 100 kg of condensed milk.

2. Groenewold J C

   Dairy Wastes - Literature Review (1981)

   The substitution of nonphosphate cleaners & sanitisers for current ones can result in a 53% reduction in the phosphate concentration in the effluent.

   Dairy plant wastewater was characterised by Vandamme & Waes who related it to the milk received, milk loss & water intake. The average milk loss was 1,65% of the milk received. The average water intake was 1,63 kl/kl milk. One kg BOD (at BOD : COD ratio 0,69) corresponds to 10 l milk loss.

3. Pepper D

   Improvements in Whey Concentration by Reverse Osmosis

   Since the first whey concentration plant was installed in 1975, over 100 PCI tubular plants are in operation. Whey can now be concentrated up to 24 - 28% T.S.

   The main developments have been in :-

   a. engineering, to enable multi-stage recycle plants to be built;

b. membranes, made of synthetic polymer that can be cleaned at up to 60°C with nitric acid or caustic soda;

c. pretreatment of the whey to avoid precipitation of calcium phosphate.

The new plants use ZF 99 RO membranes having a pH range 3-11 and temperatures up to 80°C.

The same plants can concentrate whole milk to 24% T.S. and skimmed milk to 18% T.S.

4. Pico R F & Groenewold J C

Dairy Wastes - Literature Review (1979)

Puhan experimented with membranes for recovering milk solids from dairy rinsewater and concluded that under certain conditions, the combination of ultrafiltration and reverse osmosis almost completely removed milk solids and reduced BOD_5 from 6 200 - 13 500 mg/l to 50 - 80 mg/l with RO and to 8 000 mg/l with U.F.

5. Holmström P

Converting Evaporator Condensate to Fresh Water by Means of Sterilisation, Ion Exchange and Activated Carbon Filtration

Condensate from evaporators can largely replace fresh water in dairies, whether the condensate originates from skim milk evaporation or whey evaporation. Modern evaporators are designed for efficient separation but entrainment and carry over still occurs.

To compare the qualities of condensate from different evaporation techniques $KMnO_4$ values are used:-

Source of condensate	**$KMnO_4$ (mg/l)**
skimmed milk	5 - 10
sweet pasteurised & cooled whey	10 - 20
non-pasteurised whey	20 - 40
butter rinse water	150 - 200

The acid components in milk & whey are distilled during evaporation, but can be removed by ion-exchange. Anionic followed by cationic resins are used. After ion-exchange the condensate is passed through activated carbon for odour removal.

6. Spatz D D

Reclamation and Reuse of Waste Products from Food Processing by Membrane Processes

Original applications of membranes for concentrating cheese whey operated on the whole whey, concentrating it for drying as cattle feed. With development of UF, the protein in the whey is removed whereas the lactose and ash pass through the membrane. A two stage plant comprising UF followed by RO was conceived.

7. Private Communication

Sweet cheese whey can be concentrated to various concentrations depending on the type of cheese and whether or not the pH is corrected as follows:-

Without CO_2 dosing			**Max concentration % T.S. at** 28°C	20°C	10°C
Gouda/Edam	pH	6,4 - 6,6	11,5	16	22
Cheddar	pH	5,8 - 6,2	16	20	24
Emmenthal	pH	below 6,0	24	24	24
	pH	6,2	22	24	24
Camembert	pH	6,2 - 6,4	12	18	24

With CO_2 dosing to pH less than 5,8	**Max concentration % T.S. at** 28°C	20°C	10°C
Gouda/Edam	22	24	CO_2
Cheddar	24	24	not used
Emmenthal	24	24	at
Camembert	22	24	this temp

Acid whey

Lactic acid or HCl casein wheys can be concentrated to 24% TS at 35°C.

Demineralised whey

These are generally easier to treat because the osmotic pressure is lower and calcium phosphate fouling should not occur.

5.2.5 Potato and starch

1. Bambridge M, Chudacek M, Fane A G & Fell C J D

   Starch Waste Concentration with Ultrafiltration

   Starch is recovered from wheat flour by a process involving addition of water to flour with subsequent washing to separate insoluble gluten from the starch and other soluble materials. 15 kg water was used for each kg flour with 90% water rejected as effluent of typical analysis; total solids 0,85%, SS 0,2%, protein 0,17%, BOD_5 4 000 mg/l and pH 3,4-3,8. The protein lost in the effluent represents 15-20% of that in the flour. The UF permeate was bacterially sterile, free of SS and had negligible amounts of protein; the constituents being principally sugars and inorganic salts.

2. van Bellegem T M

   Methane Production from the Effluent of the Potato Starch Industry

   In starch production the juice of the potato is separated from insoluable compounds such as starch granules & cell wall materials.

   The liquors were fed to a sludge blanket up-flow anaerobic reactor which gave the following results:-

Parameter	Feed	Effluent
COD (mg/l)	18 000	800 - 1 200
COD removal (%)		90 - 95
N removal (%)		5 - 10
Biogas yield		6,5 - 7,5 kl/kl water
Temp		35°C
Loading		7,5 kg COD/kl/day

5.2.6 Vegetable oil & margarine

1. Grant P E

   Treatment of Fatty Effluents

   Fatty contaminants in effluents can be characterised by polarity, biodegradability and physical characteristics. Polar contaminants are usually derived from animal & vegetable sources, the non polar fatty contaminants arise from petroleum or mineral oil sources and are generally non biodegradable. The nature of fatty matter will be highly dispersed and readily removable by gravity separation.

Comparisons of sedimentation and DAF for fatty matter separation are given as follows:-

Inlet TFM	Outlet TFM (Total Fatty Matter) Sedimentation		DAF	
mg/l	mg/l	% rem	mg/l	% rem
2 274	872	62	252	89
2 116	942	55	441	79
1 291	225	82	118	90
1 721	270	84	92	94

For wash water or processing effluents, a major proportion of the fatty matter is bound in a stable emulsion.

Treatment of highly dispersed emulsified oils depend on the stability of the emulsion. Fatty material in food industry wastes is normally negatively charged and treatment therefore involves addition of an ion of the opposite charge to destabilise the emulsion. The effectiveness of the added ion increases with valency. Commonly used components for emulsion breaking are ferric chloride, sodium aluminate, alum, ferrous sulphate and lime.

The table below provides data on the efficiency of various flocculants for removing fatty material from abattoir effluents.

Flocculant	Removal efficiency % N	COD
pH adjustment only	32	60
aluminium sulphate	35	60
lignosulphonate	65	80
di-calcium phosphate	45	70

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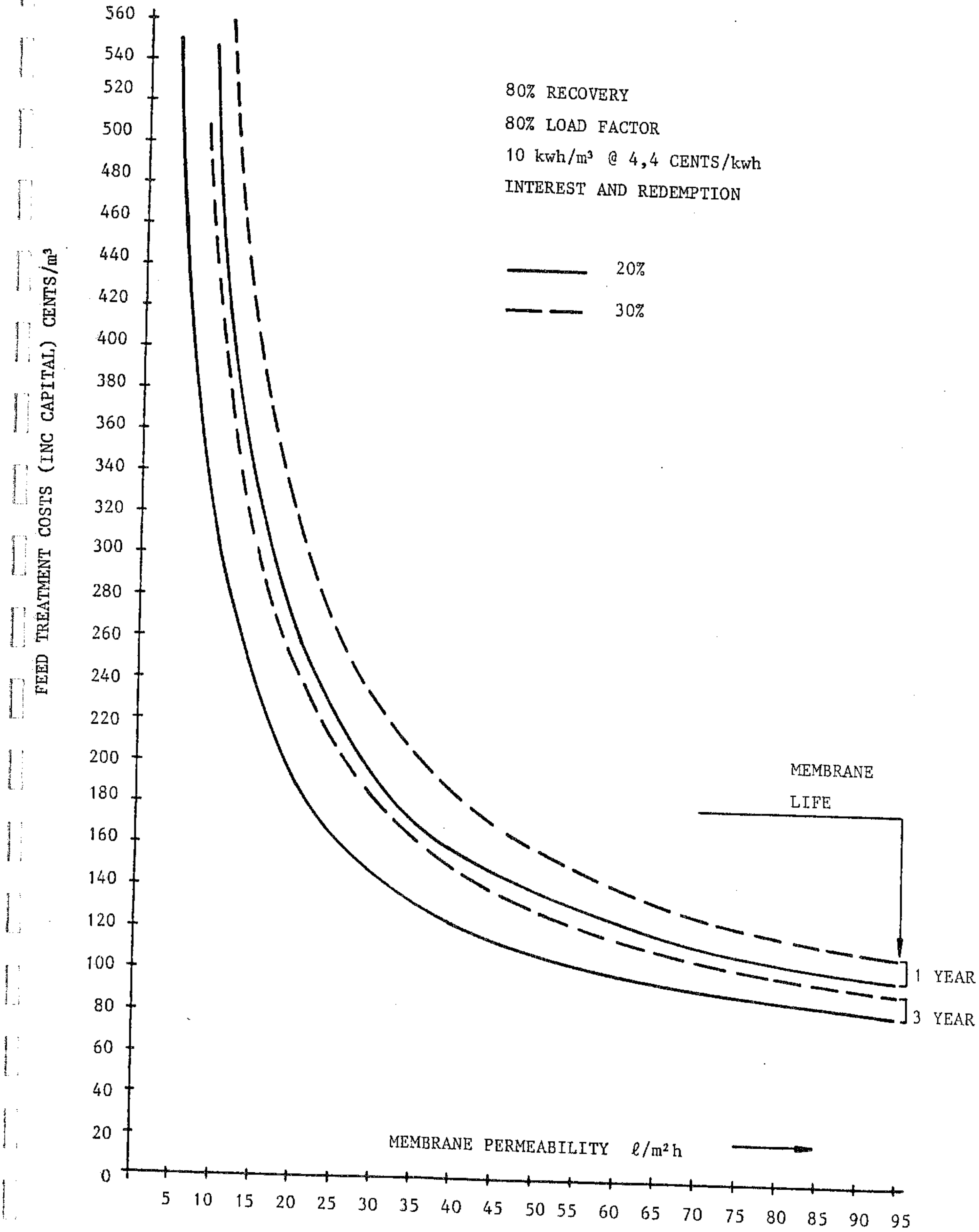
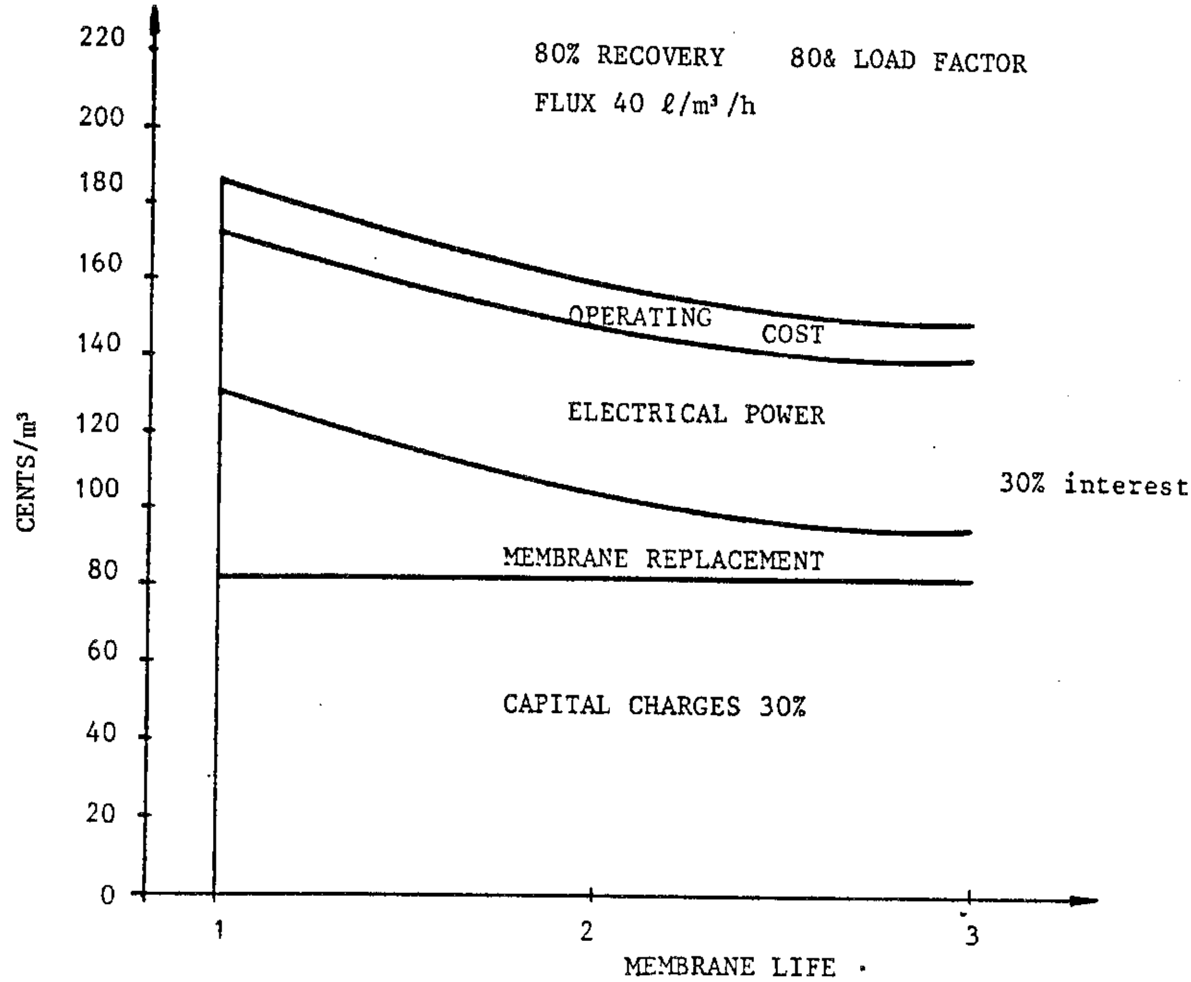
APPENDIX 1

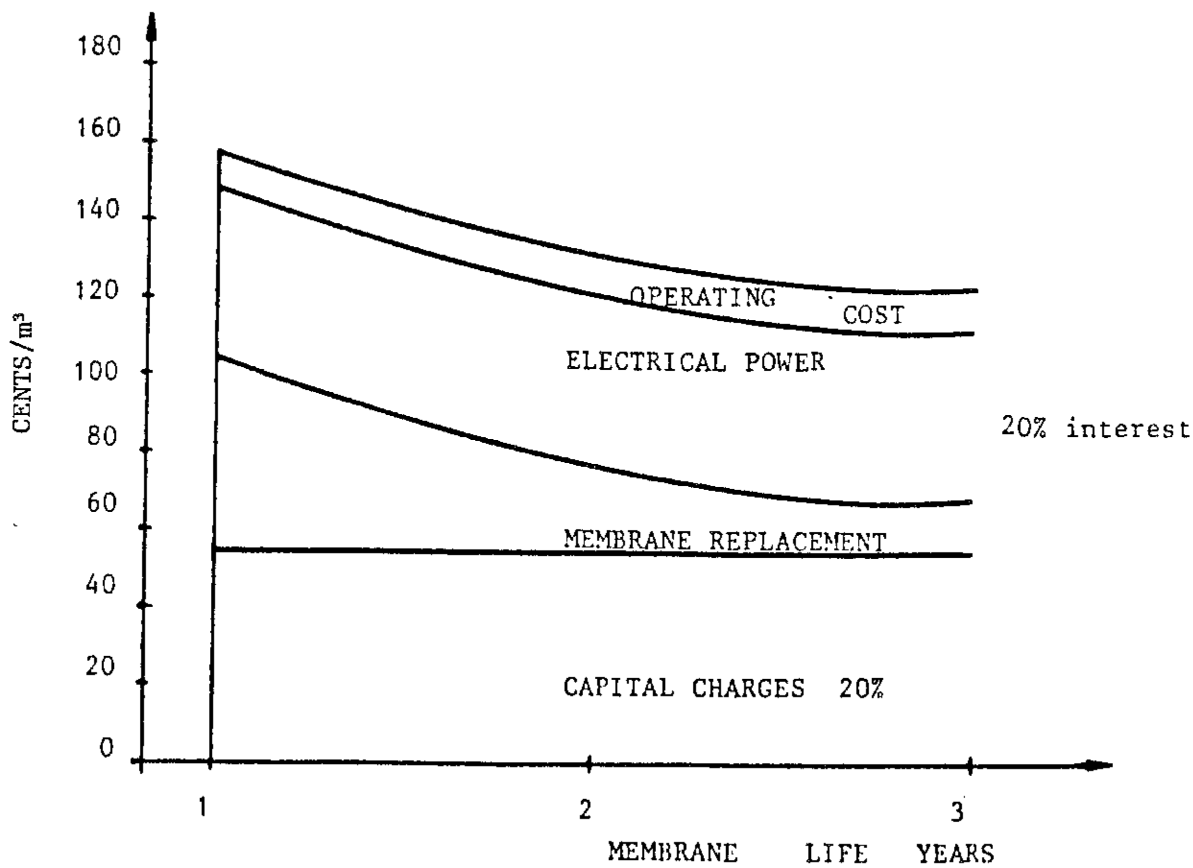
TOTAL COSTS OF RO TREATMENT-
TUBULAR PLANTS



Appendix 1.1 (a)

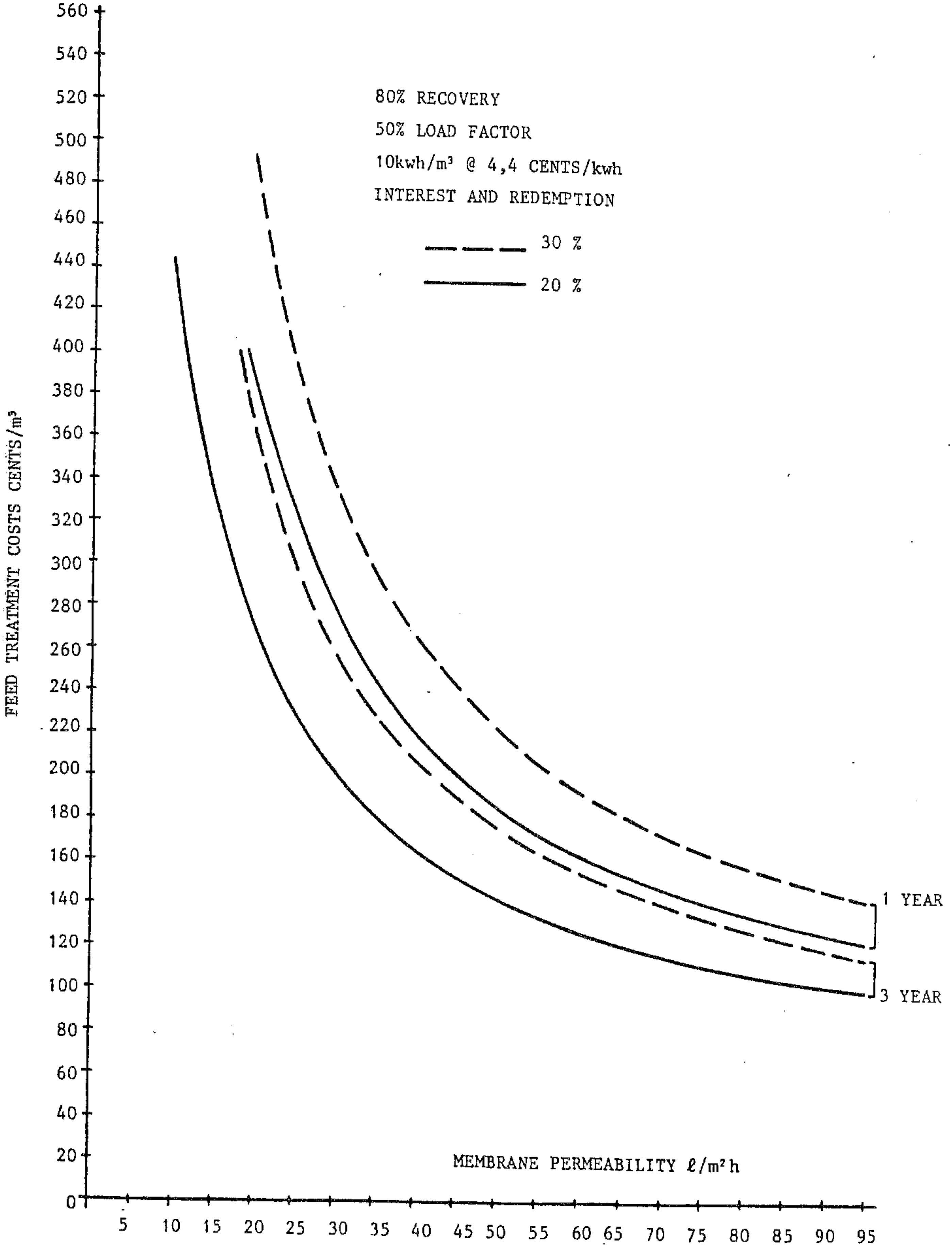
BREAKDOWN OF RO TREATMENT COSTS-
TUBULAR PLANT





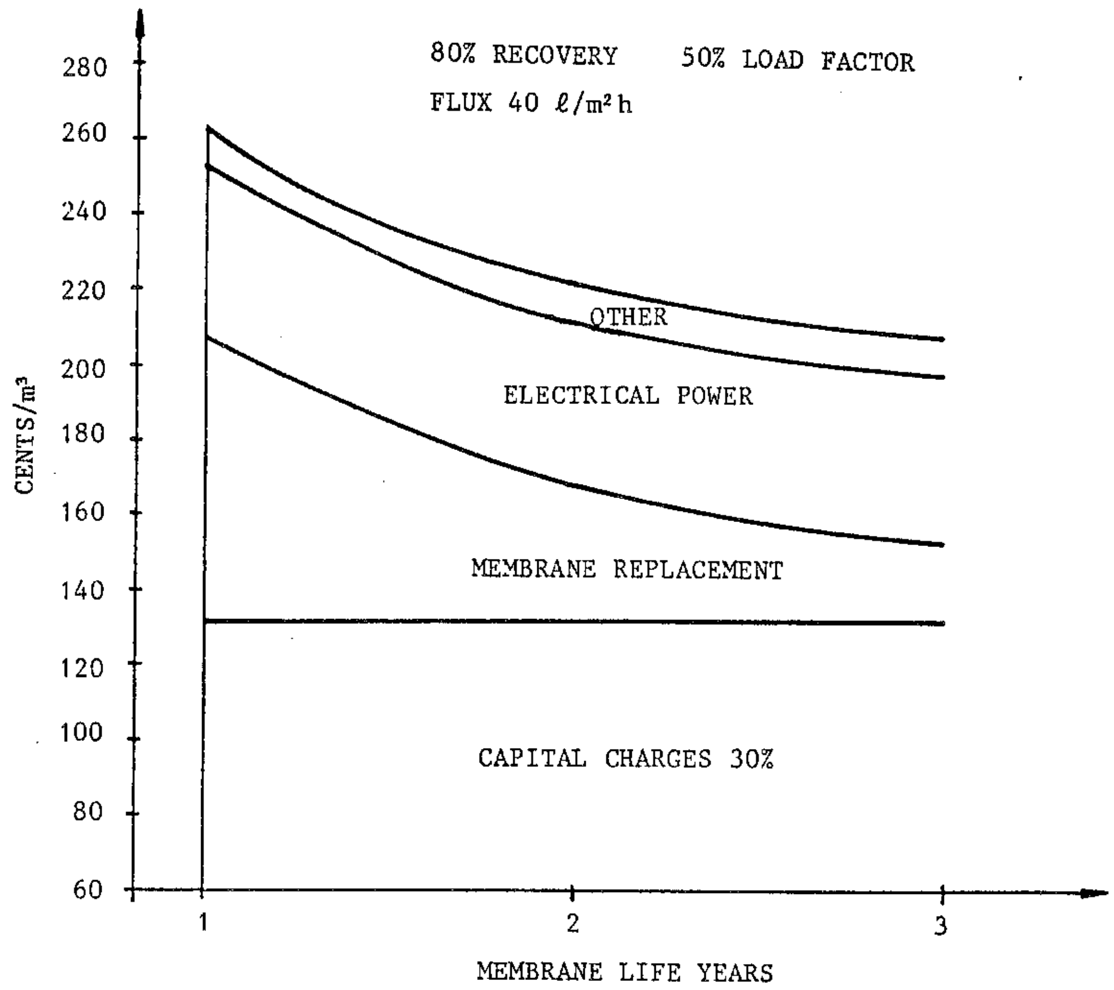
Appendix 1.1(b)

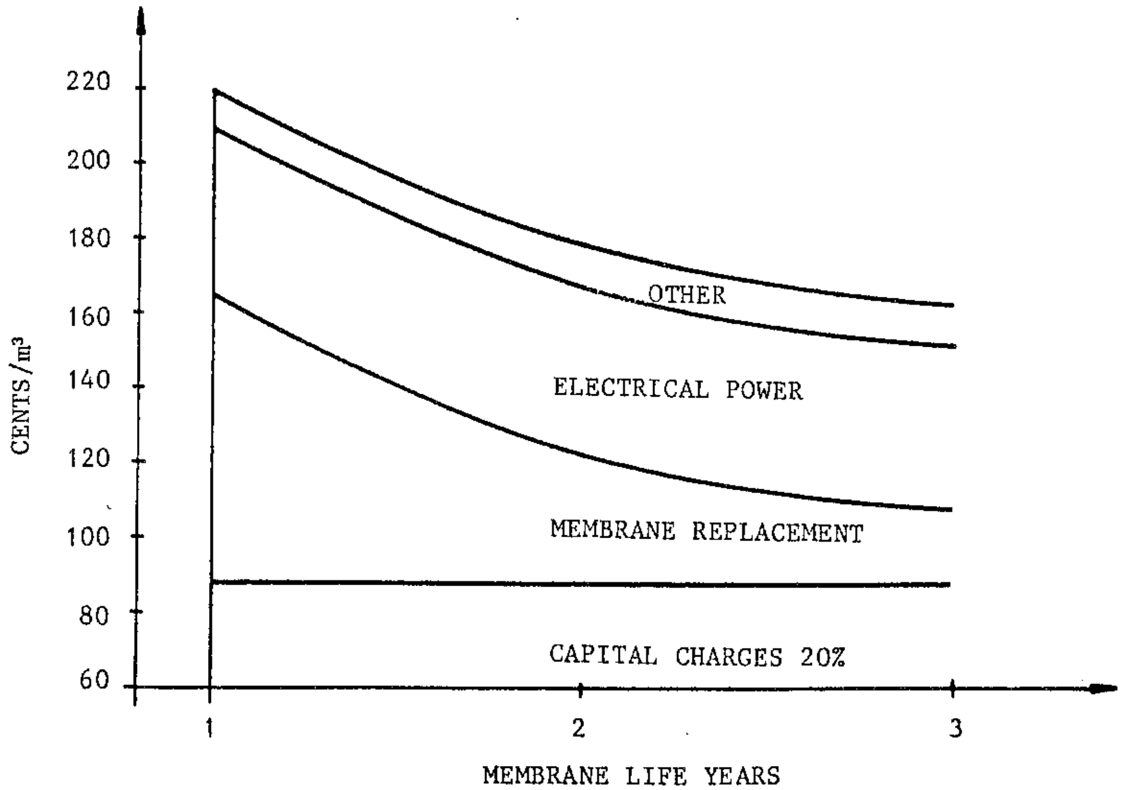
TOTAL COSTS OF RO TREATMENT-
TUBULAR PLANT



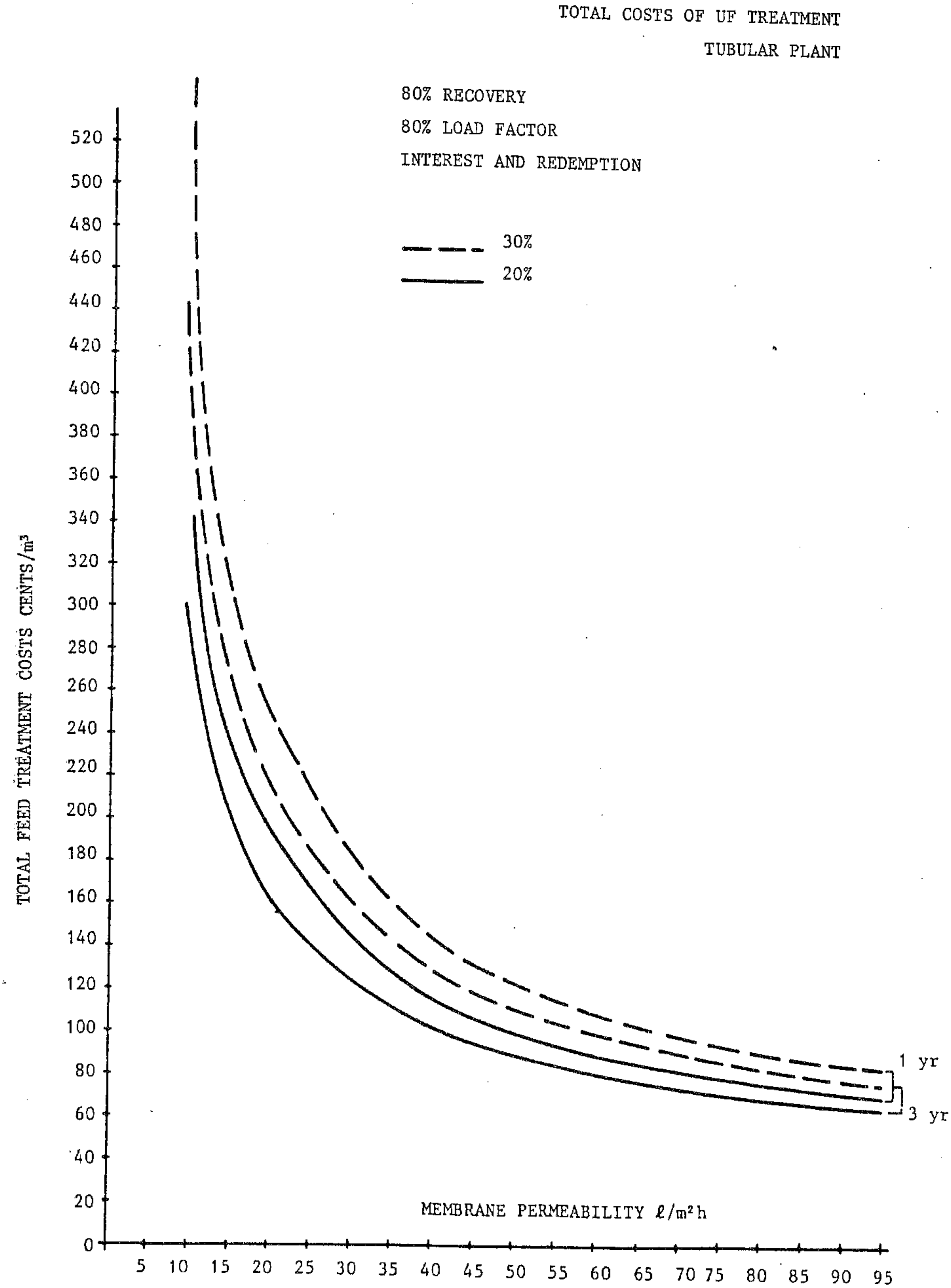
Appendix 1.2(a)

BREAKDOWN OF RO TREATMENT COSTS-
TUBULAR PLANT



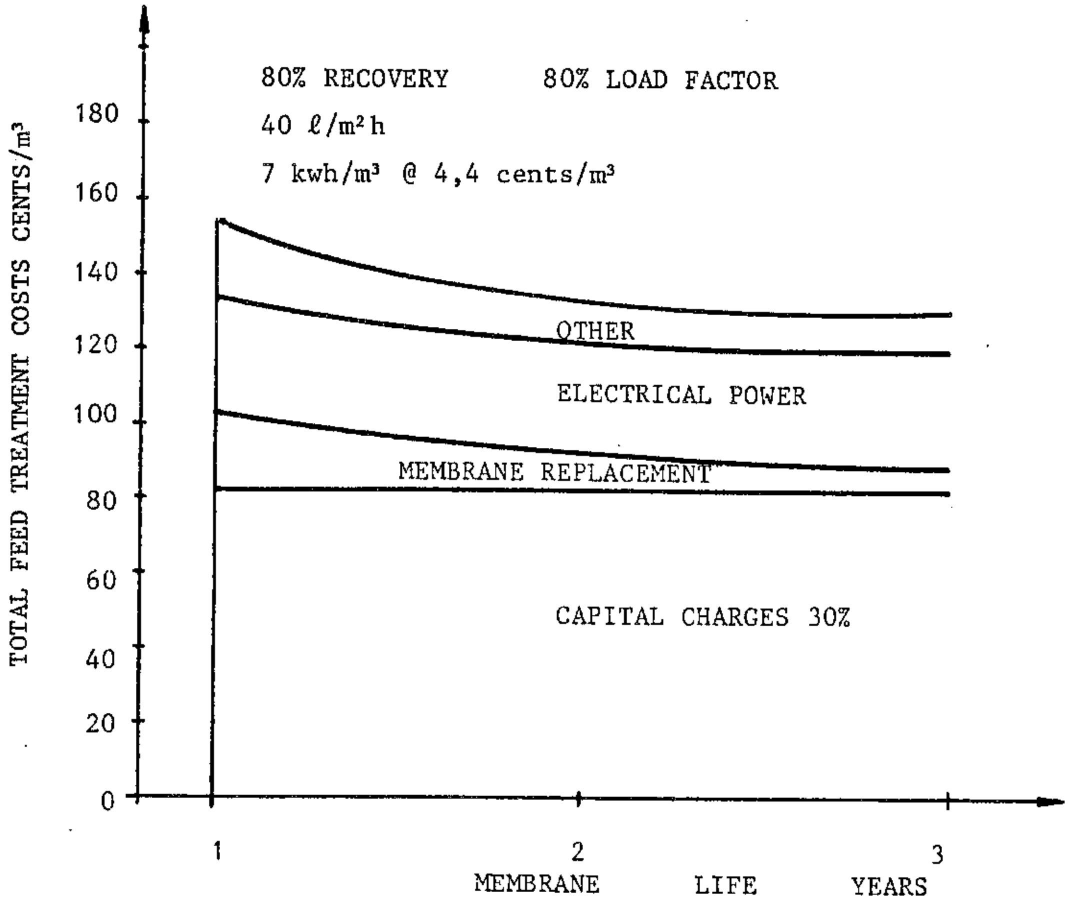


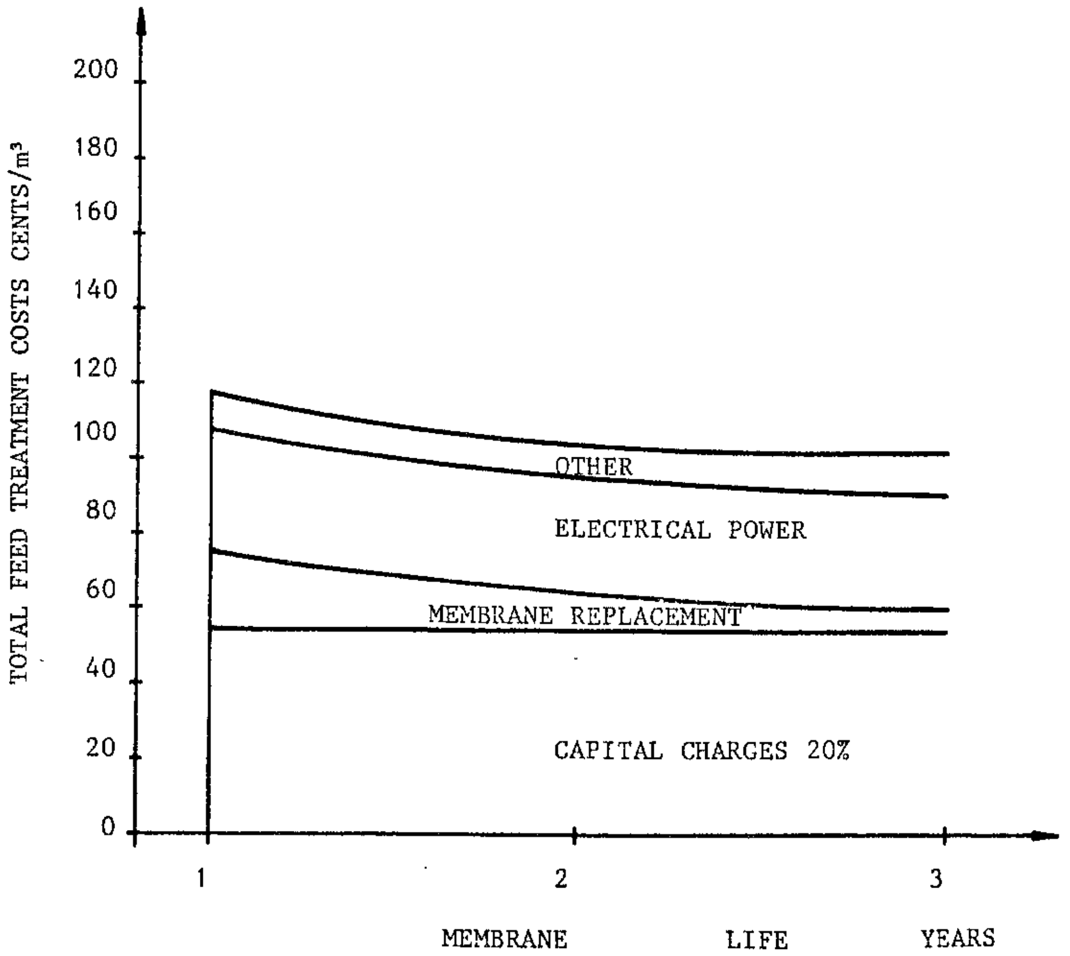
Appendix 1.2(b)



Appendix 1.3(a)

BREAKDOWN OF UF TREATMENT COSTS-
TUBULAR PLANT





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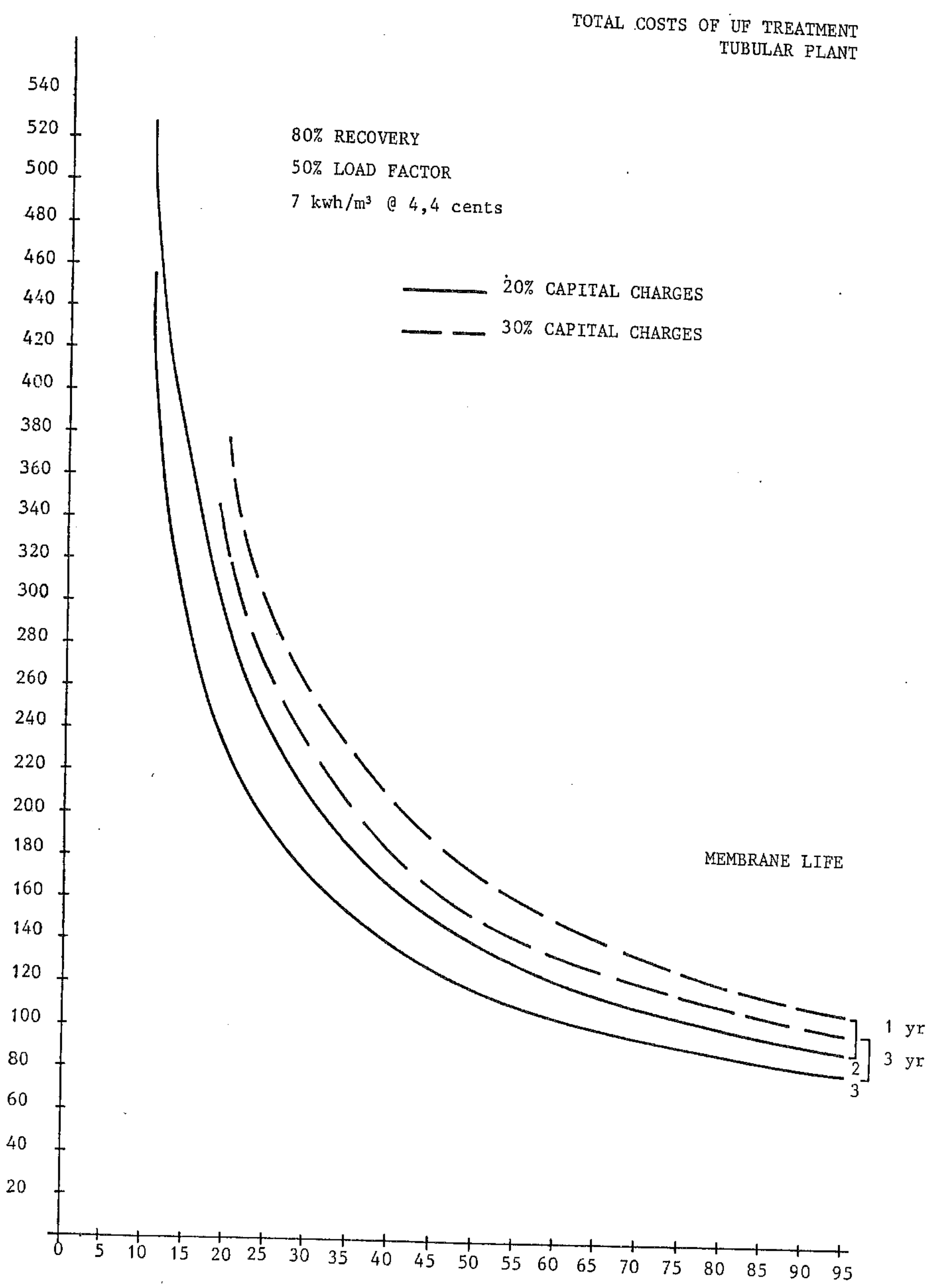
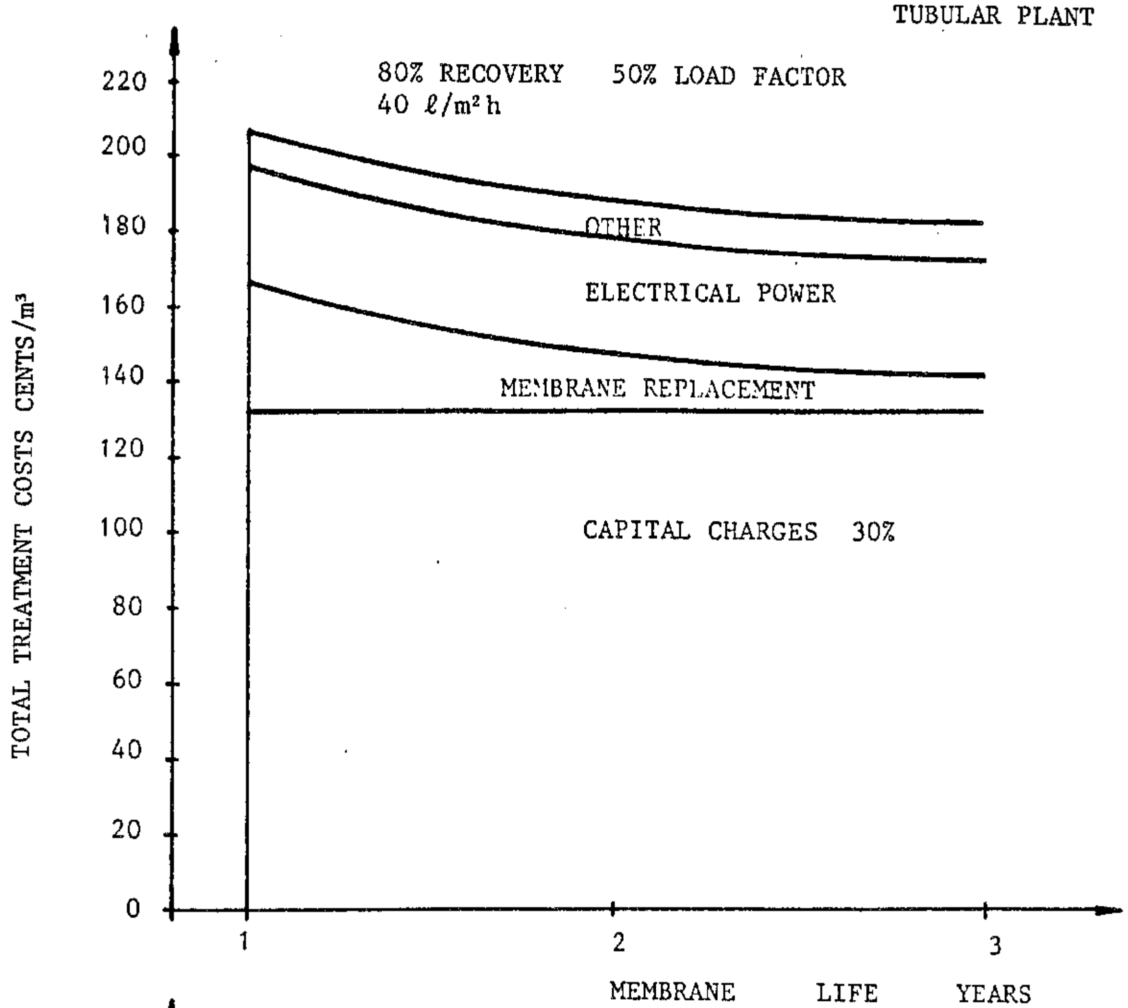
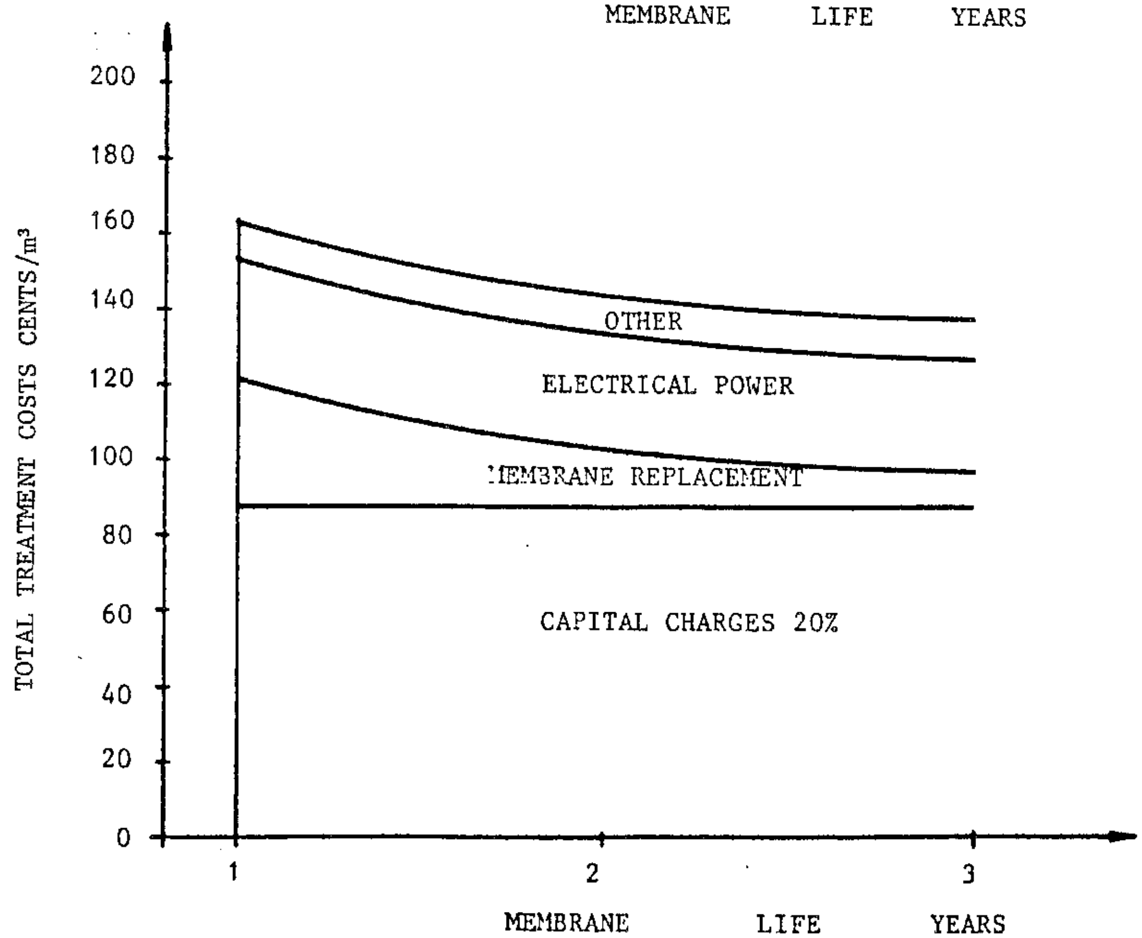
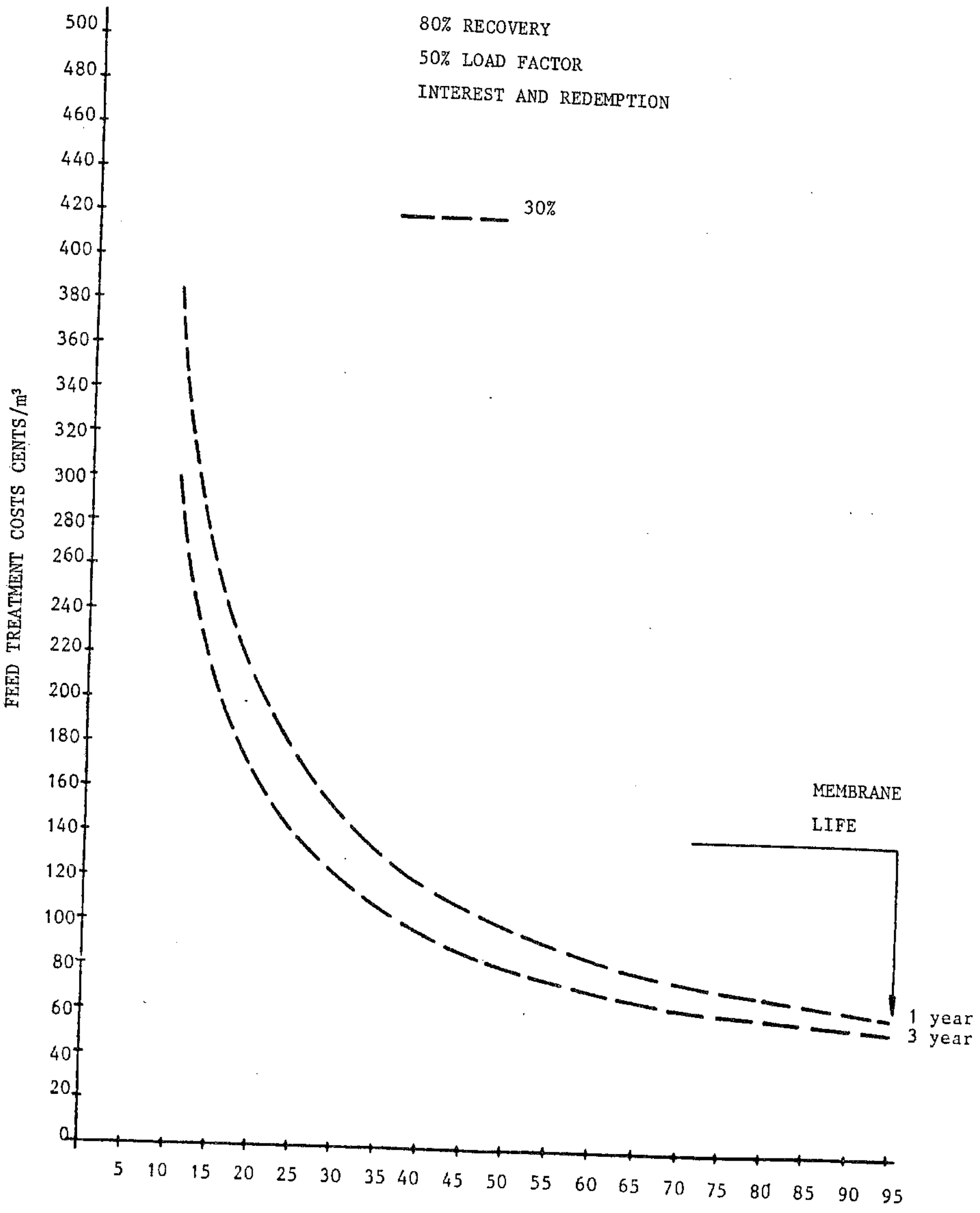

TOTAL COSTS OF UF TREATMENT
TUBULAR PLANT
80% RECOVERY
50% LOAD FACTOR
7 kwh/m³ @ 4,4 cents
20% CAPITAL CHARGES
30% CAPITAL CHARGES
MEMBRANE LIFE
1 yr
3 yr
2
3
540
520
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95

BREAKDOWN OF UF TREATMENT COSTS
TUBULAR PLANT





TOTAL COSTS OF UF TREATMENT-
PLATE AND FRAME PLANT



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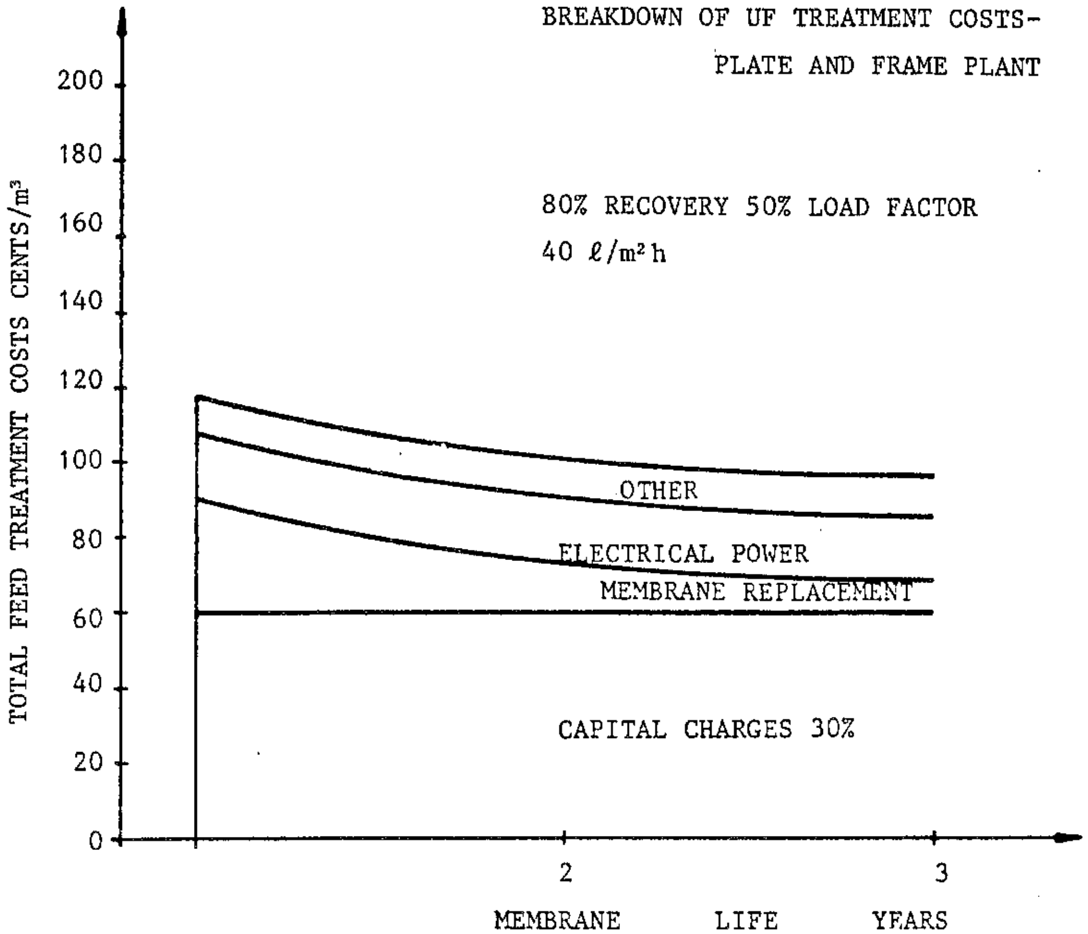
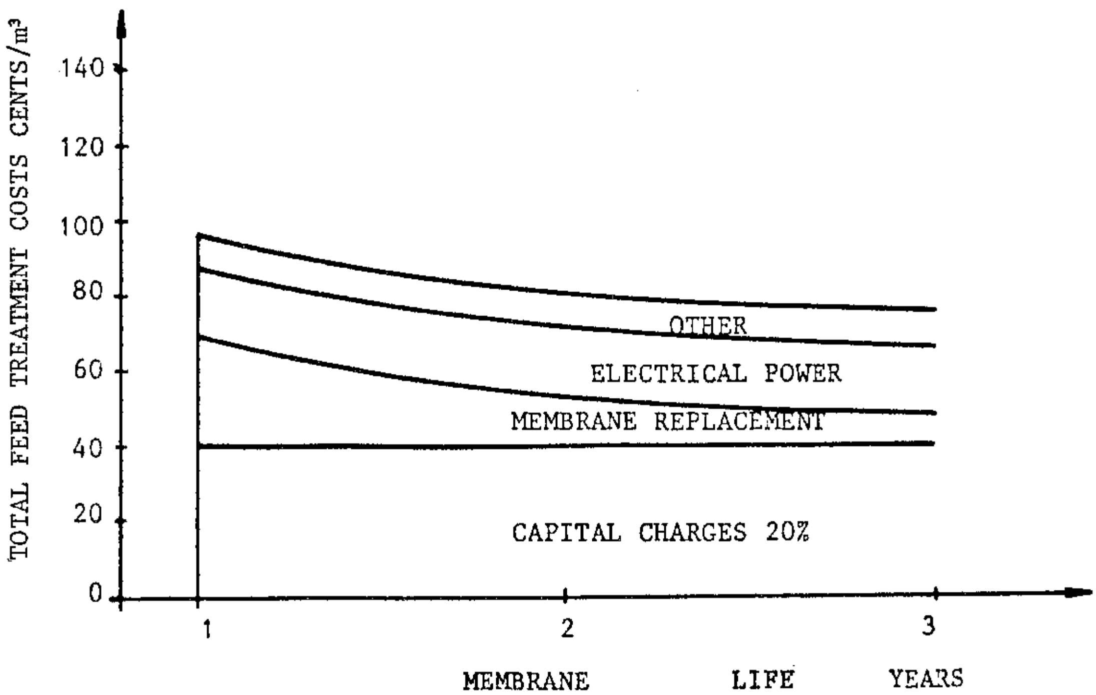




Appendix 1.5(b)

DAF costs for treating 650 kl/d abattoir effluent
(Running time : 24 h/d, 5 d/wk, 4 wk/mth, 12 mth/a)

COST	RATE/COMMENT	AMOUNT
Capital Costs		
Screens	@ R15/kl/d	9 750
DAF plant	@ R95/kl/d	62 000
Civil engineering		20 000
Sludge handling		60 000
Balancing tank	@ 300 kl	30 000
Total capital costs	R/a	181 750
Running Costs		
Capital charges	@ 30% Interest & redemption	54 525
Maintenance	@ 10% Capital cost	18 175
Operators	@ R2 000/mth	24 000
Electricity	@ 4cts/kWh & 70 kW	16 130
		112 830

Chemical costs	Treatment type:	HMP+Acid	$FeCl_3$+Lime	LSA
HMP	@ 170 mg/l & 160 R/t	4 243	-	-
Acid	@ 400 mg/l & 156 R/t	9 734	-	9 734
Lime	@ 400 mg/l & 73 R/t	4 555	4 555	4 555
$FeCl_3$	@ 300 mg/l & 103 R/t		4 820	
LSA	@ 500 mg/l & 115 R/t			8 970
		18 532	9 375	23 259
Total running costs	R/a	131 362	122 205	136 089
Less sludge value	@ 700 kg/d & 35cts/kg	58 800	-	58 800
Net running costs	R/a	72 562	122 205	77 289
Treated water costs	R/kl (156 000 kl/a)	0.46	0.78	0.49
Add water costs	R/kl	0.30	0.30	0.30
Add effluent disposal costs	R/kl	0.30	0.30	0.30
Overall Costs	R/kl	1.06	1.38	1.09

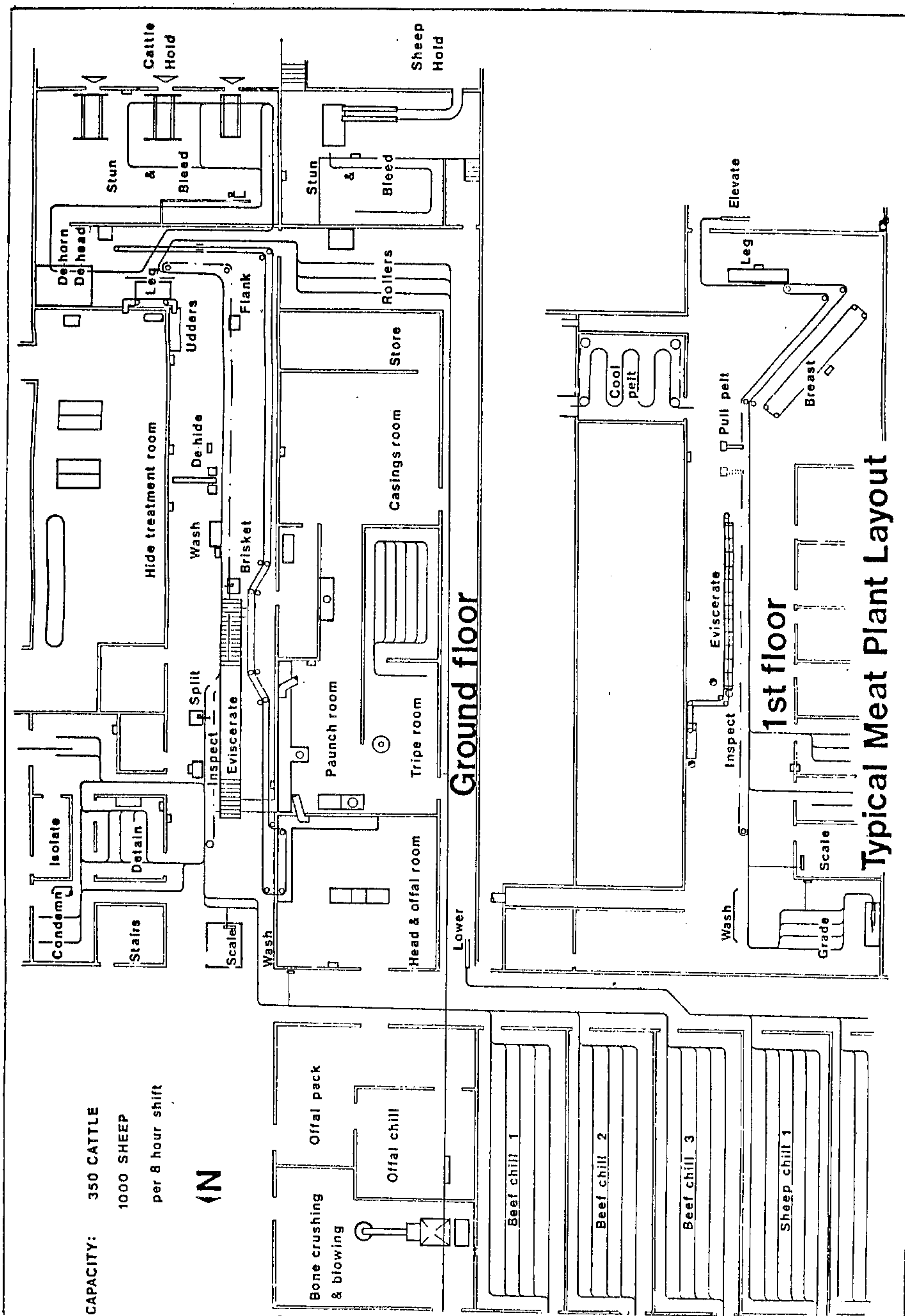
Appendix 1.6

Tubular RO costs for treating 650 m^3/d abattoir effluent
(Running time : 24 h/d, 5 d/wk, 4 wk/mth, 12 mth/a)

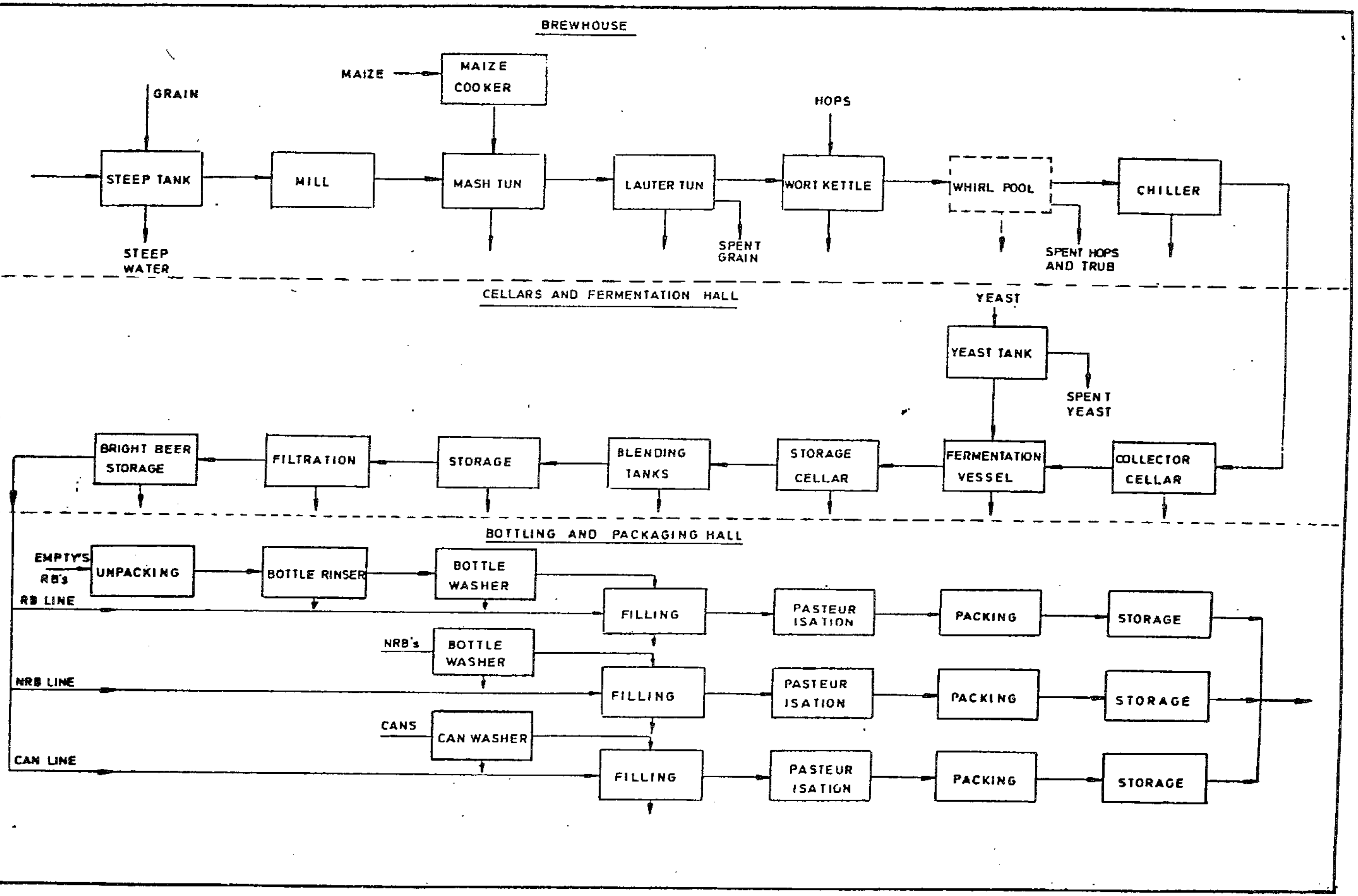
COST	RATE/COMMENT	AMOUNT
Capital Costs		
Screens	@ R15/kl/d	9 750
Tubular RO plant	190 modules @ R4 400/module	836 000
Civil engineering		10 000
Sludge handling		60 000
Balancing tank	@ 300 kl	30 000
Total capital costs	R/a	945 750
Running Costs		
Capital charges	@ 30% Interest & redemption	283 725
Maintenance	@ 10% Capital cost	94 575
Operators	@ R2 000/mth	24 000
Electricity	@ 4cts/kWh & 10kWh/m^3	62 400
Chemicals	@ 2kl/d 0,1% NaOH for cleaning	10 000
Total running costs	R/a	474 700
Less sludge value	@ 1 200 kg/d & 35cts/kg	100 800
Net running costs	R/a	373 900
Treated water costs	R/kl (156 000 kl/a)	2.40
Add membrane costs	Replacement @ 20 cts/kl	0.20
Overall Costs	R/kl	2.60

DAF and Spiral RO costs for treating 650 m^3/d abattoir effluent
(Running time : 24 h/d, 5 d/wk, 4 wk/mth, 12 mth/a.)

COST	RATE/COMMENT	AMOUNT
Capital Costs		
Screens + DAF	See Appendix 1.6	181 750
Spiral RO plant		280 000
Total capital costs	R/a	461 750
Running Costs		
Capital charges	@ 30% Interest & redemption	138 525
Maintenance : DAF	@ 10% Capital cost	18 175
: RO	@ 10% Capital cost	28 000
Operators	@ R4 000/mth	48 000
Electricity : DAF	@ 4cts/kWh & 70 kW	16 130
: RO	@ 4cts/kWh & 70 kWh/m^3	43 680
Chemicals : DAF	HMP + Acid : see Appendix 1.6	18 532
: RO	@ 2kl/d 0,1% NaOH for cleaning	10 000
Total running costs	R/a	321 042
Less sludge value	@ 1 200 kg/d & 35cts/kg	100 800
Net running costs	R/a	220 242
Treated water costs	R/kl (156 000 kl/a)	1.41
Overall Costs	R/kl	1.41


Typical Meat Plant Layout
Ground floor
1st floor
CAPACITY: 350 CATTLE
1000 SHEEP
per 8 hour shift
N
Cattle Hold
Sheep Hold
Stun & Bleed
Stun & Bleed
Dehorn
Dehead
Leg
Udders
Flank
Rollers
Store
Hide treatment room
De-hide
Wash
Brisket
Casings room
Split
Inspect
Eviscerate
Paunch room
Tripe room
Isolate
Detain
Condemn
Stairs
Scale
Wash
Head & offal room
Lower
Offal pack
Offal chill
Bone crushing & blowing
Beef chill 1
Beef chill 2
Beef chill 3
Sheep chill 1
Elevate
Leg
Cool pelt
Pull pelt
Breast
Eviscerate
Inspect
Scale
Wash
Grade

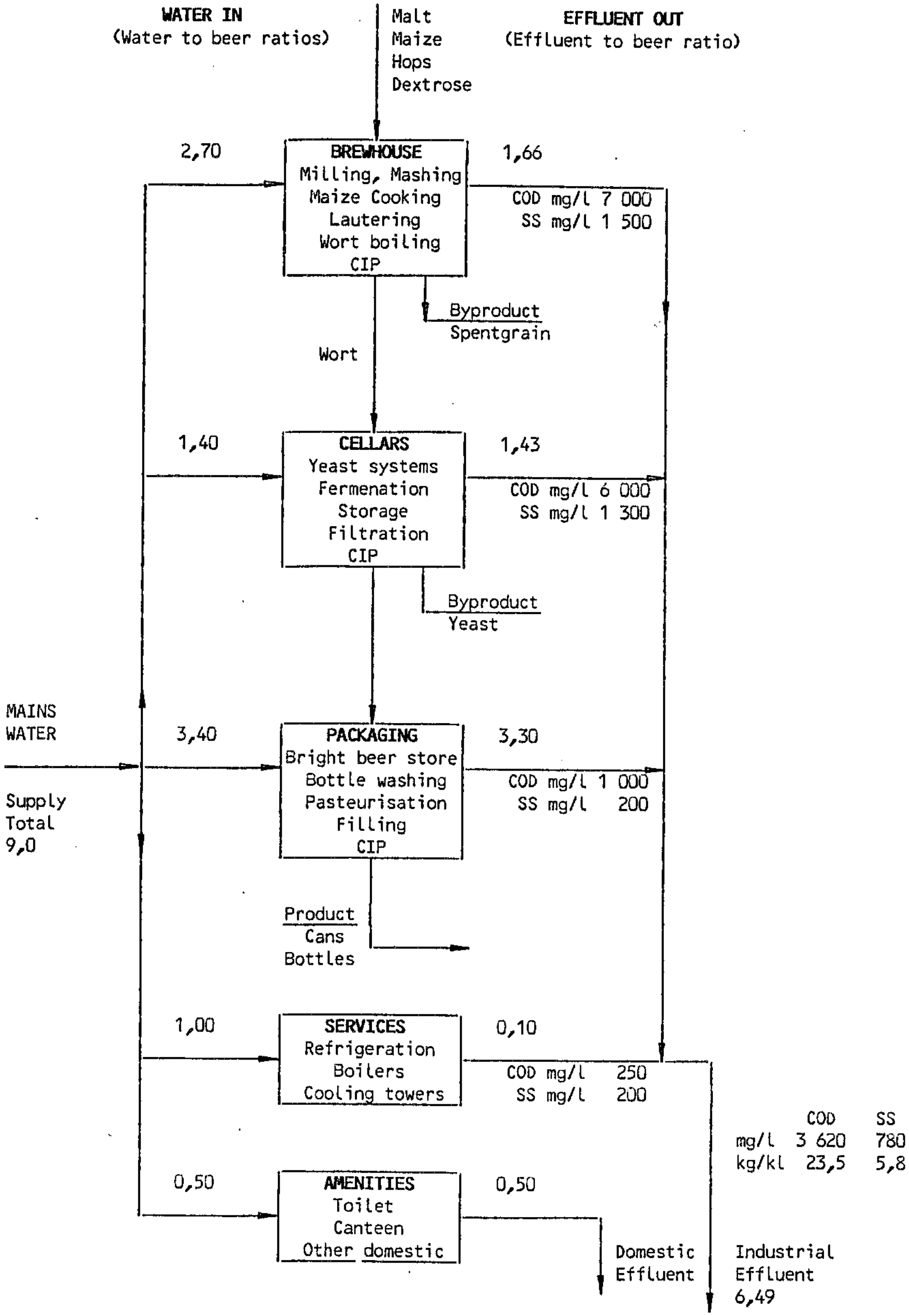
Appendix 1.9



Typical barley brewery layout

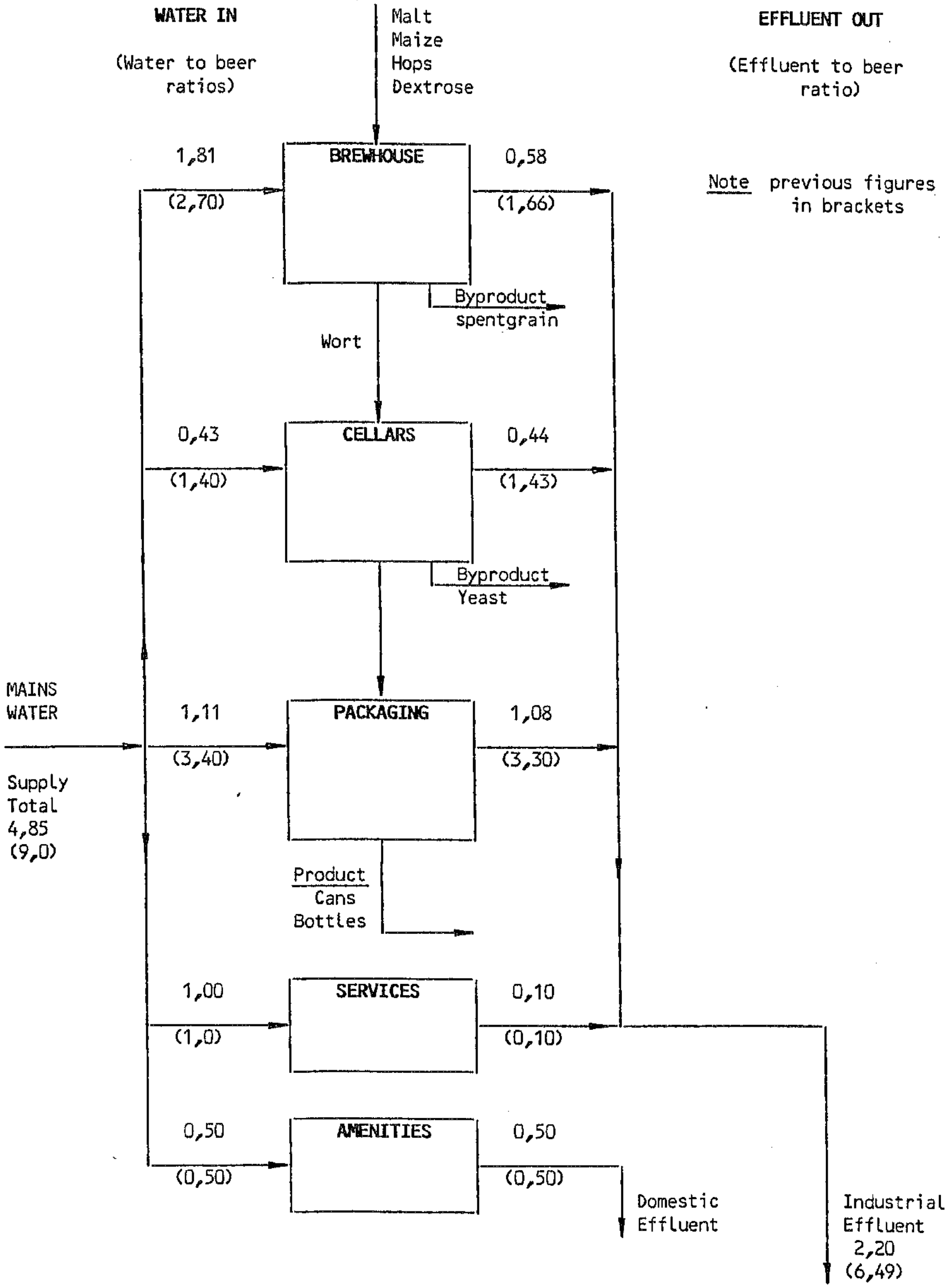
BARLEY BREWERY WATER DISTRIBUTION

BEFORE WATER ECONOMY

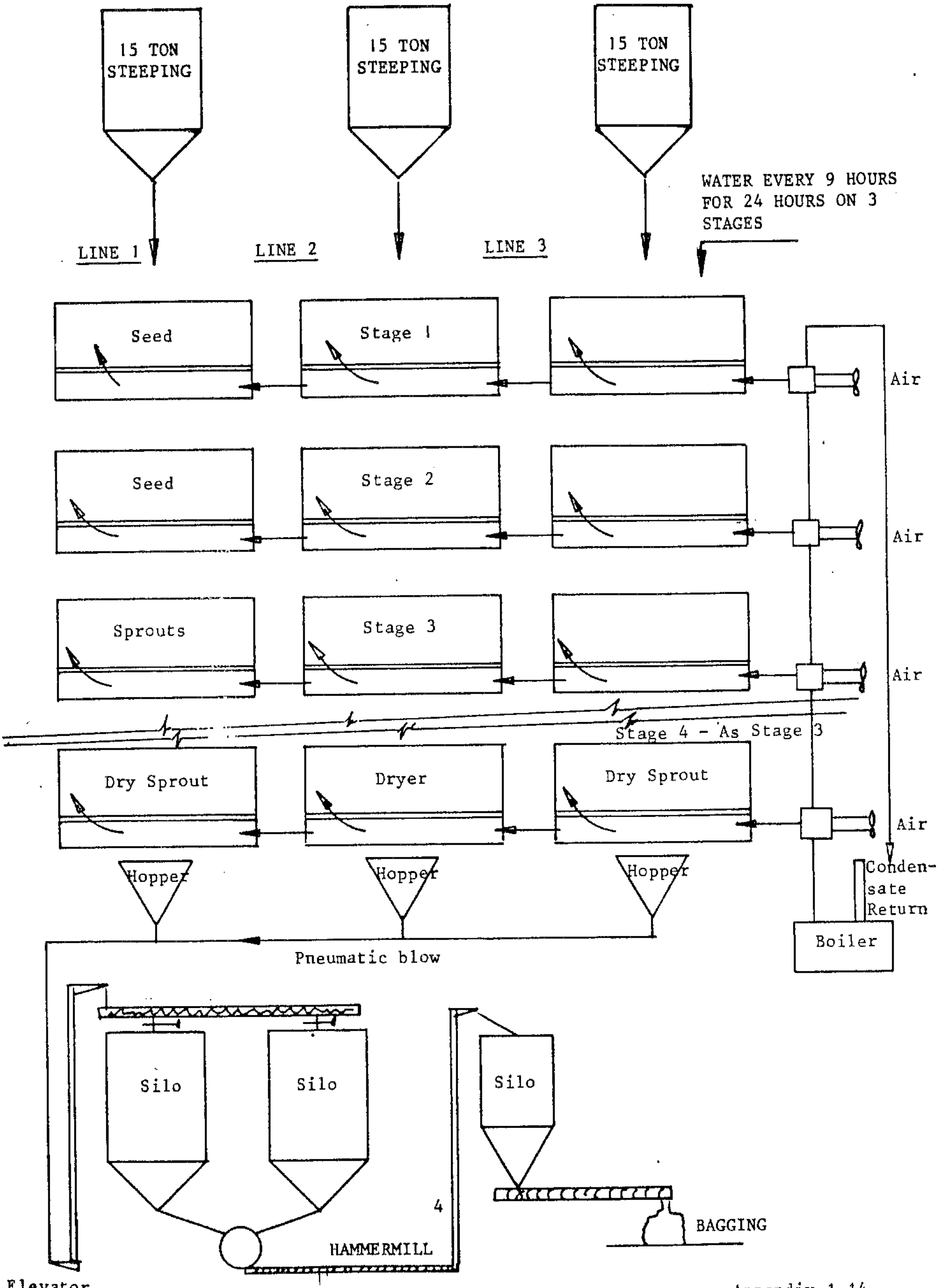


Appendix 1.12

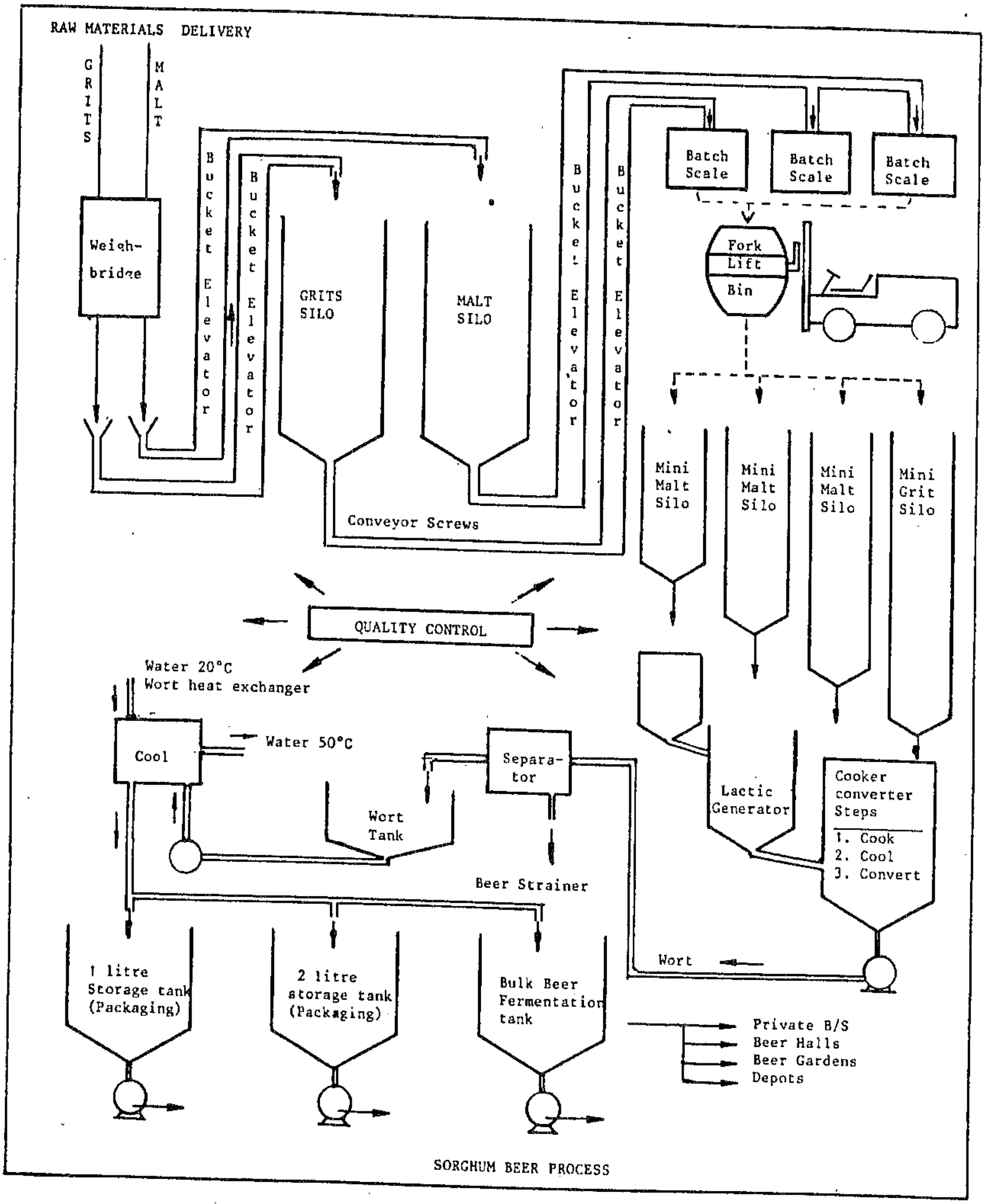
BARLEY BREWERY WATER DISTRIBUTION AFTER WATER ECONOMY



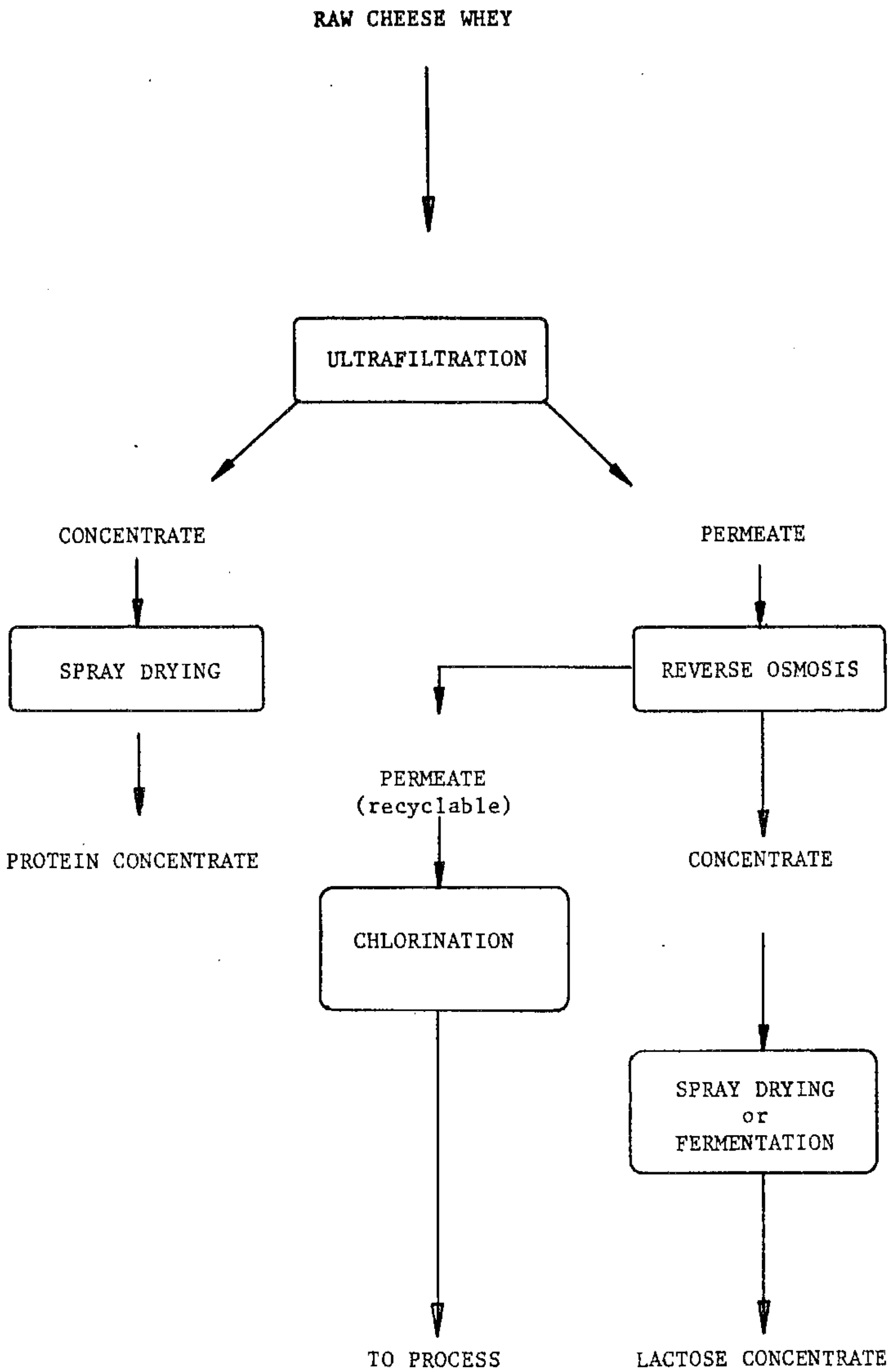
Appendix 1.13


15 TON STEEPING
15 TON STEEPING
15 TON STEEPING
WATER EVERY 9 HOURS FOR 24 HOURS ON 3 STAGES
LINE 1
LINE 2
LINE 3
Seed
Stage 1
Air
Seed
Stage 2
Air
Sprouts
Stage 3
Air
Stage 4 - As Stage 3
Dry Sprout
Dryer
Dry Sprout
Air
Hopper
Hopper
Hopper
Condensate Return
Boiler
Pneumatic blow
Silo
Silo
Silo
4
BAGGING
HAMMERMILL
Elevator

Typical sorghum brewery layout

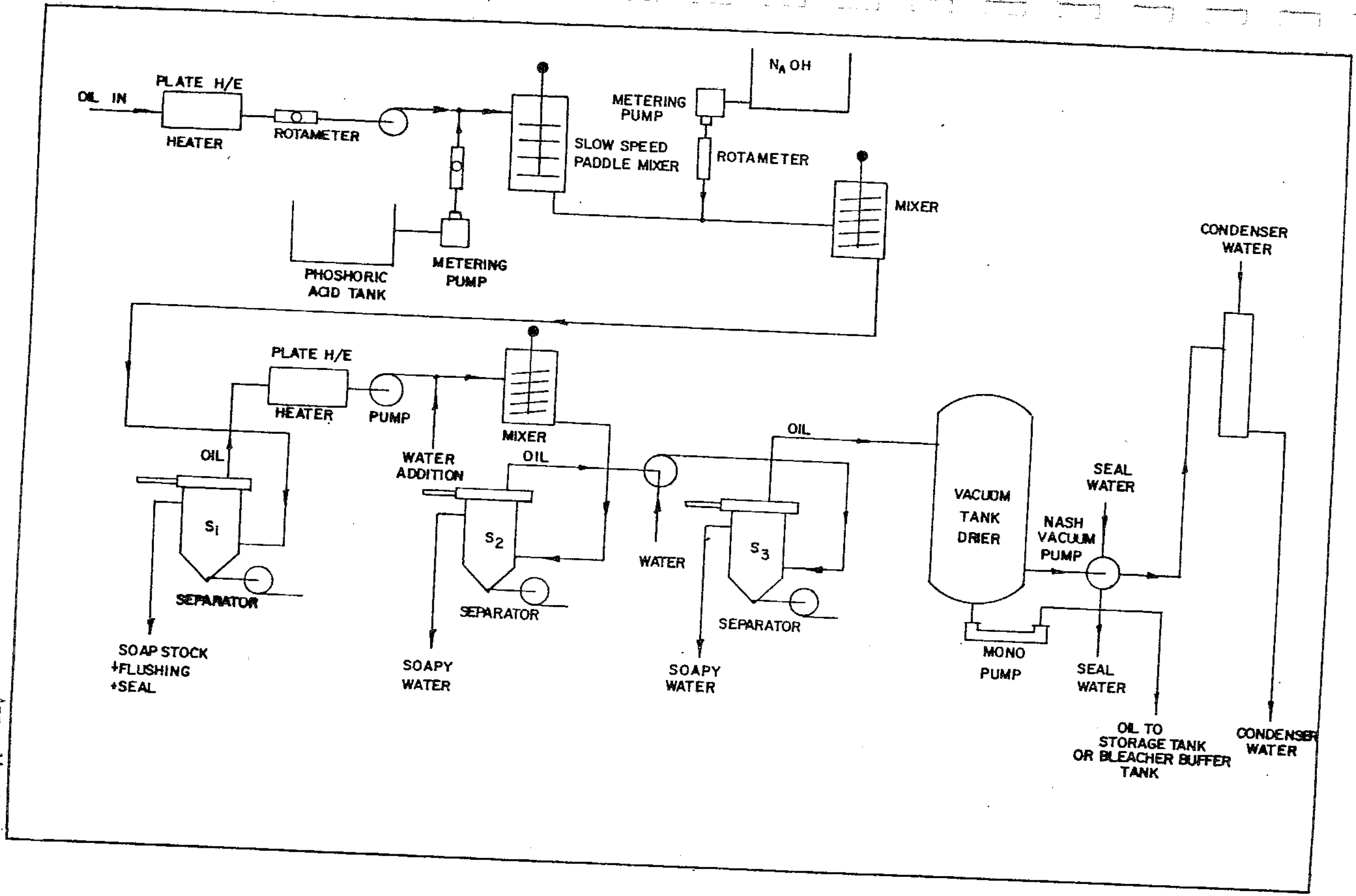


Appendix 1.15



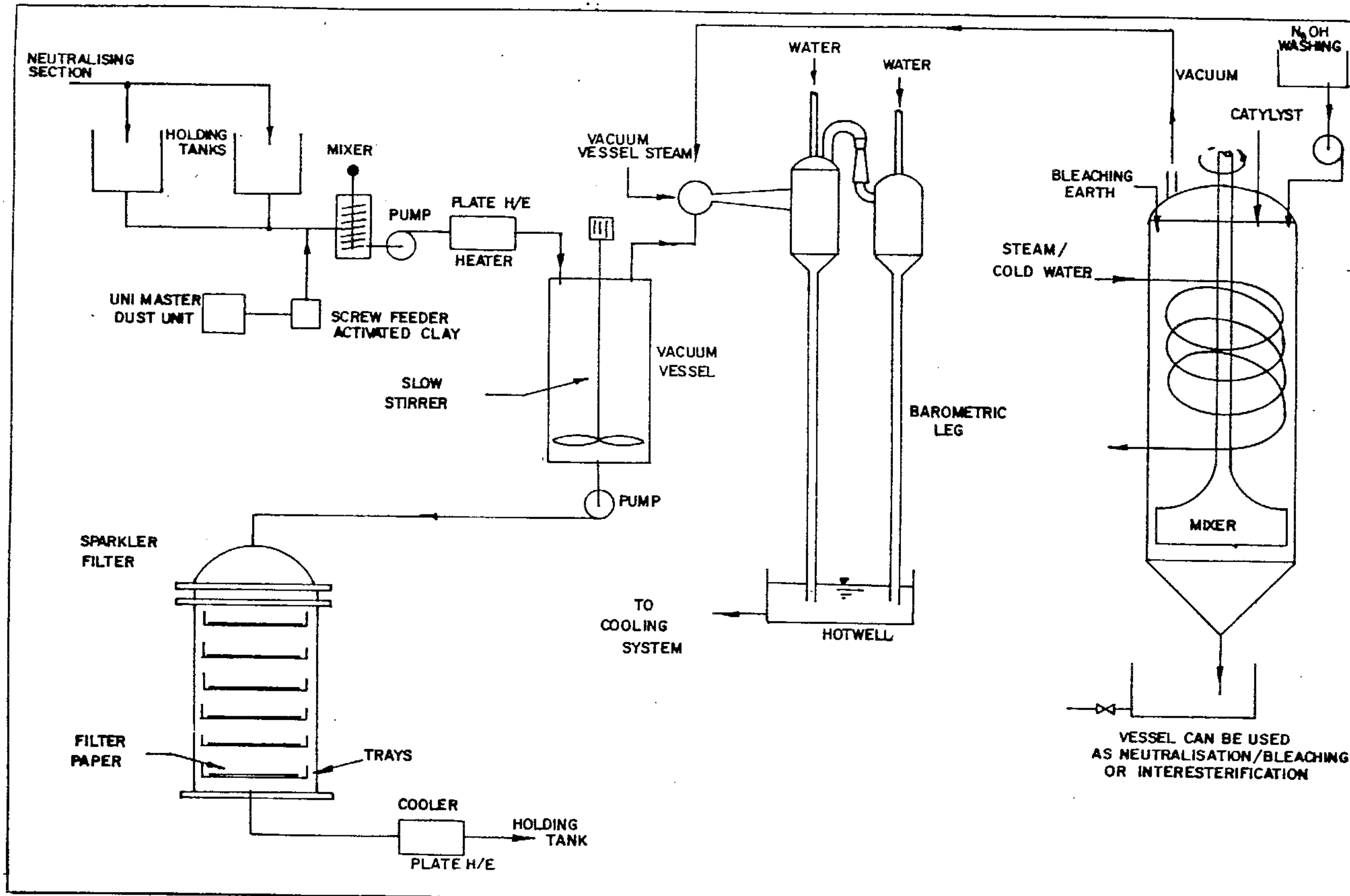
FRACTIONATION OF CHEESE
WHEY BY MEMBRANE PROCESSES

Appendix 1.16



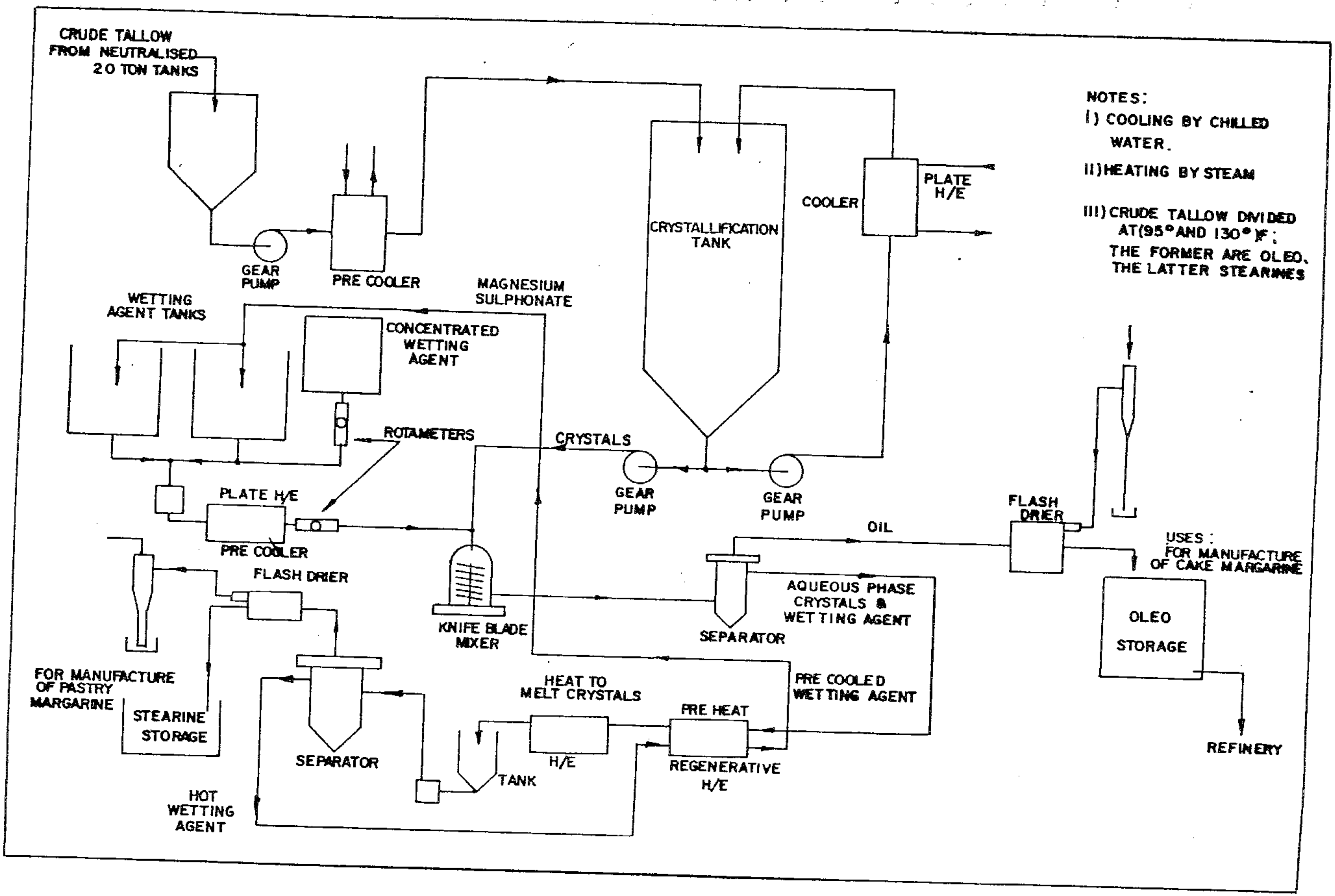
Vegetable Oil Refining
Degumming & Neutralization

Appendix 1.17



Vegetable Oil Refining
Bleaching

Appendix 1.18



Vegetable Oil Fractionation

Appendix 1.19

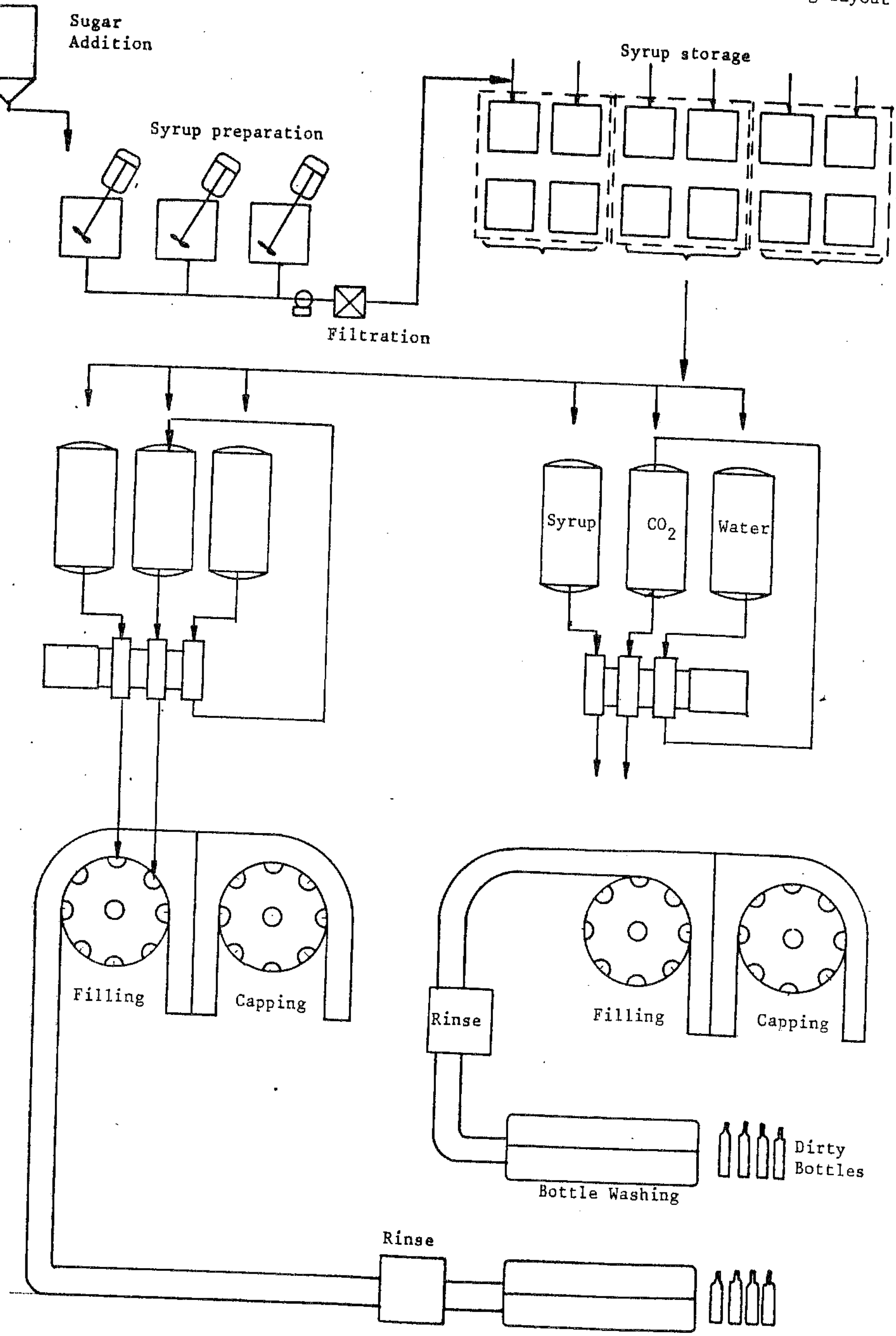
MARGARINE PLANT- TYPICAL EFFLUENT ANALYSIS

Effluent Description	SS mg/l	BOD mg/l	COD mg/l	TOC mg/l	Kjeldahl-N mg/l	SO_4 mg/l	Fatty Matter Total mg/l	Fatty Matter Emul mg/l
Soapy water	-	670	1570	-	-	-	730	90
Soapy water	130	1600	2400	-	-	500	310	310
Soapy water	-	2300	3470	-	3,2	750	1800	1800
Deodoriser Effluent	-	560	3200	1150	-	-	1230	130
Deodoriser Effluent	100	450	1060	-	1	-	230	50
Boiler house sump	-	60	470	-	-	33	170	14
Acid water	-	1100	4080	-	-	-	777	97
Acid water	-	2300	3600	-	-	37500	360	210
Acid water	-	4000	7100	-	37	41250	358	38
Acid water	-	1800	2200	710	1	47500	158	130
Final Effluent *	-	300	1410	-	7,6	-	210	80
Final Effluent *	-	4800	9550	3500	2,6	150	2800	1600
Final Effluent *	420	1400	2080	720	1	100	2570	320
Final Effluent *	2400	5400	7800	2900	1	100	2800	1100
Final Effluent **	1040	2000	2830	1000	12	4500	690	170

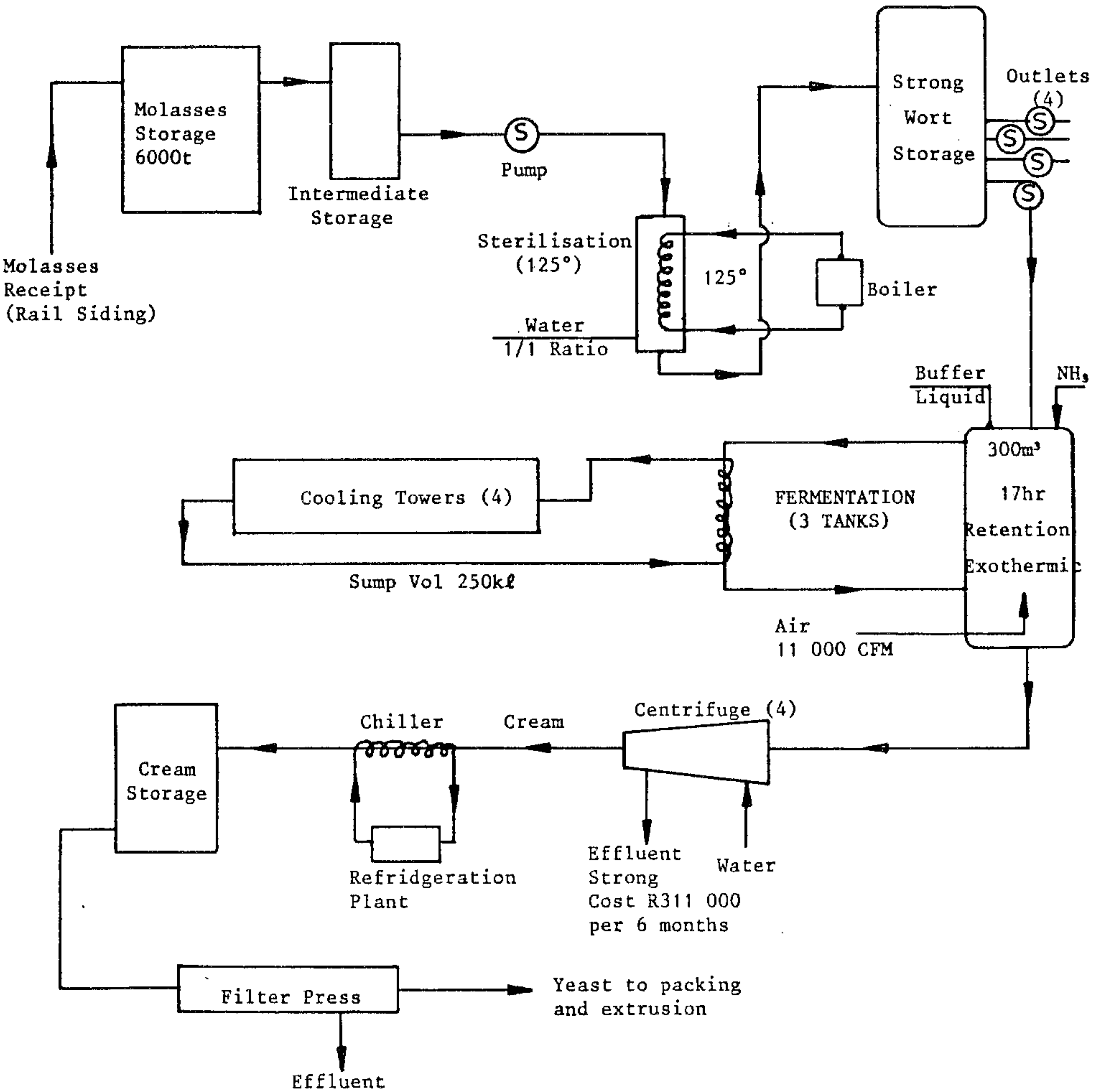
* Excluding neutralised acid water
** Including neutralised acid water

Appendix 1.20

Typical soft drink manufacturing layout



TYPICAL YEAST PROCESSING LAYOUT



APPENDIX 2

A REVIEW OF METHODS FOR PROTEIN AND LACTOSE RECOVERY FROM CHEESE WHEY

Binnie & Partners
LONDON
April 1980

CONTENTS

1.0 INTRODUCTION

About 13 per cent of the milk produced in the UK is made into hard or semi-hard cheese. A bacterial starter is added to the raw milk and as acidity develops, rennet is added to assist the formation of the curd. The curd is recovered, leaving the whey which has a very high pollution potential. The whey contains a proportion of all the major components of the raw milk as shown in Table 1.

Table 1. Composition of milk, cheese and whey

	Protein g/kg	Fat g/kg	Carbohydrate, mono-saccharide g/kg	Calcium g/kg	Phosphate as PO_4 g/kg	Non-protein nitrogen compounds g/kg
Milk, whole	30	33	44	1,1	8	
Cheese, cheddar	253	345	0	8,1		
Whey	9	3	49	0,4	8	2,6

Depending on the method of recovery, a mixture of the whey protein (or lactoalbumen) and the lactose (which comprises the majority of the carbohydrate) may be used as animal feed or baby feed. Pure lactose has only limited industrial applications. Lactoalbumen, on the other hand displays properties very similar to egg albumen, and if obtained in substantially pure form could be equally valuable (7).

2.0 METHODS OF BY-PRODUCT RECOVERY

2.1 RECOVERY BY EVAPORATION

Ashworth and Forbes (1) describe a variety of conventional recovery methods. For example whey may be concentrated 8 to 10 times and lactose recovered by crystallisation. The quantity of whey processed in this manner is limited by the modest industrial demand for lactose.

Alternatively whey may be evaporated and then roller or spray-dried to give whole whey solids. The high mineral content of this product limits the quantities which can be fed to livestock.

However the whey may be demineralised by electrodialysis and then dried at low temperatures to give a high purity lactose/protein product. The main and limited use for this product is in babyfoods.

2.2 RECOVERY BY PHYSICAL NON-EVAPORATIVE METHODS

In order to recover the potentially valuable lactoalbumen in an undenatured and purified form, Ashworth and Forbes advocate the use of ultrafiltration. Test work indicated that an ultrafiltration concentrate contained as much as 21.6% protein but only 5,95% lactose, 1.0% minerals and 0,42% non-proteinaceous nitrogen compounds.

Borne (2) cites the use of ultrafiltration to concentrate the protein content followed by reverse-osmosis of the ultrafiltration permeate to concentrate the lactose content. Lactose could then be removed from the concentrate by crystallisation. Borne also cites a method for the recovery of a denatured protein by submitting the whey to heat treatment at near boiling point and pH reduction, which results in the precipitation of the protein.

Grant (4) and Palmer (7) describe two ion exchange processes using cellulose based ion exchange resins to absorb large protein molecules from solution. It is claimed that high quality lactoalbumen can be recovered by this means, with a value similar to that of egg albumen. The main disadvantage of this approach is the relatively high capital cost of the ion exchange plant and the solids/fat removal facilities. Grant's test work which was carried out in New Zealand was concerned with the recovery of animal albumen. It is noteworthy that the Meat Industry Research Institute of New Zealand is now developing the use of sodium hexametaphosphate (HMP) for the recovery of abattoir effluent proteins.

2.3 PROTEIN RECOVERY BY CHEMICAL PRECIPITATION

From a review of the literature it is observed that polyphosphates have been used on a number of occasions for the precipitation of dissolved proteins at ambient temperatures. Work at Binnie & Partners London Laboratory shows that egg albumen can be precipitated from solution by HMP at a low pH, yielding a complex having a protein:HMP ratio of approximately 7:1. Finley et al (3) used a variety of polyphosphates successfully, especially HMP, to precipitate protein from gluten-washing effluents. Ferripolyphosphates, produced by the reaction of ferric chloride with Calgon (HMP), were used by Mather and Srinivasan (6) to precipitate protein from wheys at low pH. The resulting precipitate, after purification by dialysis, contained 53% protein, 13% iron and 22% phosphorous (or 56% metaphosphate). This composition was claimed to be useful as an animal feed of high assimilability.

Work carried out in our laboratories showed that 3 g HMP was required to precipitate 7,6 g protein. By stoichiometric calculation this precipitate will likely contain 78% protein, 18% phosphate and 4% calcium. (The calcium having been initially present in the whey.) The phosphate requirements and levels compare favourably with the ferripolyphosphate.

The ferripolyphosphate and HMP precipitated proteins could be used for animal feed. However the full value of lactoalbumen can be realised only if the albumen is isolated in a fairly pure form. In their work on sarcoplasmic-fish-protein precipitation, Spinelli and Kowry (8), found that sodium tri-and tetrametaphosphate precipitated protein contained only one third of the phosphates contained in HMP precipitated protein. The authors pointed to previous work where blood plasma precipitated in the presence of tetrametaphosphate contained no bound phosphates.

If the above is also the case for lactoalbumen, then an economic method for the production of high quality lactoalbumen would be avilable. Calcium also would be precipitated by tetrametaphosphate and therefore would have to be removed in a pretreatment ion exchange stage, using conventional styrene based resins or by electrodialysis. The deproteinised liquor would comprise mainly lactose together with smaller concentrations of sodium and acid phosphates and some non proteinaceous nitrogen compounds. The lactose could be crystallised out and the mother liquor recycled so reducing polyphosphate costs. It would be necessary to include a periodic blow down although this would have to be kept to a minimum having regard to the cost of tetrametaphosphate which is approximately three times that of HMP. The viability of this process would have to be checked by laboratory experiments.

3.0 PRECIPITATION OF WHEY PROTEINS BY SODIUM HEXAMETAPHOSPHATE

3.1 INTRODUCTION

It has not been possible to establish from the literature whether polyphosphates alone have been used as whey protein precipitating agents. However, it was established that both HMP and tetrametaphosphate (tetraMP) were considered suitable. Furthermore it was considered that tetraMP, though less efficient and costlier than the HMP, could possibly yield a pure lactoalbumen. Experimental work however would be necessary to test the reaction of those reagents on the whey.

At this stage we have restricted our experimental work to the use of HMP.

3.2 WHEY PREPARATION

Curds are normally precipitated from raw milk by lactic acid, which is a product of bacterial action on lactose. It is principally the reduction in pH which is responsible for the precipitation and it was by this means that whey was produced in the laboratory using 500 ml samples of pasteurised milk and adding sufficient hydrochloric acid to atain pH 3. The curds were separated by centrifuging and the whey poured off.

3.3 DISCUSSION OF RESULTS

50 ml aliquots of whey were dosed with HMP. The resulting white precipitate was separated from the liquor by gravity filtration through 0,45 micron millipore filters. Vacuum filtration could not be used as this resulted in a cloudy filtrate.

Protein removal was assessed by ultra violet absorption at 190 nm. Protein concentration was assessed as Kjeldahl N x 6,25 allowing for 2,6 g/l of non-proteinaceous nitrogen organic compounds. Polyphosphates and orthophosphates were assessed using stannic chloride method as described in "Standard Methods". The results of this experiment are shown in Tables 3.1 and 3.2 overleaf.

Table 3.1. Reduction in protein by HMP dosing

HMP dose g/l	Absorbance (Total)	Absorbance protein	Reduction %
0 unfiltered	599	572	
0 filtered	247.6	221	0
2	117.6	90.9	59
3	64	37.3	83
4	29.6	2.9	98.7
5	26.7	0.0	100

Table 3.2. Phosphates and protein in solution

HMP dose g/l	PO_4 in solution g/l	Kjeldahl N g/l	N x 6.25 total g/l	Protein (Nx6.25-2.6) g/l	Reduction in Protein %
0 filtered	7.93	1.68	10.5	7.9(9)	0
2	9.15				
3	9.15	0.466	2.9	0.3(1.4)	96(84)

The protein content of the filtered whey indicated in Table 3.2 fits well with the protein content of whey given in Table 1.1. The protein content of the 3g/l HMP dosed liquor is far less than inferred by the solutions absorbance. If the non-proteinaceous nitrogen compounds content ratio is reduced from 2.6 to 1.5 g/l, then the protein content in the raw filtered whey is increased to 9 g/l and to 1.4 g/l in the HMP treated liquor. Thus a 3 g/l HMP dose reduced the protein content by 84% which is in agreement with the removal precentage indicated by the absorbance results.

In the calculations it has been assumed that the concentration of non-proteinaceous nitrogen compounds is N x 6.25 g/l. This is not necessarily the case since if the ratio of nitrogen : total molecular mass is less than 1:6.25 then the concentration measured as N x 6.25 would be numerically less than the 2.6 g/l quoted in the literature. Lipids and amino-sugars for example, have nitrogen:total molecular mass ratios less than 1:6.25.

The necessary HMP dose of 0.4 g HMP/g protein is far greater than the required HMP dose for egg albumen. This difference could be a property of the lactoalbumen, or could be due to interference by other compounds in the whey. One possible cause of this difference could be the calcium content of the whey which would have a metaphosphate uptake of 2.02 g, measured as sodium HMP. 98% protein precipitation requires an HMP dose of 4 g/l. Should 2 g/l of this HMP be taken up by the calcium, then 2 g/l is all that is necessary for the precipitation of protein i.e. a dose of 0.22 HMP/g protein precipitated. If this is the case, then the HMP dose rates required for egg albumen and lactoalbumen precipitation are similar. Further experimental work is necessary to prove the above projections.

3.4 HYPOTHETICAL WHEY PROTEIN PRECIPITATION PROCESSES

3.4.1 Straight HMP addition

For an animal feed grade protein, HMP could be added to acidified raw whey. A dose of 400 g HMP/kg protein would be required and the final produce would contain lactoalbumen, calcium and metaphosphates.

3.4.2 Protein precipitation from calcium free whey

Calcium could be removed from the whey by adding metaphosphate to the whey at a neutral pH, or by ion exchange or by electrodialysis. The pH could then be reduced and the protein precipitated by HMP, the final product consisting of lactoalbumen and approximately 15% bound HMP. A further stage of treatment could possibly be used to reduce the HMP contamination levels.

Alternatively, the calcium free whey could be treated with tetraMP to yield a high quality lactoalbumen with significantly lower levels of bound phosphate.

4.0 COST COMPARISON OF ANIMAL FEED GRADE PROTEIN PRODUCTION BY ULTRAFILTRATION BY HEXAMETAPHOSPHATE ADDITION

4.1 ULTRAFILTRATION

A protein enriched animal whey feed could be manufactured by concentrating the protein in whey on ultrafiltration membranes followed by drying. The ultrafiltration concentrate would contain approximately 15% protein, 5% lactose and 1% minerals.

Ashworth and Forbes (1) demonstrated that whey protein could be concentrated to 21% by ultrafiltration. The rate of fall of flux rate from low protein content to 21% protein content was more or less linear with respect to protein concentration. Therefore for an economic analysis it was assumed that 15% protein is the limit to economic ultrafiltration performance.

For a plant to treat 100 m^3/d of whey containing 0.8% protein and assuming two stage treatment, 260 m^2 of membrane area (quoted water flux rate 40 l/m^2h) will be required. If membranes of the type T6/B PCI tubular design are used, operating at 4 Bar, 60 kW are required for pressurisation and concentrate recycle purposes. An automated plant of this type would cost in the region of £240 000. Annual power and membrane renewal costs would be £15 000 and £40 000 respectively. In addition, a drying plant capable of dewatering the precipitated sludge from a moisture content of 85% to 50% would cost in the order of £20 000 and would require approximately 150 kW of low grade power, at a cost of approximately £20 000 p.a. Allowing for a 5 year pay back period, Table 4.1 demonstrates that protein production costs would be approximately £538/tonne.

Table 4.1 Cost of enriched whey protein recovery by ultrafiltration - 5 year pay back period

Costs annual		Concentration Stage	Drying stage	Combined
(Capital	£)	(240 000)	(20 000)	(260 000)
Capital payback	£			52 000
Mean annual interest,	£			25 558
Power,	£	15 000	20 000	35 000
Maintenance,	£	40 000	1 000	41 000
Labour,	£			16 000
Total annual outgoings,	£			169 558
(Wt protein recovered, tonne)				(315)
Cost protein £/tonne				538

4.2 PRECIPITATION WITH HMP

Whey protein contaminated by HMP should be suitable as an animal feed. The solids would contain approximately 78% protein and 18% metaphosphates.

After precipitation, solids separation would best be achieved using dissolved air flotation, lime addition followed by sedimentation being used to precipitate excess metaphosphate. The capital costs for the DAF and a phosphate reduction clarifier would be approximately £30 000. Power costs should be in the region of £1000 p.a. The cost of food grade HMP and lime would be in the order of £82 200 p.a.

Table 4.2 Cost of whey protein recovery by precipitation with HMP - 5 year pay back period

Costs annual		Concentration Stage	Drying stage	Combined
(Capital	£,)	(30 000)	(20 000)	(50 000)
Capital payback	£			10 000
Mean annual interest,	£			4 915
Power,	£	1 000	20 000	21 000
Chemicals,	£	82 200		82 200
Maintenance,	£	1 000	1 000	2 000
Labour,	£			16 000
Total annual outgoings,	£			136 115
(Wt protein recovered, tonne)				(315)
Cost protein £/tonne				432

The economics of protein recovery by addition of HMP compare very favourably with the economics by ultrafiltration. Furthermore, having regard to the possible extension of the polyphosphate method previously described, Section 2.3 refers, a product of significantly higher value might be obtained. The process merits further investigation.

4.3 LACTOSE RECOVERY BY REVERSE OSMOSIS

Table 4.3 summarises speculative costs for the reverse osmosis concentration of whey lactose, using PCI type tubular membranes and a drying process. The drying costs were taken pro rata from the protein recovery costs.

Table 4.3 Cost of lactose recovery by reverse osmosis

Costs annual		Concentration Stage	Drying stage	Combined
(Capital	£,)	(70 000)	(125 000)	(195 000)
Capital payback	£			39 000
Mean annual interest,	£			19 168
Power,	£	4 000	125 000	129 000
Maintenance,	£	10 000	5 000	15 000
Labour,	£			16 000
Total annual outgoings,	£			218 168
(Wt lactose recovered, tonne)				(1 969)
Cost lactose £/tonne				111

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