A GUIDE FOR THE PLANNING, DESIGN AND IMPLEMENTATION OF WASTE-WATER TREATMENT PLANTS IN THE TEXTILE INDUSTRY

PART 3 : CLOSED-LOOP TREATMENT / RECYCLE OPTIONS FOR TEXTILE SCOURING, BLEACHING AND MERCERISING EFFLUENTS

Prepared for the

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which was conducted by :

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FOREWORD

This third part of "A Guide for the Planning, Design and Implementation of Waste-water Treatment Plants in the Textile Industry - Closed-loop Treatment/Recycle Options for Textile Scouring, Bleaching and Mercerising Effluents", is I believe, the most critical phase of this guide. Scouring, bleaching and mercerising effluents are the most intractable of all effluents from the Textile Industry ; the high sodium ion concentration (from the use of caustic soda on which these processes rely), makes it impossible to be treated by conventional means and creates a high fresh water pollution risk, particularly where the textile factory is sited inland. The disposal of such an effluent by the use of evaporation ponds or irrigation, does not remove the pollution potential, and marine disposal has been viewed as the only safe solution.

Effluent disposal itself implies a wastage, a wastage of water and of valuable chemicals that may be contained in that effluent. The recycling or recovery of chemicals from the effluent streams not only reduces the pollution risk, but also recovers costly raw materials for the Textile Industry.

In the first part of the guide, "Closed-loop Treatment/Recycle Systems for Textile Sizing/Desizing Effluents" it was shown how textile sizing chemicals could be recovered and reused thereby saving one of the major cost items in textile processing. In a vertical plant (spinning, weaving, dyeing, printing and finishing), this could represent 15 % of total dyes and chemical cost. Recovering size and removing it from the desize effluent stream, also removes the main contributor to the COD load in that effluent.

Sodium hydroxide is becoming an expensive basic chemical and can represent approximately 7,0 % of the total dyes and chemical costs. This third part of the guide shows how a major portion of the cost can be saved or recovered.

The second part - "Effluent Treatment/Water Recycle Systems for Textile Dyeing and Printing Effluents", showed how, by recycling and reclamation, reduction in the use of another scarce and valuable commodity, water, could be achieved. In the current guide, a major part is devoted to the reduction of the water used in the washing or rinsing process. The reduction of specific water consumption increases the concentration of the chemicals contained in that water and hence facilitates the recovery of these chemicals or treatment of the effluent.

The philosophy of meeting effluent disposal parameters by dilution of the effluent is one that is becoming less acceptable - the total pollution load is not reduced and more fresh water is wasted. The opposite is becoming the *modus operandi* where specific effluent streams are being concentration and polluting chemicals are either being recovered from these streams, or treated to remove the pollution load at source

The high capital equipment and operational costs of "hi-tech" treatment plants - ultrafiltration, hyperfiltration and electrochemical as described in the three guides, can be motivated by a return on the costs of chemicals and water which can be recovered. In-house effluent management and process control systems can reduce the effluent volumes requiring treatment and therefore reduce the required size of plant, making the treatment/recovery more feasible.

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These research and development investigations were guided by a steering committee for the project which comprised over the period of the project the following members :

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SUMMARY

This guide is intended primarily to assist the textile industry to utilise, reduce and otherwise dispose of their effluents, with particular reference to scouring, bleaching and mercerising effluents. The Guide provides the necessary information for the planning, design and implementation of various options for the treatment and/or recycle of textile scouring and bleaching effluents, in particular strong caustic scouring effluents. It will also be of value to the policy makers of the textile industry and to assist practically design engineers, consultants and executive bodies.

Adequate treatment of industrial waste waters is essential in order to preserve water quality and to achieve optimal use of the Republic of South Africa's limited water resources. Scouring and bleaching effluents produced during textile processing are typical of a non-biodegradable mineral salt-rich waste water, the control of which is of prime importance to the authorities.

Recognising the need for the development of general treatment methods for textile waste waters of the type described, the Water Research Commission contracted the Pollution Research Group at the University of Natal to investigate various process options which would enable the recycle and reuse of water, chemicals and/or energy from scouring and bleaching wastes.

The project consisted of several task areas :

(i) the characterisation of scouring and bleaching effluents from the processing of cotton, polyester and their blends, either in the form of stock or woven or knitted,

(ii) the development of possible treatment options for each type of effluent concerned,

(iii) laboratory and pilot-scale assessment of the systems,

(iv) the development of the basic design criteria for the implementation and installation of selected systems.

It is considered preferable to install productive equipment and systems within the factory to prevent or reduce the unnecessary loss of energy, water and chemicals, thus producing more consistent textile goods more effectively. At the same time the pollution load of the factory is reduced. The alternative would be the installation of non-productive effluent treatment equipment.

The basic procedure for ensuring proper water and chemical management within a factory is described. Examples of various factory surveys, which have resulted in significant chemical, water and energy savings, together with reduced effluent discharge costs, are cited. The emphasis in this section is placed on the utilization of minimum amounts of water and chemicals without sacrificing the quality of the end product. In this way effluents are produced at maximum concentration in minimum volumes.

The remainder of the Guide discusses the results of the following laboratory and pilot-scale investigations :

(i) low-temperature conventional ultrafiltration of weak polyester and polyester/cotton scouring effluents,

(ii) high-temperature dynamic ultrafiltration of weak cotton and polyester/cotton scouring effluents,

(iii) high-temperature dynamic ultrafiltration of strong cotton and polyester/cotton scouring effluents,

(iv) evaporation of strong cotton and polyester/cotton scouring effluents,

(v) electro-oxidation of strong cotton and polyester/cotton scouring effluents,

(vi) electrochemical recovery of chemicals, water and energy from strong cotton and polyester/cotton scouring effluents.

Strong caustic effluents produced during the scouring of cotton and cotton blends were identified as the most problematic of the effluents examined in terms of pollutant type and loading. For this reason investigations were primarily channelled into the development of technologies whose application would suitably alleviate discharge problems encountered with this class of textile scouring effluent.

The most effective solution to the strong caustic scouring effluent problem is an electrochemical system which enables the recovery and closed-loop recycle of sodium hydroxide, water and energy in the scouring process. The process sequence involves neutralisation of the effluent with acid gas, filtration through cross-flow microfiltration and nanofiltration membranes to remove suspended and soluble impurities and finally depletion of the sodium salt by an electrochemical membrane cell which generates :

(i) acid gas for recycling,

(ii) high quality sodium hydroxide of suitable concentration for direct reuse during scouring,

(iii) reusable wash water.

Good performance of the electrochemical unit is ensured by maintaining the conductivity of the effluent as high as possible. This is achieved by :

(i) implementation of an evaporative step to concentrate the effluent prior to treatment,

(ii) maintaining a background sodium concentration in the recycled wash water and recovering only the sodium from the effluent which has been washed from the cloth after scouring.

A detailed design of an electrochemically based treatment system has been presented. The design is based on data obtained during the operation of a pilot plant at a local textile mill. Fouling and scaling of the cross-flow microfiltration, nanofiltration and electrochemical membranes are minimal and reversible. A long anode coating life is predicted. Current efficiencies for the recovery of sodium hydroxide are 75 to 80 % and the electrical power requirements of the electrochemical unit are 3 000 to 4 000 kWh/t of 100 % NaOH. Evaporation pilot plant trials indicated that no scaling of the heat exchanger surfaces occurs during concentration of caustic scouring effluent.

A detailed economic analysis of the electrochemical recovery system is presented. The effects of washing variables, processing temperatures, background wash-water concentration and evaporator concentration factors on the plant size requirements and capital costs are determined.

The advantages of the recovery system applied to a strong caustic scouring line are that :

(i) water consumption is reduced by 85 to 95 %,

(ii) sodium hydroxide consumption during scouring is reduced by 65 to 75 %. Sodium hydroxide losses from the system include carry-over from the washer, losses in the centrate from the centrifuge after evaporation and losses in the filtration concentrates,

(iii) effluent production is minimised and pollutant loading of discharges with respect to inorganics, in particular sodium, is reduced,

(iv) the closed-loop recycle system provides for water savings, chemical savings, decrease in effluent discharge costs and energy savings.

Thus, the use of this technology at textile mills will have a significant impact on effluent discharge and will result in chemical and water savings.

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RSA - Republic of South Africa
Temp - Temperature
Cond - Conductivity
COD - Chemical oxygen demand
BOD - Biological oxygen demand
SS - Suspended solids
TDS - Total dissolved solids
TS - Total solids
ADMI - American Dye Manufacturers' Institute (colour units)
OA - Oxygen absorbed
TOC - Total organic carbon
TIC - Total inorganic carbon
ED - Electrodialysis
NF - Nanofiltration
UF - Ultrafiltration
CFMF - Cross-flow microfiltration
d.c. - direct current

GLOSSARY

Anode	The electrode at which electrons are removed from an electrochemical cell.
Anolyte	The liquid contained in the anode compartment of an electrochemical cell.
Beam (back)	A beam from which yarn is fed during the sizing process.
(weavers)	A roller on which large flanges are usually fixed, so that a warp may be wound on it in readiness for weaving.
Bleaching	The procedure, other than by scouring only, of improving the whiteness of textile material by decolourising it from the grey state, with or without the removal of natural colouring and/or extraneous substances.
Cathode	The electrode at which electrons flow into an electrochemical cell.
Catholyte	The liquid contained in the cathode compartment of an electrochemical cell.
Cold pad batch	The cold process of padding a solution onto a batch of fabric which is subject to one stage of a process at a time.
Composite membrane	Membranes made from composite materials and usually prepared by depositing a polymer film on a porous substructure.
Composite permeate	The combination of all the permeate produced during a membrane process.
Cross-flow microfiltration	A pressure-driven liquid separation process in which only colloidal and particulate solids are removed from the feed. In this technique the particular suspension or colloid is passed over the surface of a filtration medium under flow conditions favouring the transport of the suspending liquid through the membrane, while the concentration suspension is force-convected across the membrane surface and out of the filtration device. The filtration media can be microporous membranes, porous ceramic, plastic or metallic tubes or woven hose.
Curing	The heat treatment of textiles designed to complete polymerisation or condensation reaction of an added substance.

Determinand	A chemical species or physical characteristic of a substance.
Finishes	(a) A substance or a mixture of substances added to textile materials at any stage to impart desired properties.
	(b) The type of process, physical or chemical, applied to produce a desired effect.
	(c) Such properties, for example, smoothness, drape, lustre, or crease-resistance, produced by (a) and/or (b) above.
	(d) The state of the textile material as it leaves a previous processor.
Greige cloth	Woven or knitted fabrics as they leave the loom or knitting machine, i.e., before any bleaching, dyeing or finishing treatment has been given to them.
Hyperfiltration	A pressure-driven process which differs from reverse osmosis in so far as relatively small organics and non-ionic species with low osmotic pressure are also present in the feed stream and are rejected on a membrane which is of the same type as is used for reverse osmosis.
Jet	A machine for dyeing fabric in rope form in which the fabric is carried through a narrow throat by dye-liquor circulated at a high velocity.
Jig	A dyeing machine in which fabric in open width is transferred repeatedly from one roller to another and passes each time through a dyebath of relatively small volume. Jigs are frequently used for scouring, bleaching and finishing.
Liquor ratio	The ratio of the weight of liquor employed in any treatment to the weight of fibrous material treated.
Loomstate	Woven or knitted fabrics as they leave the loom or knitting machine, i.e., before any bleaching, dyeing or finishing treatment has been given to them.
Mercerising	(a) The treatment of cellulosic textiles in yarn or fabric form with a concentrated solution of caustic alkali, whereby the fibres are swollen, the strength and dye affinity of the materials are increased, and their handle is modified.

- (b) The process of steeping cellulose in concentrated caustic soda.

Nanofiltration - A pressure-driven liquid separation process in which an ultrafiltration membrane, which possesses charged groups is used. The charged membranes lead to interactions of the charged groups with ionic species in solution and with water. This can result in increased membrane anti-fouling properties, increased flux through the membrane and enhanced rejection of electrolytes. A degree of selectivity for multivalent ions is possible.

Padding - The application of a liquor or paste to textiles, either by passing the material through a bath and subsequently through squeeze rollers or by passing it through squeeze rollers, the bottom one of which carries the liquor or paste.

Point rejection - The instantaneous rejection of a membrane.

Reinforcement factor - The factor by which the feed to a padding operation has to be increased so as to counteract the dilution effect of the moisture on the incoming fabric.

Rejection - A measure of the decrease in concentration of a component in the feed and the permeate stream.

Reject - The portion of a feed solution which has not passed through a membrane.

Relaxer - A wet process which releases the strains and stresses in textile materials. This could be combined with other wet processes.

Rinsing - Treatment of textile material in water to remove substances employed in previous processes.

Scouring - Treatment of textile materials in aqueous or other solutions in order to remove natural fats, waxes, proteins and other constituents, as well as dirt, oil, and other impurities.

Size - A gelatinous film-forming substance, in solution or dispersion, applied to warps but sometimes to wefts, generally before weaving. The objects of sizing prior to weaving are to protect the yarns from abrasion in the healds and reed and against each other, to strengthen them, and by the addition of oils and fats, to lubricate them.

Stenter	- An open-width fabric-finishing machine in which the selvedges of a textile fabric are held by a pair of endless travelling chains maintaining weft tension. Such machines are used for drying, heat-setting of thermoplastic material and fixation of chemical finishes.
Texturising	- The process of introducing durable crimps, coils, loops or other fine distortions along the length of the fibres or filaments.
Thermoplastic	- Deformable by applied heat and pressure without any accompanying chemical change. The feature is that the deformation can be repeated.
Warp	- (a) To arrange threads in long lengths parallel to one another preparatory to further processing.
	- (b) Threads lengthways in a fabric as woven.
	- (c) A number of threads in long lengths and approximately parallel, which may be put in various forms intended for weaving, knitting, doubling, sizing, dyeing, or lace-making.
Washing range	- Equipment used for washing or rinsing.
Washing	- Treatment of textile material in water and detergent solutions to remove substances employed in previous processes.
Water recovery	- The fraction of liquid which has passed through a membrane.
Weft	- (a) Threads widthways in a fabric as woven.
	- (b) Yarn intended for use as in (a).
Winch	- A dyeing machine in which one or more endless lengths of fabric are drawn through the dyebath by a reel or drum rotating above the surface of the dye liquor.
	- A machine for dyeing garments in which the garments are circulated by jets of liquid rather than by mechanical means.

1 LEGISLATION AND PLANNING FOR INDUSTRIAL WASTE WATER REUSE AND RECLAMATION

1.1 INTRODUCTION

Water is the key to the continued overall development of the Republic of South Africa (RSA) (1). The critical factor for economic and industrial survival is the availability of water at a quality suitable for various urban and industrial uses.

Southern Africa is, for the most part, a semi-arid, water-deficient region of the world, subject to variable rainfall, droughts, floods and high evaporation losses. The annual rainfall amounts to only 58 % of the world average, run-off is distributed unfavourably, the availability of underground water is limited and the quality of the water resources is deteriorating (2).

The increasing salinity of the RSA's water resources is the biggest water quality problem facing the country today (3) and industry's future is largely dependent on the control of this problem. Added to this concern is the fact that, since Southern Africa is a relatively arid and water-deficient region, the industrial effluent return flow forms a considerable supplementary source of water, adding significantly to the mineralisation process.

In a recent publication by the Department of Water Affairs (2) it is estimated that the average annual run-off into rivers in the RSA is 52 000 million m^3/a (143 million m^3/d), of which 40 % or 20 800 million m^3/a (57 million m^3/d) is the assured portion which can be made available for use through the provision of storage facilities. It is estimated that future developments will increase this available portion to 50 %. A conservative estimate of the potential groundwater availability, based on current abstraction, is 3 million m^3/d, bringing the potential availability from natural water resources to 27 400 million m^3/a (75 million m^3/d).

It is estimated that if the present increase in demand materialises, then the total water needs by the end of the century will be 29 270 million m^3/a (80 million m^3/d), which exceeds the maximum expected yields.

Solutions to the problem are being sought by :

(i) improving the methods of development and utilisation of natural water sources,

(ii) raising the effectiveness of the current use of developed supplies, such as the reuse of effluents and the improved use of water for irrigation,

(iii) seeking methods for the creation of new water sources such as the desalination of sea water.

1.2 THE WATER ACT

The use of water for industrial purposes together with the control of effluent production and water pollution is governed in the RSA by the Water Act, 1956 (Act 54 of 1956) as amended. In the case of the Republics of Transkei, Venda, Bophuthatswana and Ciskei (TVBC states), the Water Act and its amendements at the time of independence were adopted. Subsequent amendments to the Water Act in the RSA are not necessarily adopted.

The Water Act is administered by the Department of Water Affairs. Any relaxation of the specified effluent standards is granted only after consultation with the Department of Health, the South African Bureau of Standards and sometimes other departments such as the Department of Environment Affairs and the Department of Agriculture and Water Supply.

The Water Act initially served its purpose well (4). It enabled water demand to be regulated in keeping with the portion of the national budget allocated to the development of additional water supplies. In addition, it safeguarded the limited available water resources from catastrophic levels of pollution without seriously constraining industrial development.

In view of the general decline in the quality of many of the RSA's water sources the initial Water Act could no longer effectively control water pollution and industrial water use. The Water Act and effluent standards were therefore amended during 1984.

The main requirements of the Water Amendment Act of 1984 retained the basic requirements of the Water Act of 1956. The more important provisions with which factory management should acquaint themselves are :

1.2.1 Industrial Water Use

In terms of Section 12 any party using a quantity of water from any source; private borehole water, sea water or public water, exceeding 150 m^3 on any one day, requires a permit of authorisation issued by the Minister of Water Affairs.

The permits are issued subject to various conditions, infringement of which is a criminal offence.

1.2.2 Effluent Discharge

The main requirement of Section 21 is that any person using water for industrial purposes is responsible for the purification to prescribed standards of this water and any effluent resulting from the use of this water, and to return the water and effluent as far as is practically feasible to the stream of its origin.

Section 21 also provides for the exemption from compliance with the above if it is considered warranted, for example, where no technology exists to achieve the prescribed standard or where the existing technology is prohibitively expensive. The Minister may withdraw or amend the permit of exemption at any time and may direct that the manufacture, marketing or use of any substance which could cause serious water pollution be restricted or terminated.

Effluent purification is seen by the Department of Water Affairs as an integral part of the normal manufacturing process and industry is expected to utilise the latest available technology to treat effluents to higher degrees of purity, thus reducing pollution and making available a good quality effluent suitable for water reclamation and reuse.

Three effluent standards exist and are prescribed in terms of Section 21 of the Water Act (**5**) :

(i) a general standard for discharge into most rivers and streams in the RSA,

(ii) a special standard for discharge into rivers in catchment areas specified by Schedule I, the so-called mountain and trout streams,

(iii) a special standard for discharge into specified catchments sensitive to phosphorus specified in Schedule II, which may cause eutrophication problems.

Table 1.1 summarises these effluent standards.

In terms of required purification to prescribed standards, the standard for total dissolved solids (TDS) is expressed as conductivity. A maximum increase of 75 mS/m above that of the intake water is generally applicable. Special standards apply in a number of selected regions and cases.

In addition, although specific provision is made in the regulations in this regard, the Department does not favour the irrigation of effluents or disposal to evaporation dams (**4**) and considers these means of discharge as temporary measures, which isolate polluting effluents from the water environment. Irrigation and evaporation dams, as a means of disposal, should be phased out as soon as the "best practicable"' means to treat these effluents to acceptable standards of purity becomes available.

1.3 STRATEGY AND POLICY GUIDELINES

A recent publication (**2**) has defined the RSA's official water policy and has attempted to increase the awareness of all water managers, scientists and consumers to the opportunities and limitations associated with water use and effluent disposal in the RSA. The book contains a summary of the major objectives, policies and views of the Department of Water Affairs.

According to the publication the major objective of the Department of Water Affairs is to "ensure the on-going, equitable provision of adequate quantities and qualities of water to all competing users at acceptable degrees of risk and cost under changing conditions".

TABLE 1.1
GENERAL AND SPECIAL STANDARDS FOR DISCHARGE IN TERMS OF THE SOUTH AFRICAN WATER ACT, 1956 (ACT 54 OF 1956)

Determinand	General standard	Special standard Schedule I	Special standard Schedule II
Colour, odour, taste	nil	nil	nil
pH	5,5 - 9,5	5,5 - 7,5	5,5 - 9,5
Dissolved oxygen (%)	not less than 75	not less than 75	not less than 75
Temperature (°C)	not more than 35	not more than 25	not more than 35
Typical faecal coliforms (per 100 mℓ)	nil	nil	nil
Chemical oxygen demand (mg/ℓ)	not more than 75	not more than 30	not more than 75
Oxygen absorbed (mg/ℓ)	not more than 10	not more than 5	not more than 10
Conductivity	not to increase more than 75 mS/m, max 250 mS/m	not to increase more than 15 % above intake, max 250 mS/m	not to increase more than 75 mS/m, max 250 mS/m
Suspended solids (mg/ℓ)	not more than 25	not more than 10	not more than 25
Sodium (mg/ℓ)	below 90 above intake	below 50 above intake	below 90 above intake
Soap, oil and grease (mg/ℓ)	not more than 2,5	nil	not more than 2,5
Residual chlorine - as Cl (mg/ℓ)	not more than 0,1	nil	not more than 0,1
Free and saline ammonia - as N (mg/ℓ)	not more than 10	not more than 1,0	not more than 10
Nitrate - as N (mg/ℓ)	not specified	not more than 1,5	not specified
Arsenic (mg/ℓ)	not more than 0,5	not more than 0,1	not more than 0,5
Boron (mg/ℓ)	not more than 1,0	not more than 0,5	not more than 1,0
Chromium - total (mg/ℓ)	not more than 0,5	not more than 0,05	not more than 0,5
Chromium VI (mg/ℓ)	not more than 0,05	not specified	not more than 0,05
Copper (mg/ℓ)	not more than 1,0	not more than 0,02	not more than 1,0
Phenol (mg/ℓ)	not more than 0,1	not more than 0,01	not more than 0,1
Lead (mg/ℓ)	not more than 1,0	not more than 0,1	not more than 0,1
Copper (mg/ℓ)	not more than 0,5	not more than 0,02	not more than 0,5
Sulphides - as S (mg/ℓ)	not more than 1,0	not more than 0,05	not more than 1,0
Fluorine (mg/ℓ)	not more than 1,0	not more than 1,0	not more than 1,0
Zinc (mg/ℓ)	not more than 5,0	not more than 0,3	not more than 5,0
Phosphate - total as P (mg/ℓ)	not specified*	not more than 1,0	not more than 1,0
Iron (mg/ℓ)	not specified	not more than 0,3	not specified
Manganese (mg/ℓ)	not more than 0,4	not more than 0,1	not more than 0,4
Cyanide - as CN (mg/ℓ)	not more than 0,5	not more than 0,5	not more than 0,5
Sum of Cadium, Chromium, Copper Mercury and Lead (mg/ℓ)	not more than 1,0	not more than 1,0	not more than 1,0
Cadmium (mg/ℓ)	not more than 0,05	not more than 0,05	not more than 0,05
Mercury (mg/ℓ)	not more than 0,02	not more than 0,02	not more than 0,02
Selenium (mg/ℓ)	not more than 0,05	not more than 0,05	not more than 1,0

* except for "sensitive" catchments specified in Schedule II

The Department's guidelines (4) include the following :

(i) The "polluter pays" principle applies and polluters are increasingly required to undertake and fund monitoring programmes and ecological impact studies to assess the environmental effects of their discharge.

(ii) Salinity and toxicity control measures are applied to the source of the problem. The Department will implement stricter control over industrial discharges into municipal sewers and will closely monitor all receiving waters.

(iii) Short-term solutions, such as discharge to evaporation ponds, irrigation or dilution and blending, will be phased out.

(iv) The necessity and extent of effluent treatment enforced in a particular instance, will be determined by the nature of the pollutant and its impact on receiving water quality, the interests of downstream users and the cost-effectiveness and cost-benefit of the application of reclamation technology.

1.4 INDUSTRY-BASED RECYCLING AND RECLAMATION

The Department of Water Affairs relies on the co-operation of both research and industrial organisations in the development of alternative approaches which will ensure the industrial and economic future of the RSA. It is the Department's policy to encourage industrialists to develop improved in-plant control.

Industry-based recycling and reclamation is desirable in that pollutants may be removed at source from segregated, purer streams. In addition, heat energy, water and chemical savings may be achieved.

Industry-based recycling will include the reuse of minimally contaminated process water, from one process, in another subsequent process. Reclamation measures include primary treatment to enable reuse of the stream, or advanced treatment to allow for the separation, recovery and direct reuse of effluent constituents.

2 THE TEXTILE INDUSTRY

2.1 INTRODUCTION

2.1.1 South African Textile Industry

The textile industry in the RSA supports 180 000 people in the agricultural sector, 3 000 in the cotton ginning industry, 30 000 in spinning and 250 000 in textile and clothing. It is a major industry with over 300 textile factories, of which about 50 are concerned with the weaving of cotton and cotton/synthetic fibre cloths (**6**). The textile industry uses 5 % (1976) of the energy requirements of the manufacturing sector (**7**).

The textile industry requires water for :

processing	steam generation
product washing	air conditioning
plant and equipment washing	transport of material
cooling systems	personnel consumption and sanitation.

Steam generation, air conditioning, human consumption and certain stages in the production of textiles require water of potable or higher quality while a water of lower quality may be employed for other uses.

2.1.2 The Need for Pollution Control in the Textile Industry

Recent amendments to the Water Act of 1956 (see 1.2.1 and 1.2.3) have placed considerable responsibility on industries to optimise their water use and to treat their effluents to the required standards. The textile industry, because of the nature of its effluents, is faced with a particularly serious set of problems.

Textile processing plants utilise a wide variety of dyes and other chemicals such as acids, bases, salts, detergents, wetting agents, sizes and finishes. Many of these are not retained in the final product and are discharged in the effluent. Textile effluents are in general relatively non-biodegradable and hence present problems in terms of discharge to both sewage systems and to the environment. Mills discharging to sewage works cause colour and chemical oxygen demand (COD) problems and those discharging to the environment need to remove very high percentages of colour, COD and mineral salts.

Typical textile processing water use is 150 to 1 400 ℓ/kg of product (**8,9**) and hence large volumes of textile effluents need to be disposed of in South Africa.

Unless appropriate and adequate care is exercised, the discharge of textile effluents to the water environment may have serious and long-lasting consequences. These include :

(i) solid wastes, such as fibre, which are unsightly and may result in anaerobic sludge layers in receiving streams,

(ii) many organic contaminants in textile effluents, such as dyes, synthetic sizes and detergents, which are relatively non-biodegradable and hence cause problems in municipal sewage works and in return flow to water sources,

(iii) other organic compounds, such as starches, with very high biological oxygen demands, which increase the cost of sewer discharge or, if discharged to receiving streams, cause anaerobic conditions,

(iv) the presence of inorganic salts, acids or alkalis in high concentrations, which will gradually make the receiving water unsuitable for most industrial and municipal purposes.

2.2 TEXTILE PROCESSING

2.2.1 Textile Fibres

The textile industry is a group of related industries which uses natural and/or synthetic fibres as the raw material to produce a wide range of finished products. Of interest in the present applications are cotton and polyester.

Cotton

Cotton is the seed hair of a wide variety of plants of the Gossypium family. Cotton fibres consist mainly of cellulose.

Natural cotton is contaminated by oil and wax (0,5 %). Pectic acid, which is soluble in hydroxide solutions but insoluble in water, is present in cotton, often in the form of calcium or magnesium salts. Cotton may also contain small amounts of mineral matter (1 to 2 %) composed of silicon, iron, aluminium, calcium, magnesium, potassium, sodium, chloride and sulphate. Nitrogen containing impurities such as proteins or polypeptides and natural colouring material are also present.

Polyester

Polyester is a truly synthetic fibre and is the product of a commercial chemical process involving the condensation of ethylene glycol and terephthalic acid.

Polyester fibres are produced by melt spinning and, being thermoplastic, can be easily shaped to produce textured effects. The fibres exhibit marked crystallinity and the closely packed, highly orientated molecules make polyester strongly hydrophobic.

2.2.2 Textile Manufacturing

Various processing operations are involved in the transformation of the raw fibre into the finished textile product (Figure 2.1). The conditions under which each operation is carried out vary depending on the type of raw fibre used.

The wet processing department of a textile plant commences with desizing in the case of cotton and polyester materials. The subsequent pretreatment operations prepare the textile material for dyeing, printing and finishing. In addition, impurities are solubilised, dissolved or dispersed and then removed by washing. Hence an adequate washing capacity during each pretreatment operation is essential for optimum results.

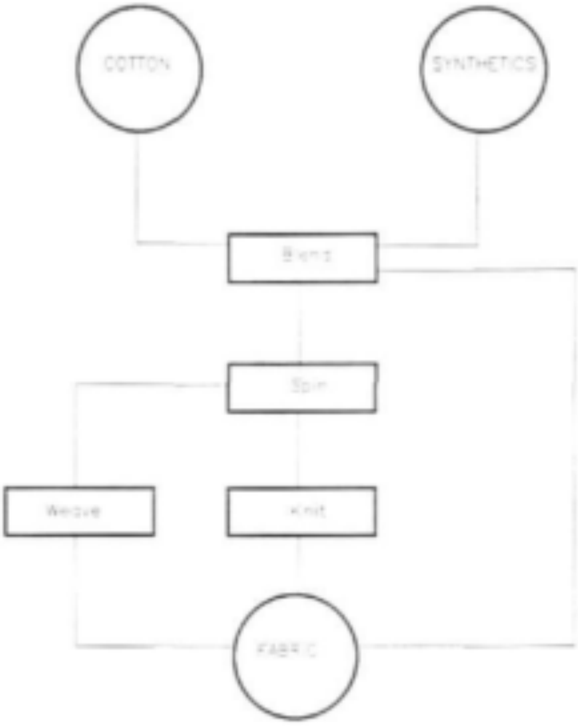


FIGURE 2.1 : PRODUCTION OF FABRIC

Accurate control of various factors is essential during wet preparation :

(i) concentration of chemicals,
(ii) reaction time and temperatures,
(iii) rate of water flow in washing.

The order in which the individual pretreatments are carried out often depends on the specific production programme of the plant and on equipment availability.

Opening

This mechanical operation opens the raw fibres and blends together various components, allowing for the removal of contaminants.

Carding and Spinning

During carding, the long axes of the fibres are aligned, short fibres are removed and blending takes place. In spinning, fibres are drawn out and twisted into yarn.

Where the yarn is to produce cloth by the weaving process, it is divided into either the warp (longitudinal threads) or the weft (lateral threads).

Warping

During warping parallel yarns are wound onto a back beam. The back beams are combined during sizing to form a weaver's beam. In the case of coloured woven fabrics, the yarn is dyed prior to warping.

Sizing

The sizing operation coats the individual yarns with a protective film of size in order to resist the abrasive action of the loom. The size strengthens the yarn and reduces the hairiness of the threads.

Weaving

Weaving is a dry operation but is normally carried out under conditions of high humidity. This helps to minimize breaks on the loom as the size film is flexible under moist conditions. After weaving the greige cloth is inspected for faults and may be cropped and singed to remove surface hairiness.

Knitting

During the knitting operation lubricating oils are continuously applied to the yarn to reduce fibre breaks and waste.

Desizing

The size is removed from the cloth, the technology utilised being dependent on the type of sizing agent employed.

Scouring

Where sizing is not carried out, scouring is almost invariably the first wet process applied to textile materials. During this operation oils, fats, waxes, soluble impurities and particulate and solid dirt adhering to the fibres are removed. Scouring generally consists of treatment with a detergent, with or without the addition of an alkali, dependent on the type of fibre and level of contamination.

Bleaching

Bleaching is carried out using oxidizing, or less often a reducing, bleaching agent which whitens the fibre by removing the natural colouring matter.

Mercerising

Mercerising refers to the treatment of fibre, usually cotton, under tension with concentrated sodium hydroxide. Mercerising imparts a sheen to the cotton fibre and increases its dyeability.

Dyeing and Printing

Stock, yarn or fabric is coloured to the customers requirements by the uniform or local application of colouring matter for either dyeing or printing respectively.

Finishing

Final processing imparts special properties such as easy handling, mothproofing, antistatic, non-slip and anti-piling to the final product.

2.2.3 Textile Mill Classification

Detailed classification of the textile industry is difficult, but two main methods are useful: fibre processing and mill operation. Figure 2.2 classifies the types of finished product by the fibre processed. The main types of mill operation, Figures 2.3 to 2.5, (**10,11,12**) include :

(i) wool scouring and/or finishing,
(ii) dry processing,
(iii) woven fabric finishing,
(iv) knit fabric finishing,
(v) carpet manufacture,
(vi) stock and yarn dyeing and finishing.

Sectors (iii), (iv), (v) and (vi) include one or more of the processes of scouring, bleaching and mercerising as applied to cotton and polyester/cotton blends.

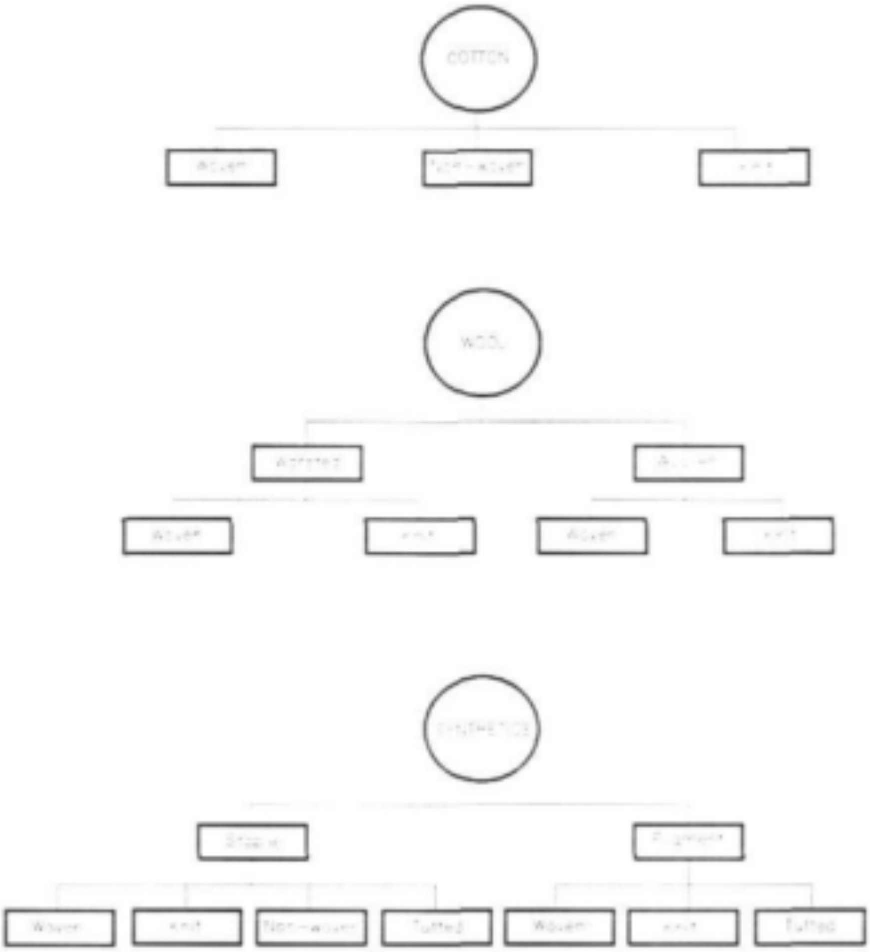


FIGURE 2.2 : TEXTILE INDUSTRY CATEGORISATION BY FIBRE PROCESSED

Wool scouring will be covered in Part 4 of this series of guides.

<u>Woven Fabric Finishing Mill</u>

Woven fabrics involving cotton are sized. The size and the natural impurities on the cotton fibre, means that these fabrics need treatment involving desizing, scouring, mercerising and bleaching. The prepared fabric is then either dyed or printed (Figure 2.3).

<u>Knit Fabric Finishing Mill</u>

Fabrics knitted with synthetic fibre receive a light scour to remove knitting oil, followed by dyeing and/or printing (Figure 2.4).

Knitted cotton is scoured and bleached prior to dyeing or printing. The same technology as for woven cotton is used, but with different machinery.

<u>Stock and Yarn Dyeing and Finishing Mill</u>

Synthetic yarns are subjected to a light scour, dyed and softened. Cotton yarns are bleached and occasionally mercerised before being dyed and softened (Figure 2.5).

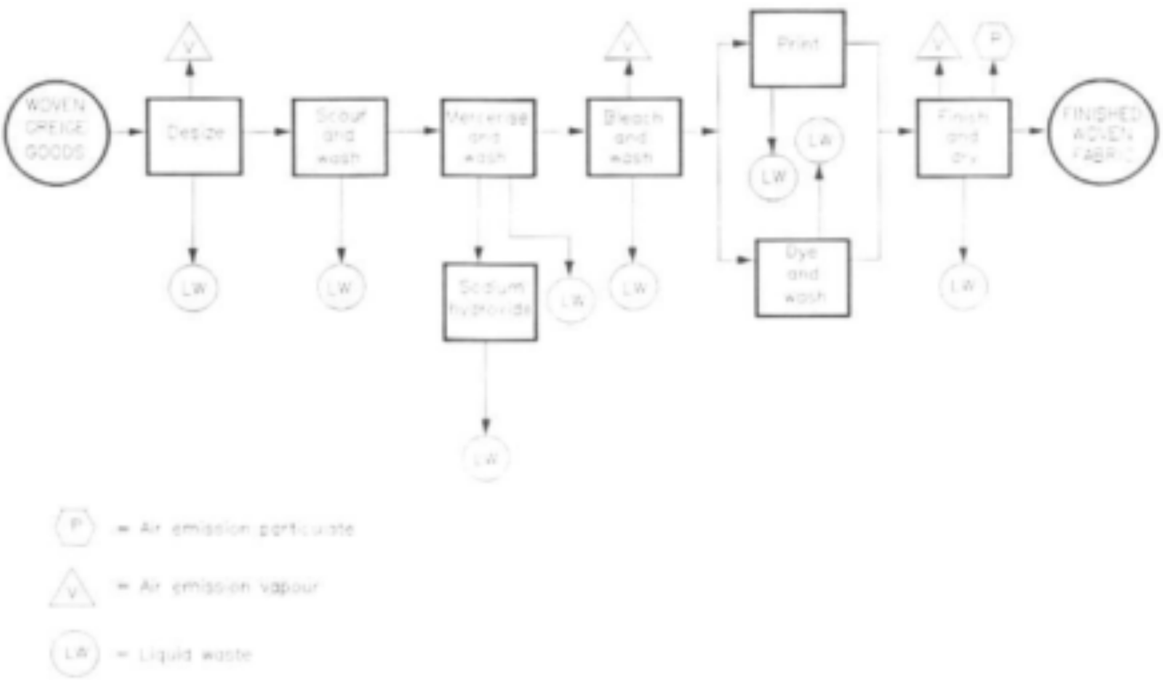


FIGURE 2.3 : WOVEN COTTON FABRIC FINISHING MILL

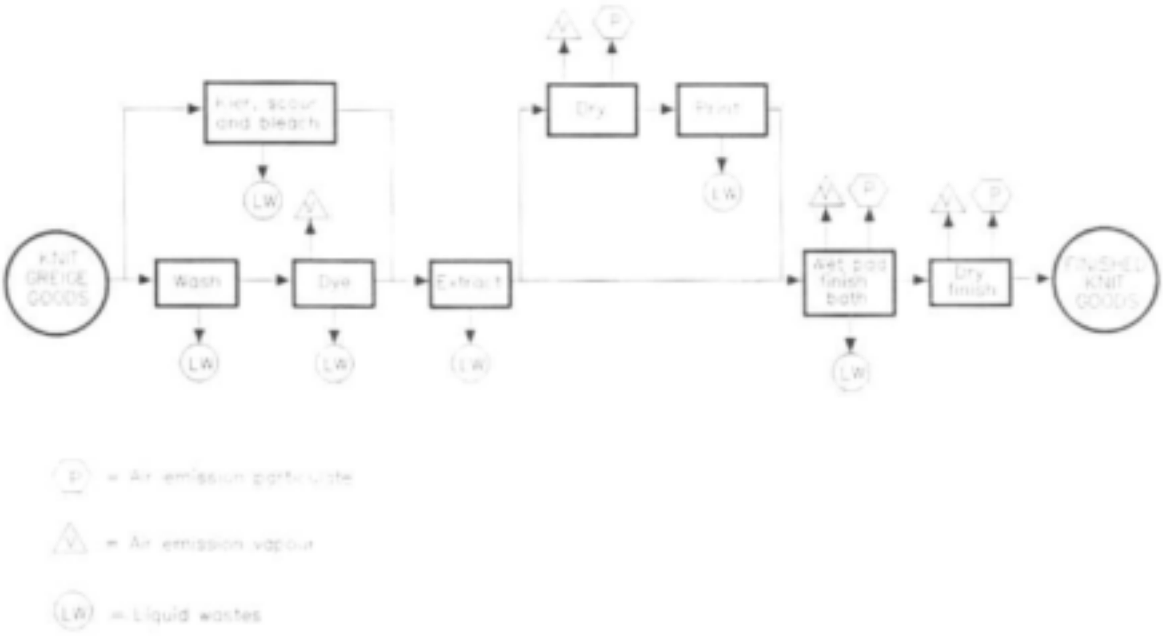


FIGURE 2.4 : KNIT FABRIC FINISHING MILL

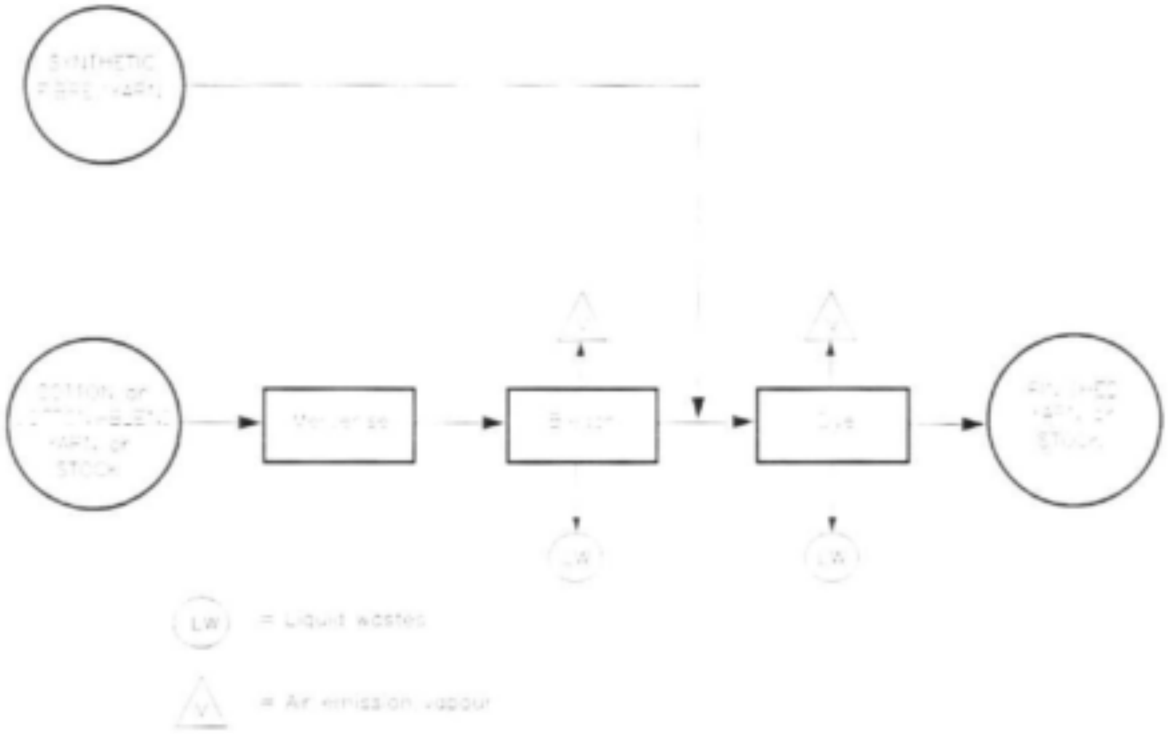


FIGURE 2.5 : STOCK AND YARN DYEING AND FINISHING MILL

2.2.4 Water Use and Effluent Production

The overall waste-water characteristics (1973) of typical textile mills of interest in this report are given in Table 2.1 (**10**). The loads will be correct - however, in the Southern African context the water use figures are considered to be high.

The contribution of the individual wet processing operations to the overall pollution load for a polyester/cotton blend is given in Table 2.2 (**13**).

2.3 SCOURING TECHNOLOGY

Scouring is a wet processing operation, designed to cleanse the raw fibres, leaving them in the optimum condition for subsequent processing.

2.3.1 Textile Scouring Methods

Scouring of Cotton

Although cotton contains small quantities of impurities, the wax contaminants, being high in molecular mass are not easily removed. In addition, the protein impurities are located within the lumen of the fibre, making them relatively inaccessible to chemical attack. The impurities can be removed from carded, woven or knitted cotton by treatment in boiling sodium hydroxide in the presence of suitable auxiliary chemicals. The alkaline scouring process :

TABLE 2.1
OVERALL EFFLUENT CHARACTERISTICS FOR VARIOUS CATEGORIES OF TEXTILE MILLS (10)

Determinand		Woven fabric finishing	Knit fabric finishing	Stock and yarn dyeing and finishing
BOD		550	250	200
SS		185	300	50
COD		850	850	524
Sulphide		3	0,2	-
Colour	(ADMI units)	325	400	600
pH		7 - 11	6 - 9	7 - 12
Water use	(ℓ/kg)	297	277	297

All units in mg/ℓ unless otherwise stated.

(i) converts the pectins and pectoses to soluble pectic salts,

(ii) degrades the proteins into soluble amino acids or into ammonia,

(iii) dissolves the mineral matter,

(iv) removes the adventitious dirt,

(v) hydrolyses the saponifiable matter to form soaps which in turn emulsify the unsaponifiable oils and retain the dirt particles in suspension,

(vi) improves the hydrophilic properties of the fibre which govern the water absorptivity and the evenness of dye and chemical uptake.

The fraction of sodium hydroxide consumed in scouring varies from 10 to 80 % depending on the temperature and on the reaction time of the process.

Cotton scouring processes are batch or continuous. Batch scouring produces a sequence of effluents of decreasing concentration. Continuous scouring produces a single effluent because the scouring solution is padded onto the cloth at high concentration and is subsequently removed in a rinsing process.

Batch Scouring

Batch scouring is generally carried out in cylindrical vessels or kiers made of cast iron or stainless steel. These may be open, when the liquor boils at atmospheric pressure (boil-off) or closed, when the liquor boils under pressure at temperatures higher than 100 °C (kier-boil). In both instances, steam is used to heat and to circulate sodium hydroxide through the cloth.

Boil-off at atmospheric pressure has been largely replaced by newer and more effective scouring methods, since the combination of atmospheric oxygen and alkali causes oxidative damage to the cellulose fibres. Where boil-off is still practised, it is carried out in the presence of a reducing agent to prevent oxidative degradation of the fibre.

Typical boil-off recipes would be :

Cloth (14)

Sodium hydroxide	10 to 20 g/ℓ.
Wetting agent and detergent (anionic)	1 to 2 g/ℓ.
Liquor ratio	3 : 1 to 7 : 1.
Batching temperature	95 to 98 °C.
Batching time	4 to 6 h.

TABLE 2.2
POLLUTION LOADS FOR VARIOUS WET PREPARATION OPERATIONS (50/50 POLYESTER/COTTON) (13)

Process	pH	BOD kg/t product (mg/ℓ)	SS kg/t product (mg/ℓ)	TDS kg/t product (mg/ℓ)	Oil and grease kg/t product (mg/ℓ)	Colour kg/t product (mg/ℓ)	Water use ℓ/kg product
DESIZING							
Enzyme starch	6 - 8	38,5 (3 078)	77 (6 155)	19,8 (1 583)	3,6 (288)		12,5
Polyvinyl alcohol	6 - 8	2,5 (200)	5 (400)	50,4 (4 029)	3,6 (192)		12,5
Carboxymethyl cellulose	6 - 8	3,9 (314)	5 (400)	54,5 (4 349)	9,4 (751)		12,5
SCOURING							
Unmercerised greige fabric	12	10,8 (432)	5 (200)	9,8 (392)	20 (799)		25
Mercerised greige fabric	12	8,3 (333)	5 (200)	9,7 (387)	15 (100)		25
MERCERISING							
Greige fabric	12	5,7 (343)	5 (300)	77 (4 616)	5 (300)		16,7
Scoured fabric	12	3,2 (192)	5 (300)	77 (4 616)			16,7
Bleached fabric	12	1,3 (76)	5 (300)	72 (4 317)			16,7
BLEACHING							
Hydrogen peroxide (Woven goods)	10	1,3 (78)	4 (240)	20 (1 199)			16,7
Hydrogen peroxide (Knit goods)	12	15,3 (183)					83
Hydrogen peroxide (Yarn goods)	10	13,8 (138)		50 (500)	1,0 (10)		100
DYEING							
Direct & disperse (Woven goods)	6 - 8	10,7 (257)		114 (2 734)		0,5 (12)	42
Vat & disperse (Woven goods)	12	22,8 (547)		122 (2 926)		1,4 (33)	42
Sulphur & disperse (Woven goods)	11	22,8 (547)		69,7 (1 671)		2,1 (50)	42
Napthol & disperse (Woven goods)	11	13,8 (331)		57,2 (1 372)		0,6 (13)	42
Fibre reactive & disperse (Woven goods)	12	13,5 (324)		192 (4 604)		0,7 (16)	42
PRINTING							
Pigment (Woven goods)	6 - 8	1,3 (101)	0,1 (10)	2,5 (200)		0,1 (4)	12,5
Pigment (Knit goods)	6 - 8	1,3 (101)	0,1 (10)	2,5 (200)		0,1 (4)	12,5
Vat dye (Woven goods)	10	21,5 (644)	25 (750)	34 (1 019)		0,1 (15)	33,3
Vat dye (Knit goods)	10	21,5 (644)	25 (750)	35 (1 049)		0,5 (15)	33,3
FINISHING							
Resin (Woven goods)	6 - 8	(96)		22 (1 759)			
Resin	6 - 8	6,3 (505)	12 (959)	17,3 (1 383)			12,5
Flat curing (Woven goods)							12,5

Typical rinsing effluent parameter loadings from the boil-off of cloth for a water use of 20 ℓ/kg cloth and a wet-pick up of 100 % are :

pH	alkaline.
Temperature	hot (>80 °C).
Sodium hydroxide	10 to 20 g/kg cloth.

Cotton wool (15,16)

Sodium hydroxide	10 to 50 g/ℓ.
Detergent	2 to 3 g/ℓ.
Liquor ratio	20 : 1.
Batching temperature	98 °C.
Batching time	4 to 6 h.

Typical rinsing effluent parameter loadings from the boil-off of cotton wool for a water use of 20 ℓ/kg cloth and wet-pick up of 100 % are :

pH	alkaline.
Temperature	hot (>80 °C).
Sodium hydroxide	10 to 50 g/kg cloth.
Colour	dark.

Typical kier-boil recipes would include (17) :

Potassium hydroxide (or the sodium hydroxide equivalent)	40 g/ℓ
Wetting agent or detergent	1 to 2 g/ℓ.
Liquor ratio	10 : 1.
Pressure and temperature	100 kPa at 135 °C.
Batching time	3 to 4 h.

Typical rinsing effluent parameter loadings from kier-boiling for a water use of 25 ℓ/kg cloth and a wet-pick up of 100 % are (18) :

pH	alkaline.
Temperature	warm (50 °C).
Potassium hydroxide	40 g/kg cloth.
Colour	dark.

Continuous Scouring

Continuous scouring is generally achieved in one of three types of units, the J-box, caravans or open-width reaction chambers.

J-boxes can be used to process fabric in either rope form or in open-width form. Scouring is achieved by impregnating the cloth with sodium hydroxide, heating it to elevated temperatures (93 to 99 °C) and allowing a reaction time of approximately one hour while the fabric passes through the J-box (Figure 2.6) (19).

In the caravan system, fabric is first padded, using a solution of sodium hydroxide containing a reducing agent. It is then steamed and wound into caravans, where the cloth is rotated in a steam atmosphere (90 °C) for one to two hours.

The Vaporloc unit, by Mather and Platt, is a high-pressure reaction unit which is designed to operate under pressures of 200 kPa with temperatures above 130 °C, and scouring is achieved in periods as short as one to two minutes. Figure 2.7 (19) shows an open-width machine.

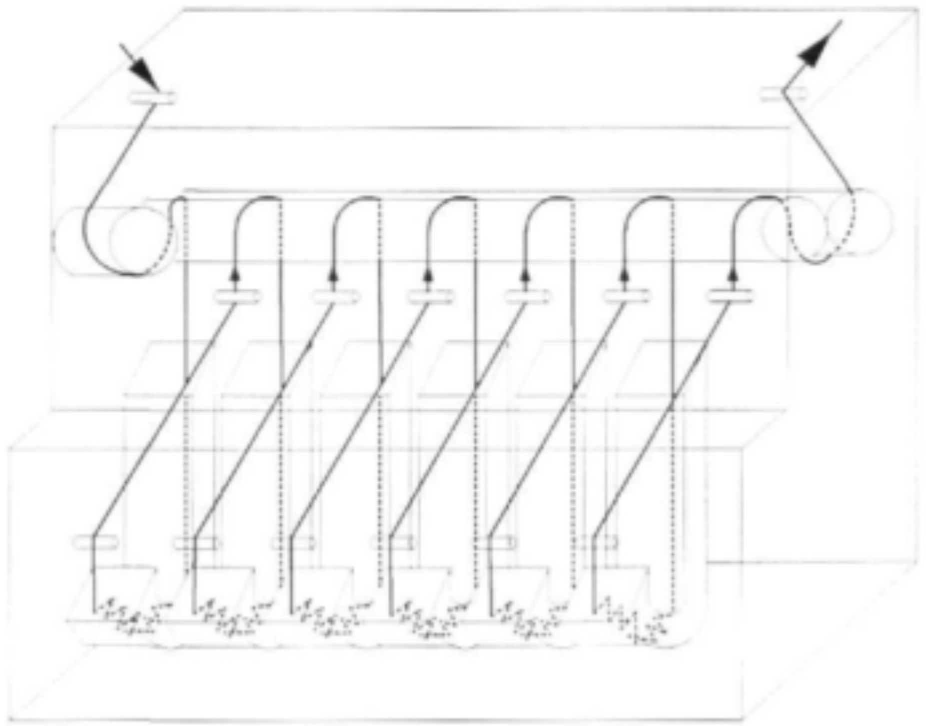


FIGURE 2.6 : SCHEMATIC OF A ROPE/J-BOX WASHING MACHINE (19)

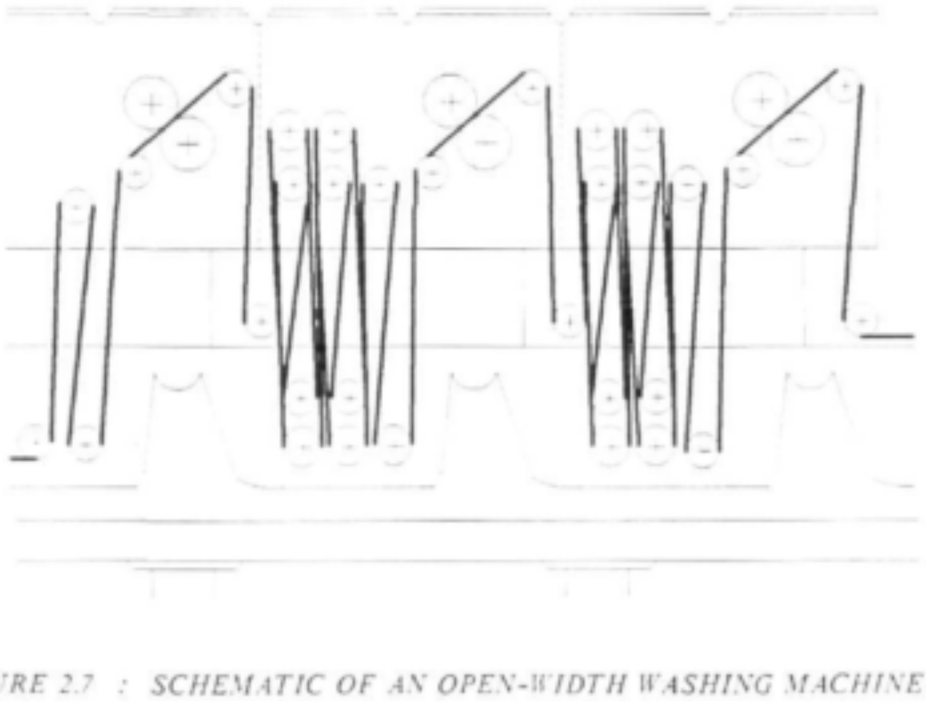


FIGURE 2.7 : SCHEMATIC OF AN OPEN-WIDTH WASHING MACHINE (19)

Typical recipes for the padding solution in any type of continuous scouring range would include (15) :

Sodium hydroxide	40 to 70 g/ℓ.
Reducing agent	20 g/ℓ.
Wetting agent	2 g/ℓ.
Liquor ratio	0,7 : 1 to 1 : 1.

After processing, the fabric is washed, usually in a counter-current washing range (Figure 2.7) and may or may not be neutralised, depending on further processing operations. Typical effluent parameter loadings for a water use of 4 to 5 ℓ/kg cloth and a wet pick-up of 90 % after padding are (15) :

pH	alkaline (>13,5).
Temperature	100 °C.
Sodium hydroxide	30 to 60 g/kg cloth.
Colour	dark.

Scouring of Polyester

The impurities which have to be removed from polyester yarn during wet processing are oils which have been incorporated during spinning and applied during weaving and knitting, as well as size applied prior to weaving. The processing oils are applied to reduce friction and breaking of the filaments and to increase lubrication of the yarn.

The knitting and spinning oils are often highly refined naptha oils. Surfactants are added to the base oil to enable effective removal of the oil during scouring. The ratio of the hydrophilic and hydrophobic fractions in these oils is carefully chosen to enable the surfactants to remain in the oil and to ensure that the oil, as a bulk phase, will not emulsify.

Typical oil content of polyester yarn is shown in Table 2.3.

TABLE 2.3
OIL CONTENT OF POLYESTER YARN

Product	Process	Oil content (% m/m)
Warp knitted	Spinning Beaming	0,5 1,0 - 1,5
Texturised	Spinning Texturising	0,5 3,0

Scouring of polyester is undertaken in warm (60 °C), alkaline conditions (sodium carbonate) with a combination non-ionic/anionic detergent. It is probable that the scouring detergent combines with the emulsifying detergent to enhance the overall emulsifying action. The alkaline conditions enable full detergent action to be achieved.

Typical recipes for batch scouring of polyester fabric would include (15) :

Sodium carbonate	1 g/ℓ.
Detergent	1 g/ℓ.
Liquor ratio	10 : 1.
Batching temperature	60 °C.
Batching time	30 min.

Typical effluent parameter loadings for a water use of 20 ℓ/kg cloth and a wet pick-up of 100 % are (15) :

pH	alkaline (8,0 to 12,0).
Temperature	warm (40 to 60 °C).
Sodium	0,2 g/kg cloth.

Scouring of Polyester/Cotton Blends

Polyester/cotton blends are considered either as heavily contaminated polyesters or as mildly contaminated cottons and are scoured accordingly. The alkali concentration, reaction time and working temperature that are used for cotton scouring must be adjusted to reduce tendering of the polyester to a minimum. Figure 2.8 (14) illustrates the conditions which cause unacceptable saponification of the polyester fibre. Scouring should be conducted in the region lying below the sodium hydroxide concentration lines.

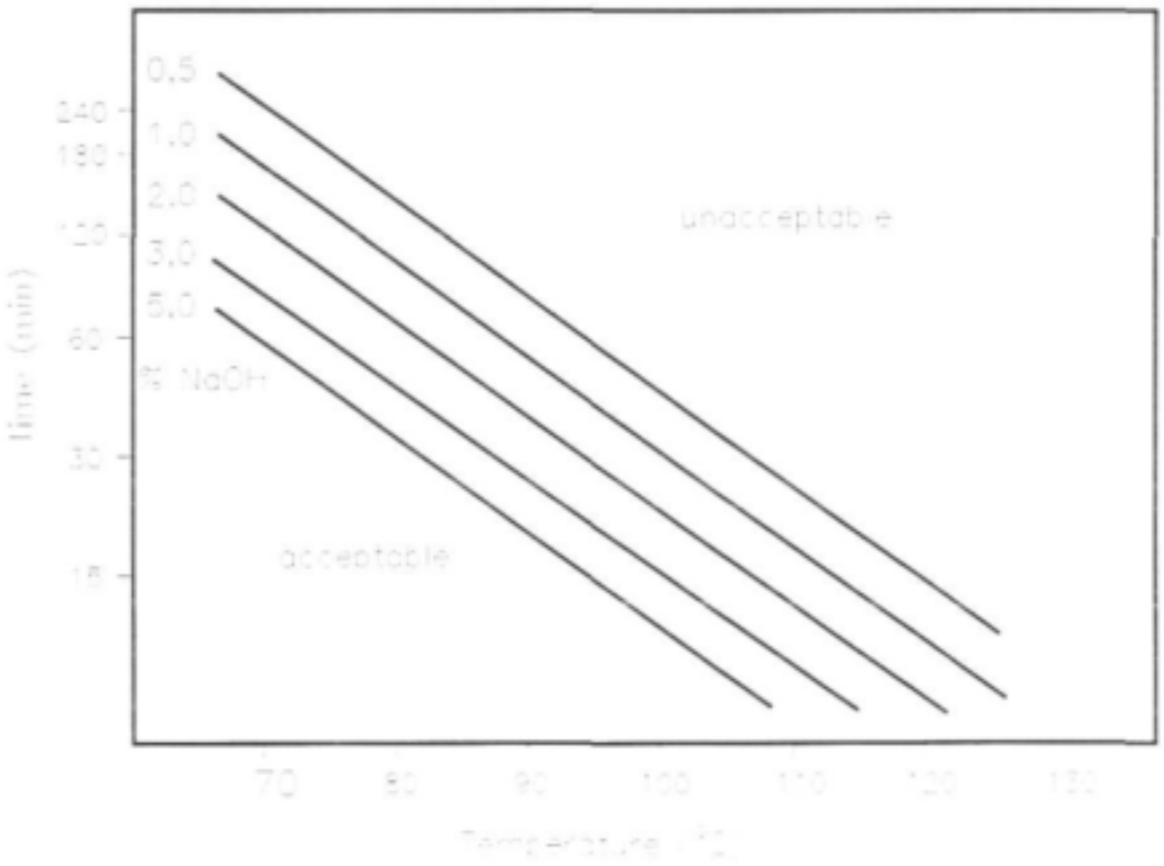


FIGURE 2.8 : ACCEPTABLE SAPONIFICATION LIMITS OF POLYESTER AS A FUNCTION OF SODIUM HYDROXIDE CONCENTRATION AND TEMPERATURE AND CONTACT TIME (14)

Typical recipes for the scouring of polyester/cotton blends would be :

Polyester/cotton yarn

Sodium hydroxide	1 g/ℓ.
Detergent	1 g/ℓ.
Sequestrant	0,5 g/ℓ.
Liquor ratio	10 : 1.

Polyester/cotton fabric

Sodium carbonate	1 g/ℓ
Detergent	1,5 g/ℓ.
Sequestrant	1 g/ℓ
Fabric lubricant	1 g/ℓ
Liquor ratio	10 : 1.

2.4 MERCERISING TECHNOLOGY

Mercerising is the treatment given to cotton fibre, under tension, using a concentrated sodium hydroxide solution to improve various properties of the fibre. A swollen and more cylindrical fibre is produced which :

(i) gives a higher, more uniform reflection of light and results in improved lustre,

(ii) promotes the tear strength but at the cost of elasticity,

(iii) improves the dyeability,

(iv) improves the dimensional stability in washing.

Mercerising consists of immersing the tensioned cotton in sodium hydroxide, followed by efficient rinsing while the fibre is still under tension. Mercerising liquor concentrations of 22 to 26 % sodium hydroxide are generally employed. During mercerising, the cotton goes into a plastic state, whereby the dimensions of the fabric can be influenced within certain limits. The new structure and the dimensions set are only sufficiently stable when the residual liquor content is 50 g NaOH/kg of fabric or less, i.e. when the liquor has been practically washed out (**20**). It is thus important that the tension in the fabric at the dimension set is retained until the minimum NaOH concentration has been reached. Temperatures are generally kept low (13 to 15 °C), since swelling of the fibres is higher at low temperatures. Some factories in the RSA mercerise at elevated temperatures (40 °C) where a weaker mercerising effect is achieved. Since the mercerising process is exothermic, cooling systems are required.

Suitable wetting agents are employed to accelerate sodium hydroxide uptake by the fibre and to improve the evenness of the mercerising effect. Such wetting agents must be readily soluble in concentrated sodium hydroxide and must possess no affinity for the fibre in order to prevent rapid consumption.

Mercerisation may be carried out dry-on-wet or wet-on-wet. Constant control of the sodium hydroxide concentration is essential. Centrifugation of the recirculating liquor is necessary during the mercerising of fabrics which have not been prescoured using an alkaline earth extractor to remove accumulated calcium and magnesium salts. Yarns that are to be processed into knitgoods must be prescoured using alkaline earth extractors prior to mercerising, to ensure minimum variation in the mercerising effect.

After mercerisation it is customary to neutralise the fabric in the penultimate rinse bath of the washing range. Acetic or formic acid is commonly used for this purpose.

Typical recipes for mercerising would include (14) :

dry-on-wet

Sodium hydroxide in saturator	239 to 250 g/ℓ.
Surfactant (anionic)	5 to 7 g/ℓ.
Temperature	13 to 15 °C.
Sodium hydroxide as replenishing addition	296 to 319 g/ℓ.

wet-on-wet

Sodium hydroxide in saturator	273 to 296 g/ℓ.
Surfactant (anionic)	1 to 3 g/ℓ.
Temperature	13 to 15 °C.
Sodium hydroxide as replenishing addition	354 to 538 g/ℓ.

The wash-off after mercerising constitutes the effluent. Typical effluent parameter loadings for a water use of 6 to 10 ℓ/kg cloth and a wet pick-up of 90 % are (18) :

pH	highly alkaline (>13,5).
Temperature	100 °C.
Sodium hydroxide	270 to 480 g/kg cloth.

2.4.1 Mercerising Equipment

The standard mercerising machines in a textile finishing plant are the chain, roller and yarn types.

The chain and roller machines are used for mercerising woven fabrics. Knitgoods are mercerised using the roller machine and are stretched in both directions before entering the mercerising field, in order to ensure maximum lustre.

In general, woven fabrics are mercerised after desizing and scouring and either before or after bleaching. White goods should be mercerised before final bleaching, since the hydrophilic properties and the degree of whiteness are usually impaired to some extent by mercerising.

CHAIN MERCERISING MACHINES consist of the impregnation section, the draw-off rollers, a stenter for weftwise tension and a rinsing, neutralising and after-rinsing section. These machines permit exact adjustment and control of the tension in both warp and weft directions.

ROLLER MERCERISING MACHINES are equipped with a system of rollers, arranged in two rows, one above the other. The fabric is tensioned between the bottom and top rollers while passing through both the sodium hydroxide treatment and the stabilizing sections. The fabric is then neutralised in an enclosed open-width washing section.

YARN MERCERISING MACHINES are either batchwise or continuous types. In batchwise mercerising the yarn is tensioned by sliding rollers and is immersed in or sprayed with the mercerising liquor. After a short reaction time (1 to 3 min) the excess liquor is removed by squeezing. The yarn is then rinsed and neutralised. In continuous mercerisation the individual yarns, running parallel to one another, are impregnated with the mercerising liquor, stretched, freed from sodium hydroxide, rinsed and finally neutralised.

2.5 BLEACHING TECHNOLOGY

Bleaching destroys the colouring matter of fibres and associated impurities. Oxidising or reducing bleaches may be used in combination with wetting, softening and stabilizing agents. Bleaching is often carried out by passing the cloth through a standing bowl containing the bleaching chemicals, after which the cloth is rotated on a beam for 2 to 8 hours.

2.5.1 Textile Bleaching Methods

Bleaching of Cotton and its Blends

Cotton is generally bleached with oxidising chemicals including sodium hypochlorite, sodium chlorite and hydrogen peroxide.

The impurities contained in polyester/cotton blends are almost exclusively those from the cotton and such blends are bleached as for cotton.

Bleaching is performed batchwise in winches, jets or by cold pad batch and continuously by padding followed by steaming or in a J-box system.

Bleaching with Sodium Hypochlorite

The chemical composition of a sodium hypochlorite solution changes with pH (Figure 2.9) (14) due to the reaction :

$$NaOCl + H_2O \Leftrightarrow NaOH + HOCl$$

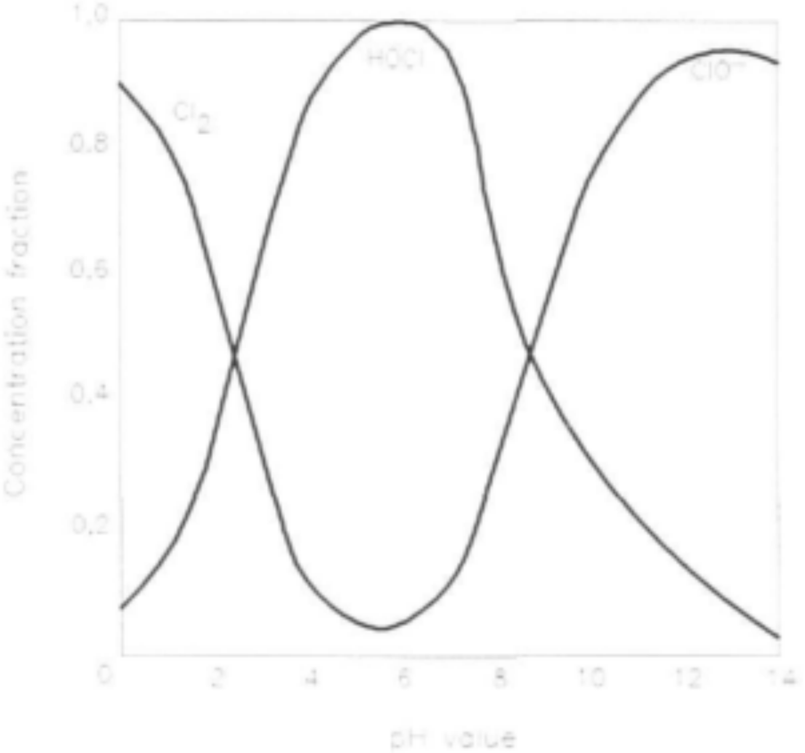


FIGURE 2.9 : COMPOSITION OF A SOLUTION OF SODIUM HYPOCHLORITE AT VARIOUS pH VALUES (14)

The bleaching efficiency of the slightly dissociated hypochlorous acid is based on its degradation to active oxygen and hydrochloric acid :

$$HOCl \rightarrow HCl + O^*$$

Cellulose fibre tendering is avoided during hypochlorite bleaching by careful control of bleaching conditions. This includes buffering the bleach solution with alkali to prevent excessive release of oxygen and carrying out the reaction below 25 °C.

Typical recipes for continuous sodium hypochlorite bleaching would include (18) :

Sodium hypochlorite	1,2 g/ℓ.
Sodium hydroxide	0,4 g/ℓ.
Oxidation stable surfactant/wetting agent	0,5 g/ℓ.
Liquor ratio	1 : 1.

Typical recipes of batch bleaching of cotton wool in pressurised vessels would include (15) :

Sodium carbonate	1,1 g/ℓ.
Sodium hypochlorite	2,1 g/ℓ.
Liquor ratio	6 : 1.

Bleaching with Sodium Chlorite

The composition of aqueous solutions of sodium chlorite at different pH values is given in Figure 2.10 (14).

The bleaching agent is active oxygen formed from chlorous acid :

$$NaClO_2 + H_2O \rightleftharpoons NaOH + HClO_2$$

$$HClO_2 \rightarrow HCl + 2O^*$$

Bleaching with chlorite is carried out at elevated temperatures (90 °C) and at pH 3 to 4,5, where chlorous acid is the predominant species. Buffers are added to the bleaching bath to maintain the pH above 3. Activators such as anhydrides of organic compounds, are present to enable gradual lowering of the pH of the bleaching bath.

Typical recipes for padding solutions used in continuous chlorite bleaching would include (14) :

Sodium chlorite (80 %)	30 to 40 g/ℓ.
(lower for polyester/cotton blends).	
Activator	
Surfactant	2 to 3 g/ℓ.
Initial pH	6 (adjusted with formic acid).
Liquor ratio	0,7 : 1 to 1 : 1.
Reaction time	45 min.
Reaction temperature	90 °C.

Typical recipes for winch batch chlorite bleaching would include :

Sodium chlorite (80 %)	4 to 5 g/ℓ.
Wetting agent and stabiliser	2 to 3 g/ℓ.
Sodium nitrate	2 to 3 g/ℓ.
(for corrosion prevention).	
pH	3,5 (adjusted with formic acid).
Liquor ratio	5 : 1.
Batching temperature	80 to 95 °C.
Batching time	2 to 4 h.

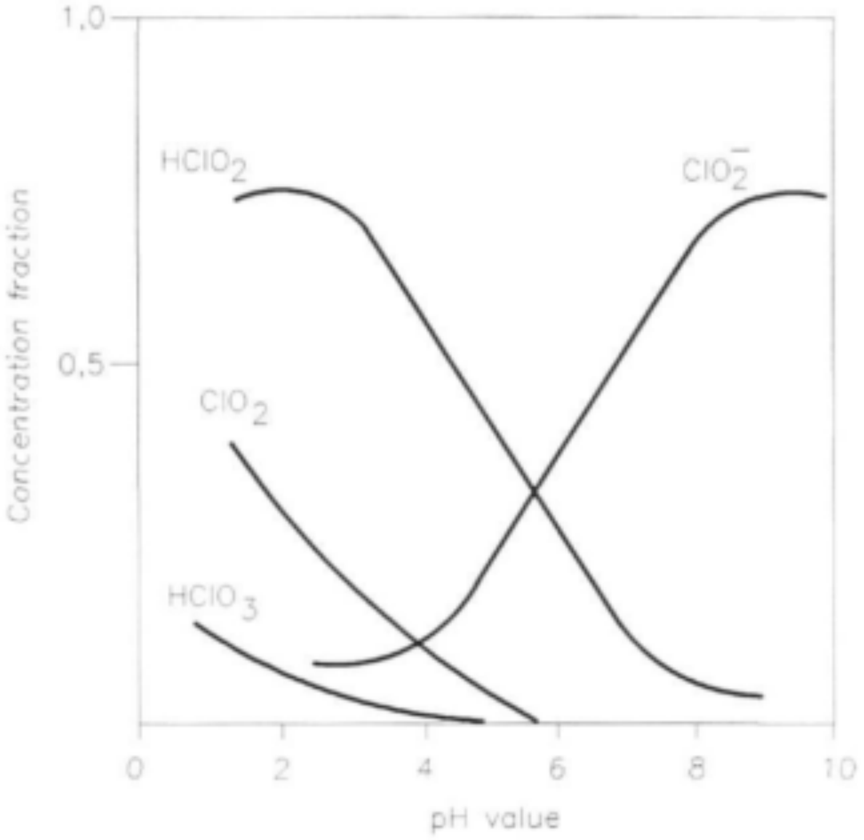


FIGURE 2.10 : COMPOSITION OF A SODIUM CHLORITE SOLUTION AT VARIOUS pH VALUES (14)

Bleaching with Hydrogen Peroxide

This is the most common bleaching agent used since it may be used in all types of bleaching systems (winch, cold pad batch bleaching and high-temperature shock bleaching).

Hydrogen peroxide is a weak acid and in alkaline solution the hydrogen peroxide anions are the source of active oxygen for bleaching :

$$H_2O_2 + OH^- \rightarrow H_2O + HO_2^-$$

$$HO_2^- \rightarrow OH^- + O^*$$

Stabilisers are added in order to control the bleaching process.

During cold pad batch bleaching the goods are padded, batched, wrapped in plastic sheets and rotated at room temperature for a period of time. Typical recipes for the cold pad batch padding solution would include (18):

Sodium hydroxide	11 g/ℓ.
Sodium silicate stabiliser	21 g/ℓ.
Additional stabiliser	6 g/ℓ.
Detergent/sequestrant	3 g/ℓ.

Hydrogen peroxide (50 %)	30 mℓ/ℓ.
Surfactant	4 g/ℓ.
Liquor ratio	1 : 1.

Winch, or long liquor bleaching is a high-temperature (85 to 95 °C) batch process with typical recipes for the bleaching bath including (15) :

Sodium hydroxide	1 to 2 g/ℓ.
Stabiliser	1 to 2 g/ℓ.
Hydrogen peroxide (35 %)	3 to 6 mℓ/ℓ.
Surfactant	1 g/ℓ.
Liquor ratio	5 : 1.
Batching time	3 h.

Continuous bleaching in J-box or pressure chamber units is carried out using padding solutions with typical recipes including (18) :

Sodium hydroxide	2 to 3 g/ℓ.
Sodium silicate stabiliser	4 to 6 g/ℓ.
Additional stabiliser	4 to 6 g/ℓ.
Detergent/surfactant	2 to 3 g/ℓ.
Hydrogen peroxide (35 %)	20 to 40 mℓ/ℓ.
Liquor ratio	0,7 : 1 to 1 : 1.

2.6 SINGLE-STAGE DESIZING, SCOURING AND BLEACHING

The one-step oxidative desizing, scouring and bleaching has the advantage of reducing the number of textile padding and washing processes. The cost of the chemicals, however, is greater than in the conventional route.

Typical recipes for the padding solution for continuous processing would include (15) :

Sodium hydroxide	9,8 g/ℓ.
Sodium silicate	15 g/ℓ.
Hydrogen peroxide	25 mg/ℓ.
Potassium persulphate	1,5 g/ℓ.
Scouring/wetting agent	6 g/ℓ.
Sequestrant/organic peroxide	
Stabilizer	2 g/ℓ.
Liquor ratio	1 : 1.

The characteristics of the effluent for a water use of 5 ℓ/kg cloth and a wet pick-up of 50 % would be (15) :

pH	alkaline (11,0).
Sodium hydroxide	5 g/kg cloth.
Total solids	184 g/kg cloth.
Temperature	100 °C.

2.7 EFFLUENTS FROM WET PROCESSING : SCOURING, MERCERISING AND BLEACHING

In the pretreatment processes under consideration the wash-off generally constitutes the effluent. In general the chemical composition of effluents from a particular operation on a specific material will vary from plant to plant. The concentration of the effluents will show the greatest variance and will be determined by the :

(i) impurity level on the raw fibre before wet processing,

(ii) use of batch or continuous systems,

(iii) type and configuration of the wash ranges,

(iv) chemical concentration in the batch or padding solution,

(v) efficiency of the washer,

(vi) liquor ratio and the wash-water flow rate.

2.7.1 Effluent Loads

The relative pollution load of the singeing, desizing, scouring, bleaching and mercerising effluents of a particular mill processing cotton and polyester blends is given in Table 2.4 (**16**).

TABLE 2.4
RELATIVE POLLUTION LOAD - SINGEING, DESIZING, SCOURING, BLEACHING AND MERCERISING (16)

Process	Effluent volume %	COD mass %	TS mass %	OA mass %	TC mass %
Singeing	2,1	8,2	5,7	7,0	6,4
Desizing	33,9	57,0	44,0	47,9	61,6
Scouring	22,2	25,6	36,8	25,8	26,6
Bleaching	22,2	5,9	7,2	13,3	3,3
Mercerising wash 1	0,8	0,1	0,4	0,1	0,1
Mercerising wash 2	19,8	3,2	5,9	5,9	2,0
Total load (g/kg cloth)		130	186	21	55
Concentration (mg/ℓ)		10,4	14,3	1,6	4,4

At this mill, the scouring effluent contributed over 25 % of the COD and over 36 % of the TS loading of the wet preparation section. On a mill basis, both the COD and TS constituted 10 % of the total factory effluent loading.

The bleaching and mercerising effluent volumes were comparable to that of the scouring effluent. However, the contribution of these effluents to the COD and the TS of the effluent from the wet preparation section was relatively low (3 to 7 %).

2.7.2 Effluent Characteristics

As a guide to the range of characteristics of the effluents under consideration from the wet processing of cotton, polyester/cotton and polyester, Table 2.5 gives the approximate effluent concentrations and pollution loads.

The data in the table have been extracted from various surveys (**15-18**) and can also be used to predict the effluent characteristics of a process, or a series of processes.

TABLE 2.5

POLLUTION LOADS AND EFFLUENT CONCENTRATIONS FOR VARIOUS WET PREPARATION OPERATIONS (15-18)

Process and fibre	Type	Production (1)	Effluent	pH	Cond.	TS		Na		Ca		Mg		NaOH		TOC		COD	
			l/kg		mS/m	g/kg	g/l	g/kg	g/l	g/kg	g/l	g/kg	g/l	g/kg	g/l	g/kg	g/l	g/kg	g/l
Scouring:																			
cotton (high grade)	fibre	boil-off (b)	20	11-12	1 700			45	2,3					48	2,4	41	2,1		
		kier-boil (b)	17	10-13	1 500			33	1,9					45	2,7	24	1,4		
cotton (low grade)	fibre	boil-off (b)	20	12-13	1 300			59	2,9					84	4,2	68	3,4		
cotton	woven	kier-boil 1 (b)	30	10-13	100-3 400	206	7	53	1,8	0,8	0,03	0,6	0,02	45	1,5	36	1,2		
cotton	woven	kier-boil 2 (b)	18	9-12		72	4	22	1,1							26	1,5	68	3,3
polycotton	woven	caravan (c)	3,8	13,5	7 400	194	51	65	17	0,3	0,08	0,08	0,02	99	26	38	10	122	32
polycotton	woven	J-box (c)	2,3	13										18	9				
polycotton	woven	openwidth 1 (c)	3,1	13,5	8 200	93	30	34	11	0,1	0,03	0	0	59	19	12	4	31	10
polycotton	woven	openwidth 2 (c)	7,3	13										41	6				
polycotton	woven	openwidth 3 (c)	2,5	10-12		59	24									13	5,3	30	12
polycotton	knit	1 (b)	42	8-10		28	0,7	5	0,13							4	0,1	4	0,1
polycotton	knit	2 (b)	21	9	100	27	2,7	1,3	0,1	0,2	0,02	0,2	0,02			10	1,1		
polyester	woven	(b)	21	10	100	13	1,3	1,9	0,2	0,1	0,01	0	0			11	1		
Oxidative desizing, scouring and bleaching:																			
polycotton	woven	(c)	5	11	900	184	37	2	0,4	0	0	0	0	5	1	55	11	213	43
Mercerising:																			
polycotton	woven	(c)	2,9											166	58				
polycotton	woven	(c)	3,7			183		138						240					

Notes: (1) (b) denotes batch.
(c) denotes continuous.
1-4 denotes mill examples.

(Table 2.5 continued on next Page)

TABLE 2.5 (cont.)

Process and fibre	Type	Production (1)	Effluent	pH	Cond.	TS		Na		Ca		Mg		NaOH		TOC		COD	
			l/kg		mS/m	g/kg	g/l	g/kg	g/l	g/kg	g/l	g/kg	g/l	g/kg	g/l	g/kg	g/l	g/kg	g/l
<u>Bleaching</u>:																			
cotton	wool	1 (b)	59	7-8	90			9	0,16					0	0	2	0,04		
(high grade)		2 (b)	29	7-10	300			19	0,6					0	0	6	0,2		
cotton	wool	3 (b)	59	7-8	90			9	0,16					0	0	2	0,04		
(low grade)		4 (b)	29	4-10	300			20	0,7					0	0	6	0,2		
cotton	woven	(b)	15	7-9		8	0,6	0,6	0,4							0,9	0,08	1,1	0,07
cotton	woven	(b)	15			8	0,5	1,5	0,1							0,9	0,06	4,5	0,3
cotton	woven	cold pad (c)	5	10	100	10	2,1	1,6	0,3	0,1	0,02	0,03	0,01	0,1	0,03	3	0,6	13	2,7
cotton	knit	(b)	22	9		62	3,1	5	0,2							16	1	30	1,7
polycotton	woven	openwidth (c)	2,5	8-9		12	4,6									1,7	0,6	7	2,8
polycotton	knit	(b)	15	10-11		22	1,5	3	0,2							6	0,4	13	0,9
polyester	knit	(b)	38	9		28	0,7	1,4	0,04							55	1,4	124	3,2

Notes: (1) (b) denotes batch.
(c) denotes continuous.
1-4 denotes mill examples.

3 REVIEW OF EFFLUENT TREATMENT TECHNIQUES FOR SCOURING, BLEACHING AND MERCERISING EFFLUENTS

3.1 INTRODUCTION

Individual textile mills tend to concentrate on one method of textile manufacture (e.g. knitting or weaving) and on the processing of one fibre or its blends e.g. cotton, wool or nylon or combinations such as polyester/viscose and polyester/cotton.

The effluent composition from a mill is a function of the major fibre utilised by the mill since the techniques employed during the processing of any particular fibre are universal.

The textile effluents under consideration differ in characteristics from acid to strongly alkaline depending on the textile process and on the fibre being prepared since :

(i) scouring effluents are usually alkaline and high in inorganic salts due to the alkali used,

(ii) bleaching effluents can be acid or alkaline,

(iii) mercerising effluents are always alkaline due to the nature of the process.

For the effluents under consideration, the primary and secondary treatment methods of screening, filtering, sedimentation, flotation and biological treatment are not generally applicable. In addition, the normal tertiary and advanced treatments of coagulation, multi-media filtration, activated carbon adsorption and ozonation, are not suitable. For the treatment of these effluents it is necessary to apply chemical and physical treatment methods, which might include the demineralisation techniques of ion exchange, conventional membrane and electromembrane processing, freezing or evaporation.

The various methods which have been proposed for the treatment of scouring, bleaching and mercerising effluents are given below.

3.2 SOLVENT SCOURING AND BLEACHING

In solvent processing, water is replaced by a solvent which is recovered by distillation. Substitution of solvent treatment systems for the scouring and bleaching of cotton products reduces water pollution. However, any unrecovered solvent presents a greater disposal problem than a waste-water stream. In addition, air pollution during solvent recovery and product drying can be high.

3.3 EFFLUENT NEUTRALISATION

The removal of excess acidity or alkalinity is often necessary before either discharge of an effluent or further treatment. Acidic effluents are generally neutralised with an alkali, while sulphuric acid is generally used to neutralise alkaline effluents. Carbonation, using waste combustion products from boilers is a cheaper and feasible method of neutralising alkaline streams prior to discharge (**9,21**). In addition, the sensible admixture of effluents of an acidic or alkaline nature within a factory will assist in neutralisation of the final effluent, although there is usually an excess of alkali in plants treating cellulosic fibres (**22**).

3.4 SEGREGATION OF EFFLUENT STREAMS

Concentrated effluent streams or waste streams containing hazardous chemicals may be isolated from the main effluent discharge and confined for separate treatment or partial purification. It is beneficial to segregate hazardous or concentrated effluents and dispose of them separately. Balancing tanks may be installed to even out the pollution load.

3.5 BIOLOGICAL TREATMENT

Because textile wastes are carbonaceous they lend themselves to bacteriological decomposition as a method of treatment if the pH is not too high or low and if appropriate nutrients are present (**23**). The application of biological processes for the treatment of textile waste waters in conjunction with domestic effluent has been reported extensively (**9,24-30**). The extended aeration activated sludge process has consistently demonstrated its value as the best form of biological treatment (**31,32**). Biological treatment plants do not generally diminish the concentration of the alkaline textile effluents since the hydroxide alkalinity inhibits the biological process and hence the COD reduction.

It is possible to treat admixtures of textile effluents and domestic sewage by the activated sludge process. In the case of kier type liquors, fortified with ammonium phosphates, a reduction of 95 % in BOD (**33**) has been achieved.

It is possible to neutralise the alkaline effluents and biologically treat them in admixture with other bleaching and dyeing wastes (**9**). However, only small volume ratios may be employed due to interference of fatty matter and inorganic salts in the biological process.

It is possible to partially treat scouring and kiering liquors in percolating filters in admixture with dyehouse waste (**9**). Pilot plant results on combined kiering liquor and dyehouse wastes gave a proportional BOD removal of 8 to 48 % of the initial loading. BOD removals of 24 to 92 % were obtained on dyehouse wastes.

3.6 EVAPORATION

Mercerising effluent is normally treated by filtration and/or centrifugation to remove suspended matter, followed by evaporation to produce a concentrate suitable for reuse in the mercerising process (**34,35**).

Multi-stage circulation evaporators are commonly used (**36**) and are operated under partial vacuum and with heating in the first stage. Heat is recovered from the condensate. Since recovery of pollutants by evaporative techniques is more cost effective when the pollutants are present at a high concentration, multi-stage counter-current rinsing ranges are used to produce concentrated sodium hydroxide evaporator feed. The concentrated evaporator product may be purified by filtration or centrifugation.

Scouring effluents are generally considered too contaminated with extracted impurities to enable addition to the mercerising effluent for recovery by evaporation (**10**).

The fundamental obstacle limiting the use of evaporation is energy consumption. Practical limitations include heat transfer characteristics, crystal formation, salting, scaling, corrosion, entrainment and foaming.

3.7 FLOCCULATION

It is possible to pretreat scouring effluents by flocculation to reduce the pollution load. Acidification of scouring effluents to pH 2 to pH 7 generally flocculates large amounts of dispersed suspended material. This material is sticky and difficult to consolidate and separate. Sedimentation trials have proven unsatisfactory in concentrating the solid matter (**9**).

3.8 FLOTATION

In flotation methods gas bubbles carry the dispersed impurities to the surface of the liquid. The foam so formed is removed mechanically. The gas bubbles may be generated (**36**) :

(i) mechanically by air nozzles and turbines,
(ii) electrolytically,
(iii) chemically from gas-forming chemicals.

The one-stage chemical flotation method developed by the Textilverein Vorarlberg and the Institut Für Textilchemie und Textilphysik in Dornbirn, Austria, is used for purifying concentrated sodium hydroxide effluents under oxidising conditions with the removal of lint, dispersed matter, dyes, fatty and waxy constituents, sizes, surfactants, dissolved impurities and natural dyes (**36**).

The operation of a pilot plant (**37**) demonstrated that bleaching effluent could be reused after coagulation, flocculation and air-flotation. Aluminium sulphate, sulphuric acid and polyelectrolytes were used and there was a 41 % reduction in the suspended solids concentration, from 85 to 50 mg/ℓ, and a reduction in the COD, from 3 684 to 1 934 mg/ℓ.

The treated effluent was of suitable quality for reuse in the last washing stage in mercerising, where hot water, usually acidified with acetic acid, was used.

3.9 MEMBRANE SEPARATION

Membrane separation methods include microfiltration, ultrafiltration and reverse osmosis. These processes are pressure-driven processes capable of separating solution components on the basis of molecular size and shape, and involve neither a phase change nor interphase mass transport. Being highly cost effective, these techniques are widely used in the textile industry (**38-43**). A combination of ultrafiltration and reverse osmosis to purify and concentrate caustic effluents in the textile industry has been proposed (**36**). The membranes have the desired separation properties but the principle cannot be put into practice at present due to the instability of the membranes to sodium hydroxide and various mercerising auxiliaries.

Electrodialysis (ED) has been applied as a concentrator in the treatment of mercerising effluents to produce a pure sodium hydroxide solution for reuse. However, the process is far more complicated than evaporation. In a full-scale installation, use of ED for the recovery of a 9 to 10 % sodium hydroxide solution, free of organic impurities has been found feasible and has resulted in a recovery of 200 t/a of sodium hydroxide (**44**).

3.10 CAUSTICISING

Causticising is used in the pulp and paper industry as a means of recovering pulping chemicals for reuse in the preparation of new pulping liquor (**45**). The waste liquor contains the chemicals in a dilute solution which has to be concentrated by evaporation prior to the regeneration process. The organics in the liquor are burnt for heat generation, leaving a sodium salt or a mixture of sodium salts, depending on the pulping process. If one of the salts formed is sodium carbonate (e.g. in the kraft process) causticising is achieved using calcium oxide to convert the sodium salt to sodium hydroxide for reuse. Calcium carbonate is converted to calcium oxide in a kiln. Causticising could be applied to the treatment of selected textile effluents which are sufficiently concentrated with respect to both sodium and organics.

3.11 THERMAL OXIDATION

Wet air oxidation is a process in which aqueous wastes can be oxidised in the liquid phase using a combination of elevated temperature and pressure. The system has been commercialised by Zimpro Inc. (USA) (**46-50**). It is claimed that wastes are burned in the presence of water equally as completely as in the usual method of first evaporating the water and then incinerating the dried residue.

The Zimpro process has been applied principally in the pulp and paper industry but it has the potential for treating organic contaminated alkaline liquors from many industries.

3.12 ELECTRO-OSMOSIS

A process was proposed during the early 1920s (**51**) which was aimed at recovering sodium hydroxide from kier liquors by a combination of electrolysis and electro-osmosis. The liquid was placed inside a porous pot with a suitable electrode, which was made the anode, and the porous pot was surrounded by a vessel containing water and a nickel gauze cathode. Lead was found to be the most suitable anode material. Approximately 50 % of the total sodium present in the effluent could be recovered as sodium hydroxide and the liberated organic acids were readily sedimented.

The tests were carried out at bench scale but it was proposed that this process would be "successful in dealing with large volumes and would be more economical than the established process of evaporation to dryness, ignition and lixiviation".

4 WATER AND EFFLUENT MANAGEMENT PROGRAMMES

4.1 INTRODUCTION

The implementation of an effluent management system at a textile factory involves the development of various options which will minimize water consumption and meet the required pollution abatement. Production related modifications are essential in reducing the contamination and the flow of waste streams in order that subsequent effluent treatment and chemical recovery operations may be reduced in size.

An overall strategy for the implementation of an effluent management system would therefore involve several phases :

(i) a water, chemical and effluent survey (Section 4.2),
(ii) in-plant control measures (Section 4.3),
(iii) selection of treatment processes (Section 4.4),
(iv) design and installation of treatment equipment,
(v) continual reassessment of an effluent treatment programme.

All the phases are important. The development of an optimal effluent treatment sequence is possible only if due consideration is given to the first two phases.

This chapter outlines the principles of water and effluent management and their importance in the planning and implementation of an effluent management system.

4.2 WATER, CHEMICAL AND EFFLUENT SURVEY

The aim of a water, chemical and effluent survey is to understand fully the characteristics and variability of the overall factory effluent and the wet processing streams that produce this effluent. This is undertaken by developing detailed water, chemical and energy balances.

Information gathered in a water, chemical and effluent survey may be compared to published literature. Various references (**10,24,25,45**) are helpful in this respect. In addition information on machine water, energy and chemical use is available from textile machinery and chemical suppliers.

4.2.1 Water Balance

An overall water balance and a process water flow sheet may be established after determining the following parameters :

(i) the overall water consumption of the factory, usually from flow meters on the mains water supply,

(ii) the quality of the mains water and the pretreatment procedures required to purify this water to a level suitable for use in processing,

(iii) the process water distribution and the water consumption in each section of the factory,

(iv) a detailed plan of the water, steam and waste-water distribution pipelines and drains. Process, storm and sanitary water sources should be included, together with their point of discharge;

(v) the effluent flow.

Many flow measurement devices are available (**24,52,53**). The accuracy of the meters must be assessed and if necessary the meters should be recalibrated. Reported flows should be related to production and expressed in both m³/h or m³/d as well as in ℓ/kg or ℓ/m of cloth.

An example of the method for summarising the data is illustrated in Figure 4.1 (**54**).

FIGURE 4.1 : EXAMPLE OF A WATER SURVEY SUMMARY

Steam use, both direct and indirect, for each factory process should be determined in a similar manner with particular regard to condensate return.

Example 1 : Water Balance Spreadsheet

A textile mill was supplied with water from the local municipality and from a borehole. In addition, steam was purchased from a neighbouring factory.

A spreadsheet was developed to enable water consumption and effluent volumes at this textile mill to be computed on a weekly basis and summarised as illustrated in Tables 4.1 and 4.2.

TABLE 4.1
EXAMPLE - PROCESS WATER BALANCE
Week ending .....

Stream	Volume m^3	% Raw water	% effluent	Consumption ℓ/m	Comments
Town supply	16 270				
Borehole	596				
Steam (water equiv.)	3 734				
Total water in	20 600				
Measured effluent	17 579				
Calc. steam equiv.	0				
Total effluent	17 579	85,3			
*Sizing	252	1,2	0		
Singeing	235	1,1	1,3	0,5	
Desizing	439	2,1	2,5	0	
Scouring	851	4,1	4,8	1,7	
Mercerising	954	4,6	5,4	2,1	
Relaxing	58	0,3	0,3	6,3	
Goller	567	2,8	3,2	2,0	
Pad steaming	1 593	7,7	9,1	7,1	
Jigger	19	0,1	0,1	6,1	
Printing	1 529	7,4	8,7	8,9	
#Yarn dyeing	371	1,8	2,1	18,0	Expressed as ℓ/m (i.e. kg yarn/4)
#Jet dyeing	969	4,7	5,5	8,1	
#Winch dyeing	0	0	0	0	No water meter
#Boiler	0	0	0		
*Stenter effluent	320	1,6	1,8		
*Air conditioning	979	4,8	-		
*Cooling towers	979	4,8	-		
*Chemical lab.	168	0,8	1,0		
Ion exchange regeneration	672	3,3	-		
*Evaporation	875	4,3	-		
Sewer	1 680	8,2	-		
Miscellaneous	7 090	34,4			
Total	20 600	100,0	45,9	70,7	

# Denotes calculated value based on water meter and cloth data.

* Denotes calculated guess.

TABLE 4.2
EXAMPLE - EFFLUENT ANALYSIS
Week ending .....

	mg/ℓ	kg/h
COD	3 998	418
OA	136	14
TDS	7 061	739
Na	0	0
SS	1 807	189

The factory had made a concerted effort to install flow meters on steam, water and waste-water lines where possible. Where flow measurements were not available, estimates were made.

The water balance indicated that a certain amount of water was unaccountable and classified as "miscellaneous". Various measures were taken to account for this loss. The water balance indicated areas for investigation. In particular the discrepancies were the :

(i) estimated water consumption at the factory, calculated as the summation of the water consumption in each section and the actual factory water intake. Between 10 and 30 % of the actual water intake was classified as "miscellaneous",

(ii) sum of the individual effluent volumes which did not equal the combined factory effluent volume.

The water balance spreadsheets provided weekly information on the distribution of the water within the factory and provided a means for pin-pointing excess water consumption and effluent discharge levels (Table 4.3).

TABLE 4.3
EXAMPLE - CONTRIBUTION OF PROCESS STREAMS TO FACTORY WATER AND EFFLUENT

Water Type(1)	Process	Water m^3/a	Effluent m^3/a	Temp °C	% Total water	% Total effluent
S	Singeing	5 200	2 500	100	0,6	0,4
S	Desizing	18 400	18 000	100	2,1	2,8
S	Scouring	34 300	34 000	100	3,8	5,2
S	Mercerising	46 600	45 000	100	5,2	6,9
S	Relaxing	3 200	3 000	80	0,4	0,5
S	Goller washing & soaping	58 800	59 000	60	6,6	9,1
S	Pad steaming	96 000	96 000	60	10,7	14,8
H	Printing	107 800	108 000	20	12,0	16,6
S	Yarn dyeing	73 500	74 000	60	8,2	11,4
S	Jet dyeing	39 200	39 000	80	4,4	6,0
H	Cooling towers	48 000		20	5,3	0
H	Air conditioning	48 000		20	5,4	0
H	Chemical kitchen	8 200	8 000	20	0,9	1,2
S	Boiling	14 400		20	1,6	0
H	Sewage	82 300		20	9,2	0
S	Miscellaneous	147 000	147 000	20	16,4	22,6
S	Softener regeneration	8 200		20	0,9	0
	Evaporation	42 900		20	4,8	0
S	Stenters	15 700	16 000	20	1,8	2,5
	Total	897 700	650 000			

Note: (1) S = softened water.
H = unsoftened water.

Example 2 : Monitoring Individual Process Water Consumption

In addition to the overall water balance, the water consumption at two of the major wet-processing machines - the Goller washer and the pad steamer was carefully monitored. A target water consumption was set and the actual water consumption was carefully monitored and compared with the target consumption. Where the actual consumption exceeded the target consumption, the excess cost was calculated. Star ratings were also employed to indicate an exceptionally high water consumption. Examples of the water consumption for the two machines are illustrated in Tables 4.4 and 4.5.

Example 3 : Condensate Consumption

Examination of the process water balance tables of the above factory, indicated that a considerable amount of water was being discharged with the effluent which was not recorded as process water. This prompted an investigation into the amount of steam condensate discharged from the boiler house.

TABLE 4.4
EXAMPLE - GOLLER WASH AND SOAP, SUMMARY OF DAILY WATER CONSUMPTION

Week ending .....

Process	% Total length	% Total volume	% Total time	Flow m^3/h	Consumption ℓ/m	Target ℓ/m	Star rate	Excess cost	Target cost
Vat printing	58,5	63,6	81,5	2,0	1,7	6,0		0	993,9
Dispersed/Reactive dyeing	0	0	0	0	0	5,0		0	0
Dispersed/Reactive printing	0	0	0	0	0	5,0		0	0
Reactive dyeing	12,0	19,3	8,3	5,9	2,5	5,0		0	121,0
Reactive printing	4,7	3,0	3,2	2,4	1,0	5,0		0	47,1
Pigment printing	3,8	2,6	2,7	2,4	1,0	4,0		0	20,7
Loom stat	4,0	1,2	1,9	1,6	0,4	1,0		0	13,5
Bleaching	17,1	10,4	7,9	3,4	0,9	1,4		0	80,5
Coloured woven	0	0	0	0	0	1,4		0	0

TABLE 4.5
EXAMPLE - PAD STEAM, SUMMARY OF DAILY WATER RECORDS

Week ending .....

Process	% Total water	% Total cloth	% Total time	Flow m^3/h	Consumption ℓ/m	Target ℓ/m	Star rate	Excess cost R	Target cost R
Terindosol	0	0	0	0	0	3,0		0	0
Disp/vat	21,5	25,1	6,2	26,8	7,5	3,5	*****	65,9	58,3
Vat	42,3	34,3	8,5	38,7	10,8	6,2	***	103,3	141,2
Dyeing	8,8	0,8	0,2	323,4	90,2	6,2	********	47,4	3,5
Azoics	10,7	16,7	4,1	20,0	5,6	6,0		0	110,1
Reactives	16,7	23,1	5,7	22,8	6,4	5,0	*	33,4	126,3

Records for a particular month indicated that the condensate tanks were emptied on 303 occasions releasing 18 m^3 each time. In addition to this, a 50 mm drain line was permanently open.

The flow of discharged condensate was estimated at 9,8 m^3/h, the value of which was calculated to be in excess of R60 000/a (1986) based on 270 working days.

Analysis of this condensate indicated that its quality compared favourably with that of factory soft water and its reuse, after filtering to remove rust particles, was recommended. In addition to water and energy savings, the reuse of condensate would enable additional savings in ion-exchange resin regeneration.

4.2.2 Chemical and Effluent Balance

The raw materials into a textile finishing mill are fabric, water, energy and chemicals. The products are :

(i) modified fabric,
(ii) effluent,
(iii) waste heat,
(iv) exhausted chemicals,
(v) fabric impurities.

The effluent characteristics may be determined in one of two ways :

(i) by the analysis of samples of the effluent,

(ii) from the consumption of chemicals and their expected exhaustion in relation to the water flow.

A material balance over a wet process should include calculations of the effluent concentration and the effluent loading in mass of pollutant per mass of fabric produced.

In the development of an effluent management strategy consideration should also be given to the :

(i) discharge regulations and possible amendments,
(ii) effluent discharge costing formulae,
(iii) cost of steam, water pretreatment and alternative water supplies,
(iv) factory expansion plans,
(v) process(es) type.

Sodium hydroxide is the major bulk chemical consumed by the textile industry and substantial amounts of this chemical are discharged with the effluent. Approximately 6 000 t/a (2 % of the total market) of sodium hydroxide was consumed by the South African textile industry during 1987 (**55**). The efficient utilisation of sodium hydroxide results in a reduced raw material cost and a reduced pollution load from a textile mill. Typical data required to determine the efficiency of sodium hydroxide utilisation includes :

(i) sodium hydroxide purchases and transfers,

(ii) cloth production by individual processes,

(iii) variation in the specific sodium hydroxide consumption by individual processes,

(iv) theoretical specific sodium hydroxide consumption,

(v) mass of recycled sodium hydroxide,

(vi) potential mass of sodium hydroxide which could be recycled.

The following examples illustrate how sodium hydroxide balances over both individual processes and the whole factory can lead to substantial savings in chemical consumption and reductions in effluent loading.

Example 4 : Overall Sodium Hydroxide Reticulation Survey

A survey of all the sodium hydroxide consuming processes was conducted at a textile mill processing woven cotton and polyester/cotton blends. The aim was to take a holistic approach to the sodium hydroxide consumption as opposed to an approach where individual streams were considered in isolation.

The factory personnel had been routinely gathering and logging the following information :

(i) the amount of sodium hydroxide purchased - duplicate records existed, those at the delivery site and those at stores,

(ii) the amount of sodium hydroxide recovered for reuse after evaporation of the mercerising effluent,

(iii) the hour and water meter readings on various machines,

(iv) the chemical consumption at each machine,

(v) the recipes used for the batch make-up and the volume of each batch,

(vi) the hour meter readings on the various pumps used for conveying the mercerising effluent and the scouring effluent to the solar evaporation dams and the combined effluent from the other processes,

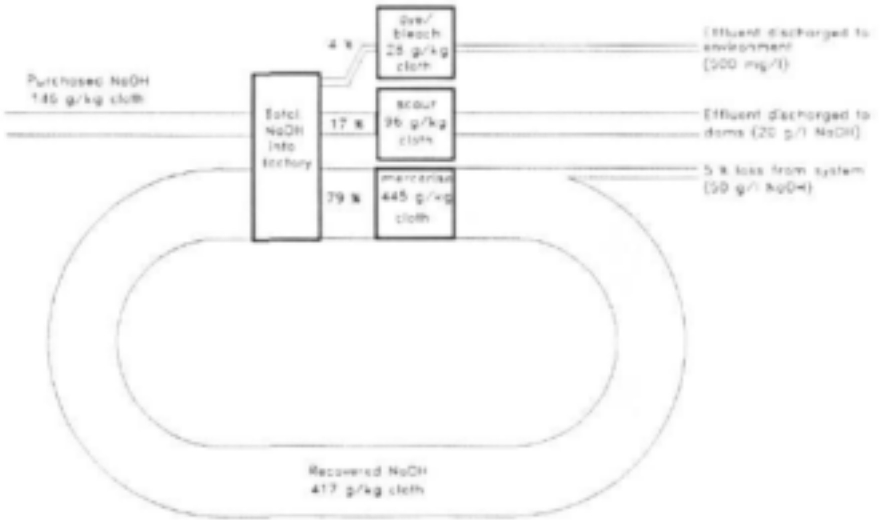
(vii) flow meter readings on some effluent pipelines,

(viii) the concentrations of various effluent and waste water streams,

(ix) cloth production data.

In addition wet pick-up data was available for various machines.

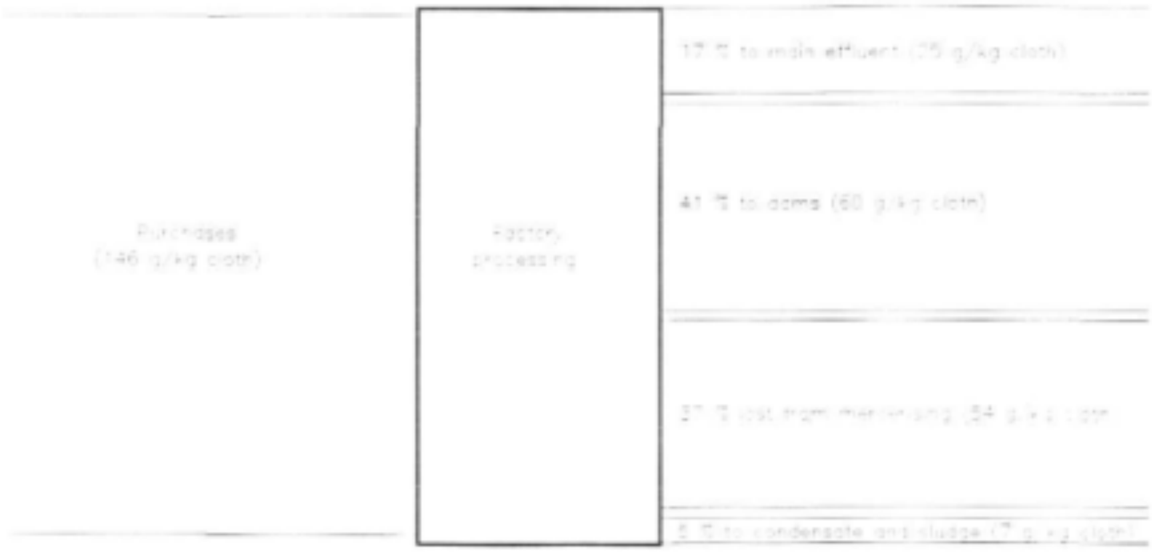
Collation and manipulation of the raw processing data, collected over a six-month period, enabled the establishment of a sodium hydroxide balance across the entire factory, which is illustrated in Figure 4.2.



Note: The width of the streams are proportional to the sodium hydroxide mass flow

FIGURE 4.2 : SODIUM HYDROXIDE BALANCE AT THE FACTORY

The areas of sodium hydroxide loss were established and are summarised in Figure 4.3. Of the net sodium hydroxide entering the factory (purchases), 17 % was discharged to the main effluent, 41 % was pumped to the solar evaporation dams and 5 % was lost at the evaporator. The remaining 37 % of the purchases (54 g/kg cloth) was lost from the reticulation system between mercerising and evaporation. At the cost of sodium hydroxide delivered to the factory (R800/t 100 % NaOH) this translated to a loss of almost R300 000 per annum (1986).



Note: The width of the streams are proportional to the sodium hydroxide mass flow

FIGURE 4.3 : SODIUM HYDROXIDE LOSSES

Recommendations were made to enable the :

(i) elimination of the major sodium hydroxide losses - investigations indicated faulty valves and drainage systems in the merceriser-evaporator reticulation loop,

(ii) optimisation of the recovery and reuse of sodium hydroxide by the scheduling of all streams,

(iii) control of sodium hydroxide consumption to reduce processing variables and to achieve maximum consistency in cloth quality,

(iv) use of a sodium hydroxide balance spreadsheet which would enable management to assess the sodium hydroxide situation within the factory at any given time.

A similar survey was conducted the following year to reassess the situation (18). The results indicated that unaccounted losses had been decreased but that the specific sodium hydroxide consumption had increased from 76 to 93 g/linear m. Consumption had increased by 23 % in the year but the recovery capacity of the evaporator had remained constant.

The inability of the evaporator to meet the demand required of it in terms of evaporative capacity resulted in 31 % of the mercerising effluent (an average of 17 t/week of NaOH) by-passing the evaporator. At a replacement value of R800/t 100 % NaOH this translated to a loss of R675 000/a (1987).

In addition, due to environmental pressures relating to the use of the solar evaporation dams, the factory management was planning the implementation of a treatment system for the recovery of sodium hydroxide from scouring effluent. It was envisaged that this would make the continual use of the dams unnecessary. The survey, however, indicated that 65 % of the sodium hydroxide loading in the dam influent was due to the discharge of mercerising effluent. Hence, management was forced to reconsider its objectives, the solution of the mercerising effluent-evaporator system became the primary concern.

Example 5 : Overall Sodium Hydroxide Reticulation Survey

A survey of all the sodium hydroxide consuming processes was conducted at a second textile mill producing woven cotton and polyester/cotton blends in order to evaluate the effectiveness with which sodium hydroxide was being used.

The factory personnel had collected, on a routine basis, records of :

(i) sodium hydroxide purchases and recoveries,
(ii) process water and chemical consumption of individual machines,
(iii) cloth production.

The survey involved the collation and analysis of data logged over a period of twelve months. Results were obtained regarding the :

(i) specific water consumption of various processes,
(ii) specific sodium hydroxide consumption of various processes and machines,
(iii) average sodium hydroxide concentration in the effluent.

The sodium hydroxide consumption at each machine was compared to the consumption calculated from recipes and batch data. The overconsumption was due to variations in the wet pick-up after impregnation and poor control in the mixing station. The excess consumption of sodium hydroxide over the twelve-month period amounted to 289 t as 100 % NaOH, which translated to an overexpenditure of approximately R180 000 (1986) for the period.

The monthly variation in the specific sodium hydroxide consumption (g/kg cloth) for the different processes was large. It was assumed that the fabric quality during the month with the lowest specific sodium hydroxide consumption (which was below the recipe consumption) in each process was satisfactory. Using these figures the excess consumption in the major sodium hydroxide consuming processes was estimated and the acceptable use was found to be 941 t lower than the actual consumption. This translated to an additional excess annual chemical cost of approximately R600 000 (1986).

Investigations showed that less than 45 % of the sodium hydroxide fed to the merceriser was being recovered since only the stream from the first washing stage was recycled to the evaporator. This loss represented 34 % of the purchased sodium hydroxide and represented an annual replacement cost of R375 000 (1986). The recovery of this sodium hydroxide would both reduce sodium hydroxide consumption and the pollution load of the effluent from the factory.

Example 6 : Sodium Hydroxide Reticulation During Mercerising

A third textile mill operated a mercerising system illustrated in Figure 4.4. The impregnator sodium hydroxide concentration was increased from 240 g/ℓ to 320 g/ℓ to improve cloth quality. Within a couple of months the overall factory consumption of sodium hydroxide had increased disproportionally from approximately 50 t/month to over 240 t/month.

A survey of the mercerising and evaporation system was conducted to determine the implications of the increase in the impregnator concentration on the sodium hydroxide consumption.

The mass balance across the impregnator is shown in Figure 4.5. Sodium hydroxide losses from the impregnator section of the mercerising unit were dependent on :

(i) drag-in water from the wetting of the fabric prior to impregnation,
(ii) drag-out sodium hydroxide from the impregnator,
(iii) overflow sodium hydroxide from the impregnator.

Manipulation of the mass balance data enabled the following relationships to be determined :

(i) the effect of drag-in water on sodium hydroxide dilution, which was dependent on the squeezing efficiency of the rollers immediately before the impregnator,
(ii) the sodium hydroxide loss by drag-out, which was a function of the operating efficiency of the squeeze rollers between impregnation and stabilisation and the concentration of the sodium hydroxide in the impregnator,

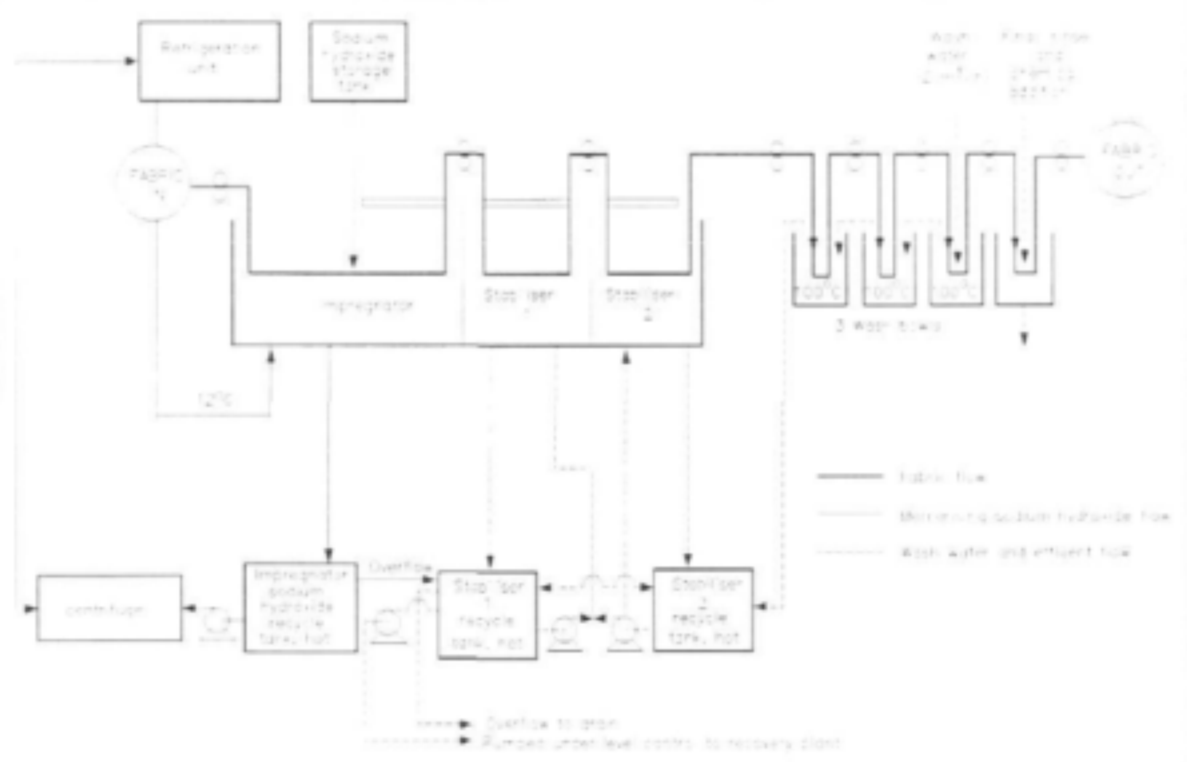


FIGURE 4.4 : SCHEMATIC OF MERCERISING SYSTEM

(iii) the overflow loss from the impregnator, which was a function of mercerising concentration and feed sodium hydroxide concentration (Figure 4.6),

(iv) the overflow loss as a function of the fraction and concentration of the recovered sodium hydroxide in the feed sodium hydroxide. Figure 4.7 indicates the mass balance used for this case. Figure 4.8 illustrates this relationship at various mercerising concentrations.

The conclusions were as follows :

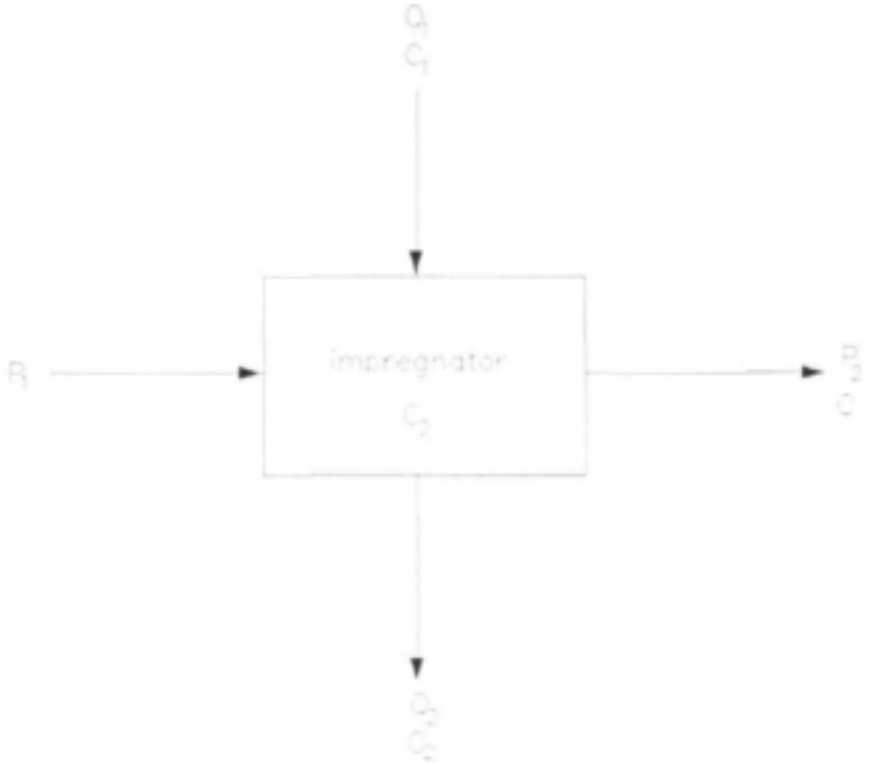
(i) The mercerising sodium hydroxide was diluted by drag-in water on the fabric. Increased expression of the squeeze rollers between the padding impregnation sections would decrease the dilution of mercerising sodium hydroxide. The overall effect would be a reduction in the amount of sodium hydroxide make-up to the impregnator.

(ii) Sodium hydroxide loss from the impregnator by drag-out on the fabric was greatest at high mercerising concentrations. At a wet pick-up of 0,59 kg solution/kg cloth, drag-out loss was :

141 g NaOH/kg cloth for mercerising at 240 g/ℓ NaOH or
188 g NaOH/kg cloth for mercerising at 320 g/ℓ NaOH.

(iii) Sodium hydroxide loss from the impregnator by overflow was strongly dependent on the feed sodium hydroxide concentration (closely associated with the fraction and the concentration of the recovered sodium hydroxide) and the mercerising concentration. At a fixed-feed sodium hydroxide concentration of 400 g/ℓ the overflow sodium hydroxide losses were :

176 g NaOH/kg cloth for mercerising at 240 g/ℓ NaOH or
1 001 g NaOH/kg cloth for mercerising at 320 g/ℓ NaOH.



P_1 = drag-in of water by fabric (g/kg cloth), typically 53 %.

P_2 = drag-out of sodium hydroxide by fabric (g/kg cloth), typically 59 %.

C_1 = concentration of feed sodium hydroxide (g/ℓ).

C_2 = concentration of merceriser sodium hydroxide (g/ℓ).

Q_1 = flow of feed sodium hydroxide (ℓ/kg cloth).

Q_2 = overflow from impregnator (ℓ/kg cloth).

For water : $Q_1 = P_2 - P_1 + Q_2$ (1)

For sodium hydroxide : $Q_1 C_1 = Q_2 C_2 + P_2 C_2$ (2)

Substituting (1) into (2) and re-arranging gives :

$$Q_2 = \frac{P_2 C_2 + P_1 C_1 - P_2 C_1}{(C_1 - C_2)} = sodium\ hydroxide\ over\,flow \quad (l/kg\ cloth)$$

$$Q_2 C_2 = \frac{C_2(P_2 C_2 + P_1 C_1 - P_2 C_1)}{(C_1 - C_2)} = sodium\ hydroxide\ over\,flow \quad (g/kg\ cloth)$$

FIGURE 4.5 : MASS BALANCE ACROSS IMPREGNATOR

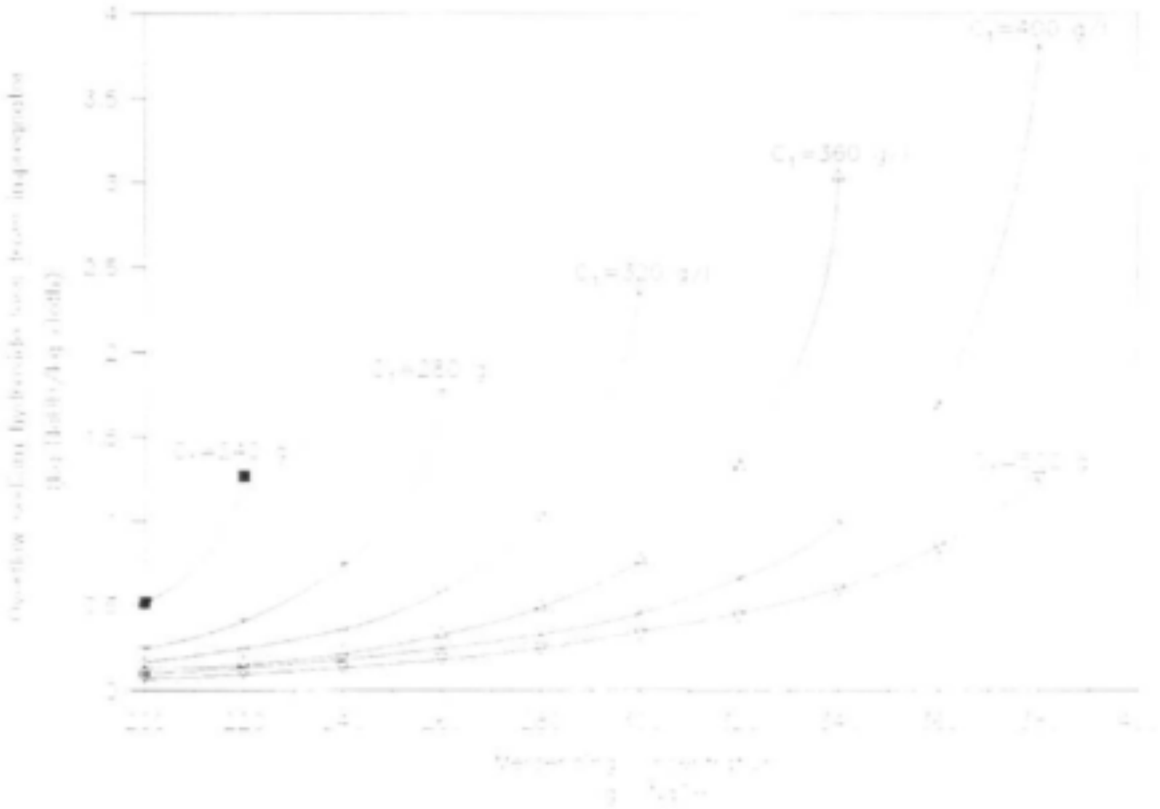


FIGURE 4.6 : VARIATION OF OVERFLOW SODIUM HYDROXIDE LOSS WITH MERCERISING CONCENTRATION AT VARIOUS FEED SODIUM HYDROXIDE CONCENTRATIONS (C_1) AND WITH DRAG-IN WATER = 0,53 ℓ/kg CLOTH

(iv) The lower the recovered sodium hydroxide concentration and the higher the fraction of it in the impregnator feed, the greater was the sodium hydroxide loss by overflow as the impregnator was maintained at a constant sodium hydroxide concentration. It was thus important that the recovered sodium hydroxide be evaporated to as high a concentration as possible.

(v) The calculated monthly consumption of sodium hydroxide was :

108 t for mercerising at 240 g/ℓ NaOH or
421 t for mercerising at 320 g/ℓ NaOH.

These figures were calculated on the assumption that the feed sodium hydroxide concentration was 400 g/ℓ, the monthly cloth production was 367 t and the drag-in and drag-out of the fabric was 0,53 and 0,59 g/kg respectively.

(vi) The total flow of effluent from the first stabilising, caused by overflow from the impregnator tank, was calculated as :

2 652 kg solution/h (2 433 ℓ) at 8,5 % for mercerising at 240 g/ℓ NaOH or
3 911 kg solution/h (3 383 ℓ) at 16,8 % for mercerising at 320 g/ℓ NaOH.

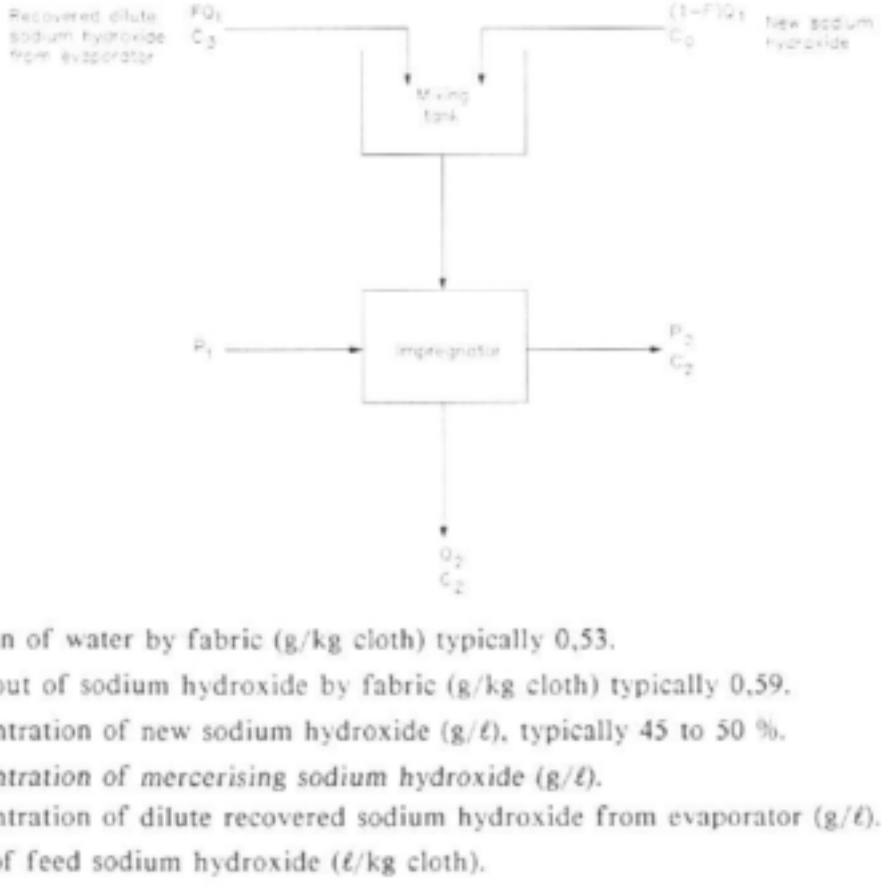
(vii) Inspection of the evaporator performance indicated that the flow of condensate being produced was 25 % that of design specifications.

The production of a 30 % NaOH concentrate from the evaporator was estimated to require a volume reduction of :

1 754 ℓ/h for a feed of 2 433 ℓ/h at 8,5 % or
1 504 ℓ/h for a feed of 3 383 ℓ/h at 16,9 %.

Thus at the operating capacity of the evaporator about half the sodium hydroxide consumed during mercerising could be recovered. This implied a loss of :

113 kg NaOH/h for mercerising at 240 g/ℓ NaOH or
263 kg NaOH/h for mercerising at 320 g/ℓ NaOH.



P_1 = drag-in of water by fabric (g/kg cloth) typically 0,53.
P_2 = drag-out of sodium hydroxide by fabric (g/kg cloth) typically 0,59.
C_0 = concentration of new sodium hydroxide (g/ℓ), typically 45 to 50 %.
C_2 = concentration of mercerising sodium hydroxide (g/ℓ).
C_3 = concentration of dilute recovered sodium hydroxide from evaporator (g/ℓ).
Q_1 = flow of feed sodium hydroxide (ℓ/kg cloth).
Q_2 = overflow sodium hydroxide from merceriser (ℓ/kg cloth).
F = fraction feed sodium hydroxide as recovered sodium hydroxide from evaporator.

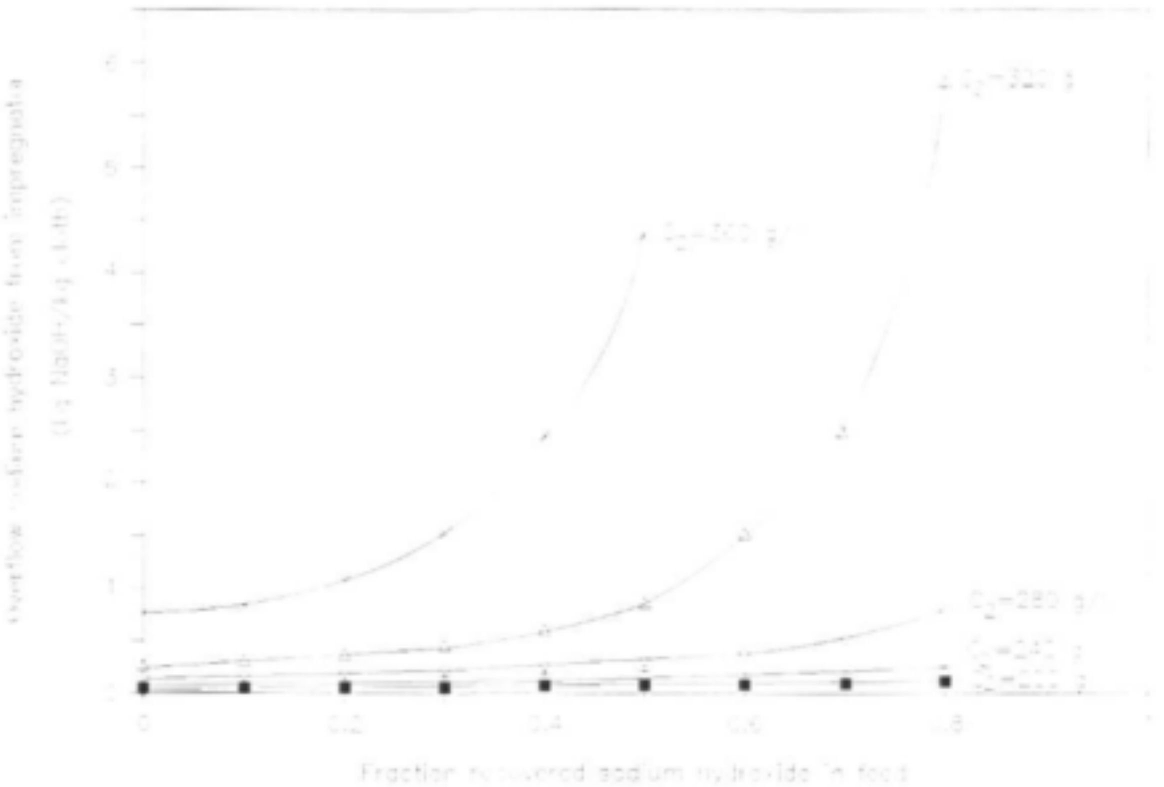
For water : $Q_1 = P_2 + Q_2 - P_1$ (1)

For sodium hydroxide : $C_3FQ_1 + C_0(1-F)Q_1 = Q_2C_2 + P_2C_2$ (2)

Substituting (1) into (2) and re-arranging gives :

$$Q_2 = \frac{P_2C_2 - C_3FP_2 + C_3FP_1 - C_0(1-F)P_2 + C_0(1-F)P_1}{(C_3F + C_0(1-F) - C_2)}$$

FIGURE 4.7 : MASS BALANCE INCORPORATING FEED SODIUM HYDROXIDE MIXING



NOTE: Drag-out = 0,53 kg/kg cloth
Recovered sodium hydroxide concentration = 200 g/ℓ.
Purchased sodium hydroxide concentration = 450 g/ℓ.

FIGURE 4.8 : VARIATION OF OVERFLOW SODIUM HYDROXIDE LOSS WITH FRACTION RECOVERED SODIUM HYDROXIDE IN MERCERISER FEED AT VARIOUS MERCERISING CONCENTRATIONS (C_2)

At a fabric production rate of 720 kg/h this translated to a loss of :

59 t NaOH/month for mercerising at 240 g/ℓ or
144 t NaOH/month for mercerising at 320 g/ℓ.

(viii) The consumption of sodium hydroxide was far higher at a mercerising concentration of 320 g/ℓ NaOH than at 240 g/ℓ NaOH. However, assuming fixed sodium hydroxide feed concentrations and nip expressions, the effluent at 320 g/ℓ was about twice as concentrated as that at 240 g/ℓ.

Thus if the evaporator was upgraded to treat all the flow from mercerising at either 240 g/ℓ or 320 g/ℓ NaOH, sodium hydroxide loss would be reduced to drag-out from the final washing bowl only. However, at the present operational capacity of the evaporator far greater sodium hydroxide losses were occurring for mercerising at 320 g/ℓ NaOH than at 240 g/ℓ NaOH, due to the large discharge to drain.

Subsequent inspection of the evaporator indicated the presence of a thick scale on the heat exchange surfaces which was mainly composed of calcium salts of mineral and organic origin. Subsequent removal of this scale and routine maintenance/cleaning improved and maintained the performance of the evaporator at the required level.

Example 7 : Prediction of Effluent Loadings

A spinning and weaving mill processing cotton and polyester/cotton blends was proposing an expansion to include the operations of wet preparation, dyeing and finishing. A forecast of normalised fabric production and resulting effluent is shown in Table 4.6.

Clearance from the local water authorities was required before effluent from the proposed operations could be discharged to river.

The effluent load from the various textile operations was predicted using the following information :

(i) type of chemicals to be used,
(ii) estimated COD loadings of chemicals to be used,
(iii) quality of water source to be used,
(iv) estimated chemical and water consumptions,
(v) estimated chemical exhaustion,
(vi) estimated wet pick-up,
(vii) production plans,
(viii) type of processing equipment to be installed,
(ix) number and size of wash boxes to be employed,
(x) previous survey results.

TABLE 4.6
FORECAST OF FABRIC PRODUCTION AND RESULTING EFFLUENT

Process	Process chemical	Normalised fabric processing rate (kg/h)	Wash water consumption (ℓ/kg cloth)	Estimated normalised chemical loading in effluent (g/h)
Sizing				
Weaving				
Singeing				
Desizing/Scouring	53 g/ℓ NaOH	1,00	12	Modified starch 33,3 PVA 25,0 Glycoride 6,3
	H_2O_2 300 g/ℓ NaOH			
Bleaching	Disperse and vat dyes	1,00	12	
Mercerising		0,43	5	
Dyeing (Jigs & Jets)		0,50	31*	
Printing (Rotary screen)		0,47	32	Pigment 13,3

Note : * This figure includes 6 ℓ/kg cloth for dye bath liquors.

A water consumption of 30 ℓ/kg cloth was predicted which was one third that of conventional cotton processing mills.

The predicted effluent composition is given in Table 4.7. The impact of this effluent on the quality of the river into which it was to be discharged was calculated at minimum, average and maximum predicted river flows. At minimum river flow (1 m^3/s) the effluent volume would have constituted 0,24 % of the river flow and the concentration of the TDS in the river water was predicted to increase by 28,3 mg/ℓ. At maximum river flow (66,8 m^3/s) the effluent volume would have made an insignificant contribution to the river flow and the increase in the TDS in the river water would be 0,4 mg/ℓ.

In order that the predicted factory discharge comply with the industrial effluent discharge regulations, particularly regarding COD and sodium, various pollution prevention measures were proposed :

(i) the installation of additional textile processing equipment was encouraged in preference to the installation of effluent treatment options - an example sited was the use of additional drying cylinders preceding the mercerising process in preference to an effluent recovery system,

(ii) the institution of a strict material control strategy was encouraged to minimise excessive use of chemicals,

(iii) the factory was urged to install water meters to all major water using areas and to institute an audit system,

(iv) the suitable design of the colour shop to minimise water and dyestuff waste.

In terms of effluent treatment options the following recommendations were made :

(i) In the case where a sodium hydroxide recovery system was preferred to the in-plant control options in (ii) below, the advantages of an evaporator to recover sodium hydroxide for the merceriser were emphasized. The advantages of evaporation included its usually favourable economics and the favourable impact which treatment of mercerising effluent would have on the sodium loading of the final factory discharge.

(ii) In the event of such an evaporator not being installed, an in-plant sodium hydroxide cascade system was formulated in which mercerising effluent was to be used for scouring, bleaching and dyeing and as an ion-exchange regenerant.

(iii) The effluent pipework should be such that the individual effluents could be segregated outside the factory at a later date.

(iv) Processing chemical baths e.g. dyebath liquor, should be segregated from weaker effluents and treated.

(v) Final effluent options for chemical and water recovery and reuse from scouring, bleaching, dyeing and printing effluent were given. These included primary treatment techniques such as flocculation and settling for colour removal from printing effluents as well as advanced technologies such as ultrafiltration for size recovery, cross-flow microfiltration for dyehouse effluents and electrolysis for sodium hydroxide recovery from scouring effluents.

4.3 IN-PLANT CONTROL

Production-related modifications should be implemented within a plant for wasteload reduction. This in-plant control is important in saving water, energy and process chemicals, thus reducing the effluent discharge.

In-plant control measures should include :

(i) minimising in-plant water use,
(ii) optimising water use during rinsing,
(iii) water and chemical recirculation,
(iv) effluent control,
(v) raw material modifications,
(vi) plant and process modifications,
(vii) housekeeping,
(viii) staff motivation.

TABLE 4.7

PREDICTED EFFLUENT COMPOSITION AND IMPACT OF ITS DISCHARGE ON THE RECEIVING RIVER WATER QUALITY

Process	Source	Cloth production kg/week	Effluent flow m^3/week	Analysis (kg/week)							
				OA	COD	TS	SS	TDS	Na	NaOH	Colour ADMI units
Effluent Characteristics											
Desizing		40 000	180	400	3 600	3 600	400	3 200	0	0	0
Scouring		40 000	200	320	2 120	5 360	80	5 280	1 160	2 000	0
Bleaching		40 000	200	120	480	600	160	440	69	120	0
Mercerising		17 100	86	0	0	5 130	0	5 130	2 958	5 130	0
Printing		19 000	133	0	0	0	0	0	0	0	0
Dyeing	Reactive jet	500	28	0	0	455	0	455	180	3	269 000
Dyeing	Reactive jig	1 000	34	0	0	160	0	160	60	0	538 000
Dyeing	Disperse	12 000	204	0	0	60	0	60	0	0	102 000
Dyeing		12 000	408	0	0	2 400	0	2 400	1 037	517	3 240 000
Total discharge			1 473	840	6 200	17 765	640	17 125	5 464	7 770	4 149 000
Conc. of discharge (g/*l*)				0,570	4,211	12,065	0,435	11,630	3,711	5,277	2 818
Spec. water use (*l*/kg cloth)			36,8								
Average flow (m^3/h)			8,8								
River Characteristics											
Average	(river flow = 12,25 m^3/s) (effluent volume contribution = 0,02 %)			0,113	0,837	2,398	0,086	2,311	0,738	1,049	0,560
Minimum	(river flow = 1,00 m^3/s) (effluent volume contribution = 0,24 %)			1,389	10,251	29,373	1,058	28,351	9,035	12,847	6,860
Maximum	(river flow = 66,8 m^3/s) (effluent volume contribution = 0,00 %)			0,021	0,153	0,440	0,016	0,424	0,135	0,192	0,103

Note: The calculations are based on a total production of 40 000 kg/week and a production time of 168 h/week.

4.3.1 Water Use

The volume of water used is a function of the :

(i) type of textile fibre being processed,
(ii) manner of processing,
(iii) processing sequence,
(iv) processing equipment.

Examples of methods for water savings should include :

(i) direct reuse of certain process water e.g. cooling water, gland water, condensate,

(ii) good housekeeping to ensure that water leaks and unnecessary washing or hose-pipe use is maintained at a minimum and that steam valves are not opened unnecessarily,

(iii) minimising water flow during processing and the prevention of water flow when the machine is stopped,

(iv) optimisation of temperature, water flow, cloth speed, water levels and tank sizes during washing,

(v) curtailing overflow rinsing,

(vi) use of more efficient washers with a reduction in the number of water feed points e.g. installation of counter-current washing,

(vii) reducing the number of process stages e.g. combination desizing-scouring or scouring-bleaching stages,

(viii) using machinery with lower specific water use,

(ix) screen washing, initially by squeegee or suction, gives low water consumption,

(x) installing a prewashing train utilising recycled water to remove impurities before final washing,

(xi) use of solvent scouring and bleaching systems,

(xii) installing water meters in all major water using areas to enable an audit system to be instituted,

(xiii) ensuring that mains water pressure is stabilised.

Of particular importance in the textile industry is the strong correlation between water and energy consumption. Since many wet-processing operations are carried out at elevated temperatures, water saving measures result in energy savings. Energy savings may be carried out by reducing water flow rates if it can be reliably determined that, in so doing, impurity removal is not effected to the extent that final cloth quality is impaired.

The relative costs of water and heat energy (1987) are as follows :

water	R0,25 - 1,00/m^3.
incremental ion exchange costs	R0,05 - 0,15/m^3.
energy (steam at R10,00/t)	R0,017/m^3.°C rise.

Water savings do not affect the pollution load of the effluent, although decreased water consumption increases effluent concentration. Most municipal effluent discharge regulations specify maximum concentration limits. Hence water saving measures might result in the effluent not complying with the maximum municipal discharge limits. An example of a tariff structure for effluent discharge to sewer is :

$$A\left[B+\left(\frac{SS}{C}\right)D+\left(\frac{OA}{E}\right)F\right]c/m^3$$

Decreasing the water consumption would result in savings of $A.B$ c/m^3.

4.3.2 Optimising Water Use During Rinsing

Washing or rinsing is a frequent operation in textile processing and it is important that it be carried out efficiently. The impurity level on the fabric must be reduced to a predetermined level and this should be done with minimum use of water. The concentration of an effluent determines the capital cost of a recovery process hence concentrated effluent is desirable.

The volume of water required for rinsing depends on the :

(i) type and concentration of impurity on the cloth,

(ii) volume and concentration of drag-out,

(iii) type of rinsing equipment and,

(iv) rinsing temperature,

(v) final concentration of impurities permissible on the cloth after rinsing.

Rinsing processes are either batch or continuous. In batch processing there is a predetermined liquor to goods ratio and a fixed volume of water per batch.

Batch rinsing machines include :

(i) jigs, which are versatile in that they can be used to process a range of fabrics. Water use during washing shows large variations and is dependent on the method employed (overflow or drop-fill),

(ii) winches, which have high water consumption and are employed for processes with many steps where frequent washes are required,

(iii) jets,

(iv) beams.

In continuous processing a continuous supply of water to the washers is required to maintain steady-state conditions in each unit i.e. the rate of inflow of impurities on the fabric is balanced by the rate of outflow of impurities in the effluent and on the rinsed cloth.

Continuous rinsing machines include :

(i) rope ranges, which are used for handling large quantities of cloth. These ranges consist of one or more boxes with squeeze rollers. Since these ranges have high water use with light fabrics two or more ropes are often processed in parallel to reduce water use,

(ii) open-width ranges, in which the water use is generally lower than that in the rope range.

Figure 4.9 (55) compares the water use of the various rinsing machines.

Batch Rinsing

The two methods of batch rinsing are overflow and drop-fill.

Overflow rinsing consists of adding rinsing water to a batch of cloth with continuous overflow for a certain period of time or until the discharge meets some criteria. This method often results in significant water wastage.

Drop-fill rinsing consists of the repetitive draining and refilling of the machine, allowing a dwell time after refilling, until the desired end point is reached. The impurity concentration of a drop will be 10 to 20 % of the impurity concentration of the previous drop.

The simplified theoretical basis for rinsing in batch machines is analysed elsewhere (54). In summary the washing efficiency is expressed as a normalised concentration ratio :

$$CR_T = \frac{C_2 - C_0}{C_1 - C_0}$$

where C_0 = concentration of impurity in the rinse water.
C_1 = machine concentration at the start of the rinse.
C_2 = machine concentration at the end of the rinse.
CR_T = overall normalised concentration ratio at the end of the rinse.

The drop-fill water consumption, Q_d , is :

$$Q_d = V(1 - CR_T)$$

where V = the machine volume.

The overflow water consumption, Q_o , is :

$$Q_o = -BV \ln CR_T$$

where B is the bypass factor to account for non-ideal conditions, typically 1,27.

For the same concentration reduction, overflow rinsing requires over 100 % more water than does the drop-fill technique to achieve the same rinsing results.

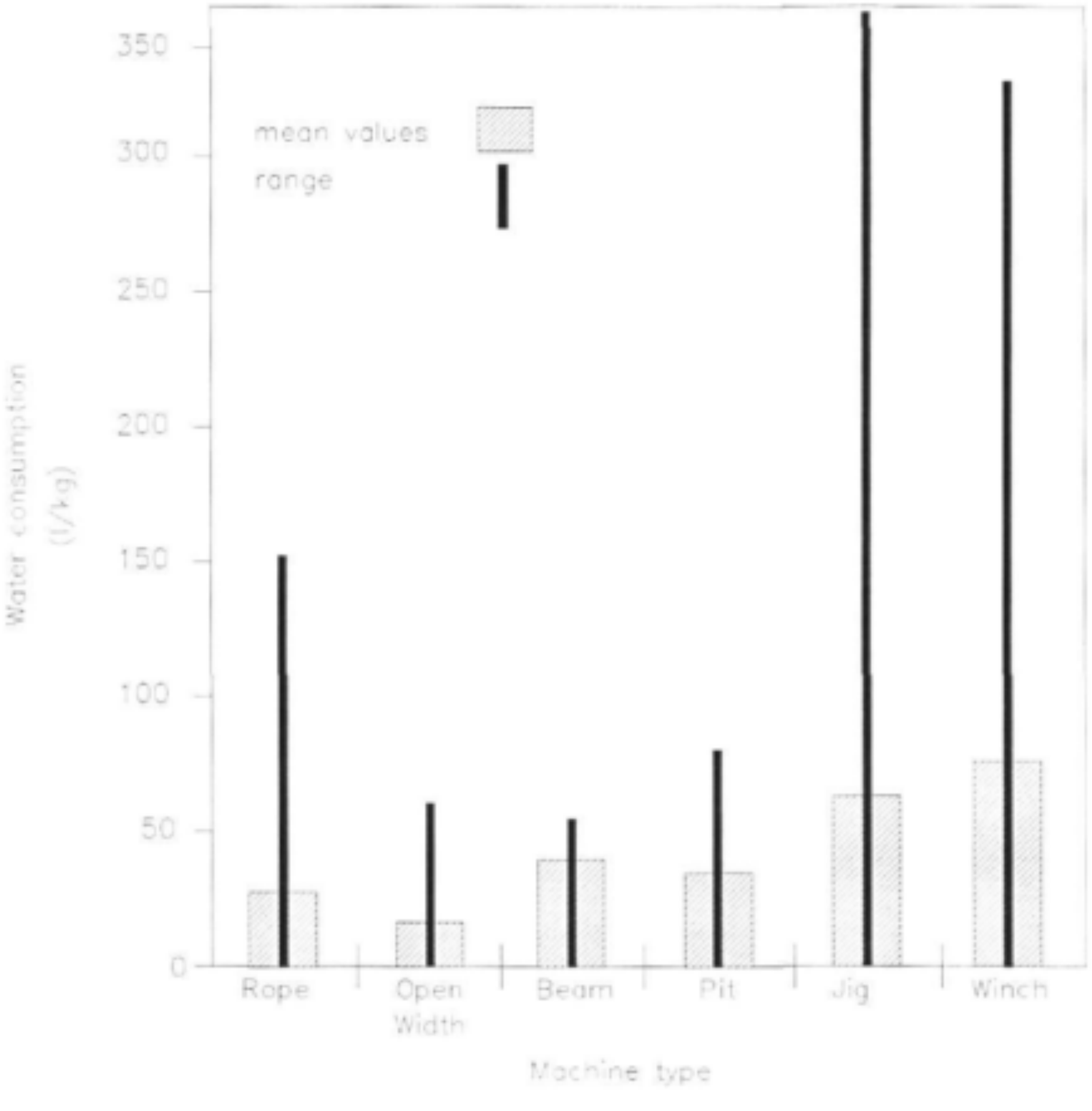


FIGURE 4.9 : COMPARISON OF WATER USES OF VARIOUS RINSE MACHINE TYPES (55)

Continuous Rinsing

Continuous rinsing in which there is a steady flow of water and cloth through the machine may be carried out in a single compartment washing range or in a multi-unit range.

Single Washing Unit

Theoretical analyses (19,56,57) of washing operations have shown that the washing efficiency or the ratio of the impurity concentration on the fabric before and after a single continuous open-width washing bowl can be expressed as :

$$\frac{C_{in}}{C_{out}} = \frac{1-k+(fk)/m}{1-k+f/m}$$

where C_{in} = impurity concentration on the fabric entering the washing bowl.
C_{out} = impurity concentration on the fabric leaving the washing bowl.
k = washing parameter.
f = specific water use (ℓ/kg cloth).
m = fabric moisture content entering and leaving the washing bowl (g/kg cloth).

This relationship assumes that all the impurities present are dissolved in the fabric moisture. The washing parameter, k, ranges from 0 (ideal impurity removal) to 1 (no impurity removal) and is influenced by :

(i) cloth speed: slower cloth speed allows more time for the impurities to redistribute themselves between the cloth and the water. At faster cloth speeds, turbulence at the cloth surface is greater and rinsing is improved,

(ii) wash water temperature: impurity removal is enhanced if washing is carried out using hot water since the rate of diffusion is increased and the viscosity is decreased,

(iii) unit design: desirable features of the design would include turbulence promotion at the cloth surface, long fabric retention times, measures to prevent the short circulation of the rinse water from the inlet to the outlet and a high nip expression to minimise the final moisture content of the cloth,

(iv) type of impurity: readily soluble impurities are easier to remove than impurities which are insoluble or which interact with the fibre;

(v) fabric type: light open weave fabrics are more easily rinsed than heavy close weave fabrics.

Figure 4.10 shows the specific water use in relation to the removal of impurities for a single washing unit. It can be seen that :

(i) at any fixed water use the impurity removal decreases as the washer becomes less ideal,

(ii) for any given washing parameter (k) there is a specific water use, above which additional impurity removal is minimal,

(iii) the less ideal a washer, the lower the maximum effective specific water use. Hence a less ideal washer should be operated at a lower specific water use. In addition, the washing efficiency of a less ideal washer cannot be improved by increasing the specific water use.

Multi-unit Washing Range

The washing efficiency, or the ratio of the impurity concentration of the fabric before and after a cross-flow multi-unit washing range consisting of n units in series, each unit fed by the same flow rate of clean water, is :

$$\frac{C_n}{C_0} = \left(\frac{C_1}{C_0}\right)^n$$

where C_1 is the impurity concentration on the fabric after the first unit and C_0 is the impurity concentration on the fabric before the first unit.

The washing efficiency can be greatly improved if the units are connected to allow counter-current flow of water. In this way the cloth leaving the range is contacted with clean water while the concentration of impurities in the wash water is maintained at a maximum, by using it to wash the cloth where it has the highest impurity concentration.

Typically two to five bowls are employed in a counter-current operation. The dependence of the washing efficiency on the moisture drag-out from the rinsing units and on the washing parameter of the wash range is analysed below.

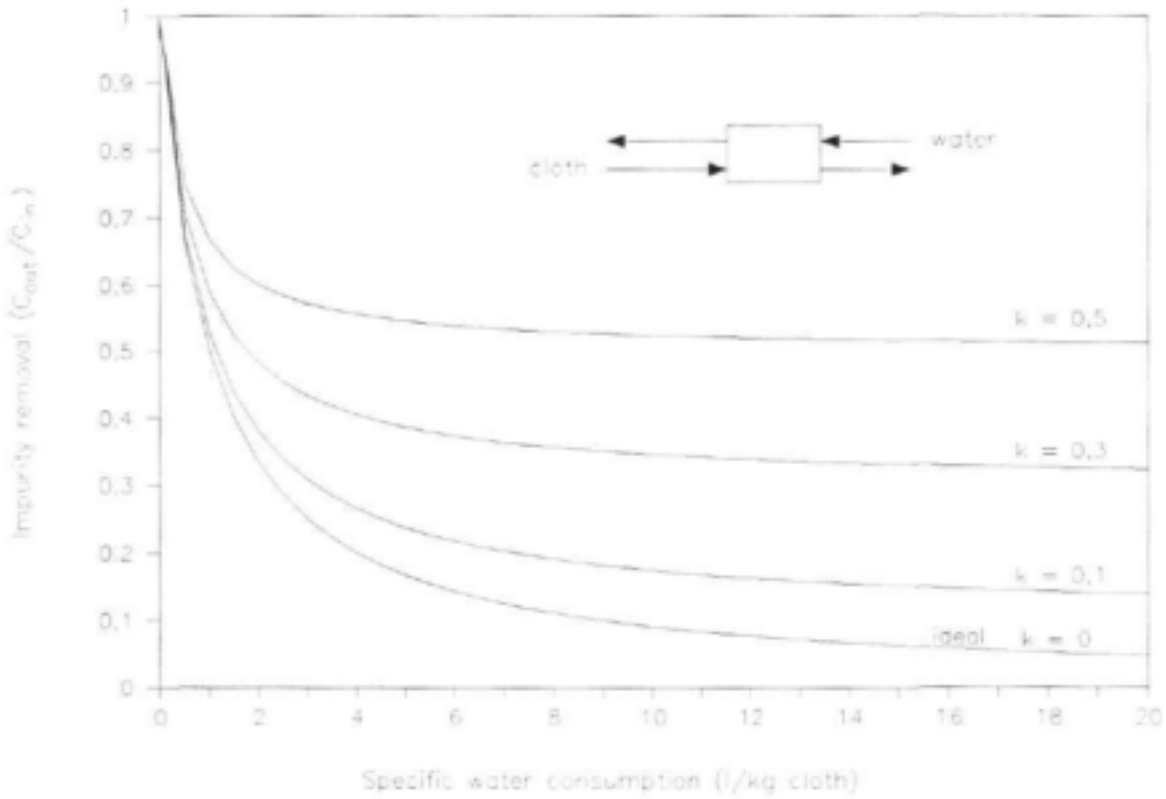


FIGURE 4.10 : SPECIFIC WATER USE IN RELATION TO THE IMPURITY REMOVAL FOR A SINGLE WASHING UNIT FOR A RANGE OF k *VALUES*

The ratio of the rinse water flow to drag-out is defined as the rinse ratio (r). The relationship between the rinse ratio, the number of rinsing tanks and the resulting dilution in the rinsing tanks to predict counter-current rinsing water requirements, is shown in Figure 4.11 (58) and are based on :

$$\frac{C_s}{C_n} = r^n = \frac{Q_r}{Q_d}$$

where n = number of rinsing tanks.
C_s = saturator (padding) concentration.
C_n = concentration in n^{th} rinsing tank (n = 1, 2, 3, . . .).
r = rinse ratio.
Q_r = flow of rinsing water.
Q_d = drag-out

Figure 4.11 also compares the recovery of the chemicals contained in the rinsing water with that entering the rinsing unit as drag-out on the unwashed fabric. This amount is potentially available for recovery and is defined by :

$$Recovery\ (\%) = \left(1 - \frac{C_n}{C_s}\right) \times 100$$

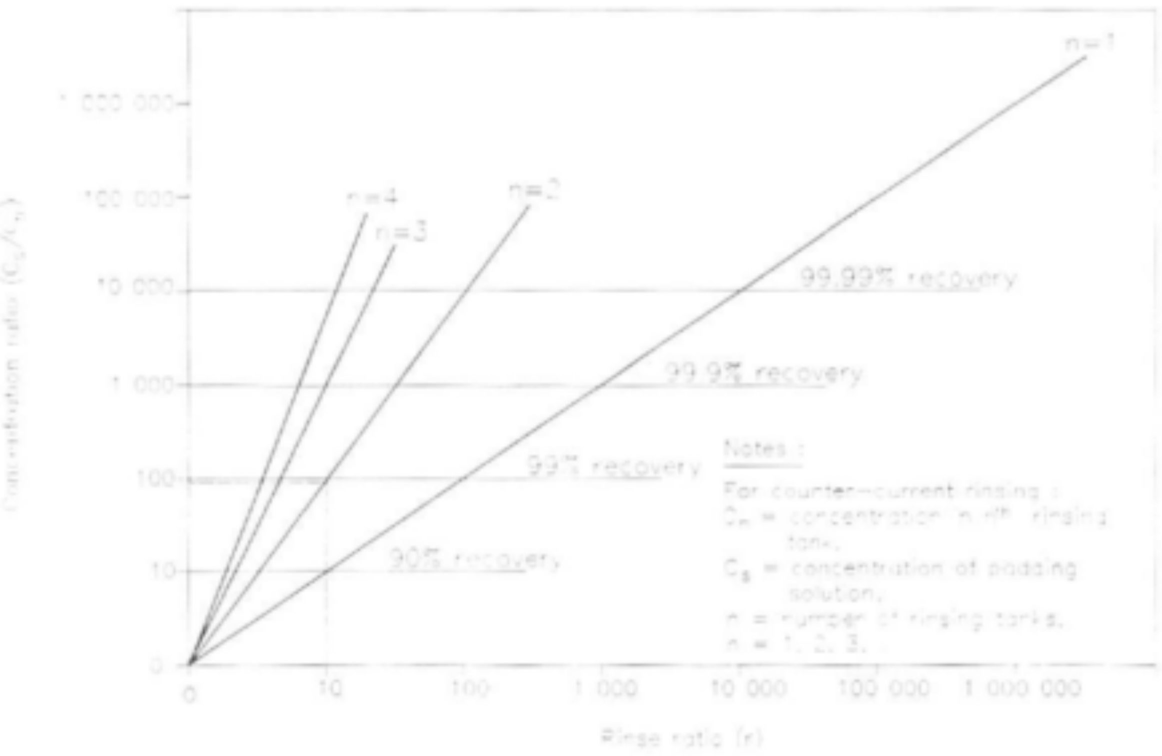


FIGURE 4.11 : RINSING WATER DILUTION VS RINSE RATIO FOR A COUNTER-CURRENT MULTI-UNIT WASHING RANGE (58)

Usually, it is assumed that the concentration of the drag-out from the final rinsing tank is equal to the concentration of the chemicals in the final rinsing tank (i.e. $k = i$).

From Figure 4.11 then, for example, if the rinse ratio were 10 in a two-bowl system, C_s/C_n would be 100. A closed-loop system would recover 99 % of the drag-out chemicals.

Figure 4.12 (58) shows different levels of chemical recovery over a range of rinse ratios for recovery from one or two rinsing tanks. For example, if chemical recovery were from one rinsing tank only, and the rinse ratio were 10 : 1, then it would be potentially possible to recover 90 % of the drag-out chemicals from the rinsing tank. If the rinse ratio were increased to 40 : 1, only an additional 7,5 % recovery would be possible. If recovery were from two rinsing tanks and the rinse ratio were 10 : 1, then 99 % recovery would be possible. If the rinse ratio were increased to 40 : 1 in the two-tanks rinsing system, then 99,9 % recovery would be possible.

Figure 4.13 (58) illustrates the relationship between the rinse ratio and the concentration in the first rinsing bowl of a 3-bowl counter-current rinsing system, which would be discharged from the process, for a spread of chemical concentrations. If the padding solution concentration, C_s, is 20 g/ℓ and the rinse ratio is 20 : 1, the concentration in the first rinsing tank is 1 g/ℓ.

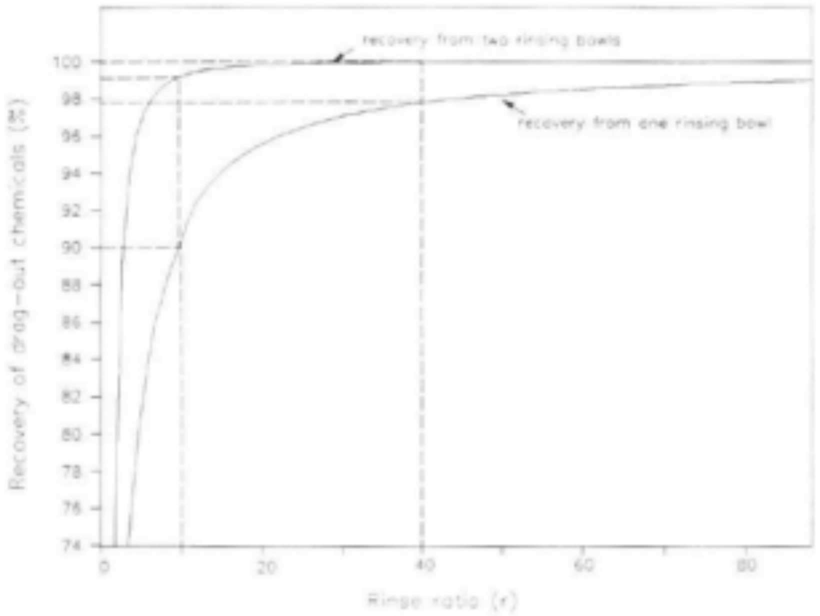


FIGURE 4.12 : RINSE RATIO EFFECT ON RECOVERY OF DRAG-OUT CHEMICALS FROM RINSING SYSTEMS (58)

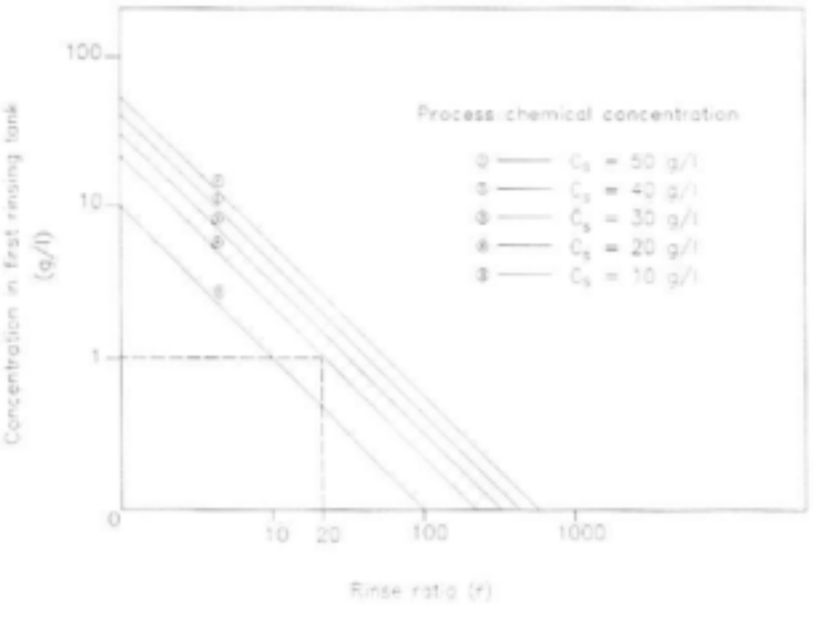


FIGURE 4.13 : DETERMINATION OF CHEMICAL CONCENTRATION OF FIRST FEED TANK (58)

Figure 4.14 (54) compares the final impurity levels, C_f, remaining on the fabric as a function of specific water use for various washing ranges ($k = 0.3$) :

(i) a three-bowl system connected in counter-current,

(ii) a three-bowl system connected in cross-flow (parallel),

(iii) a single washing unit.

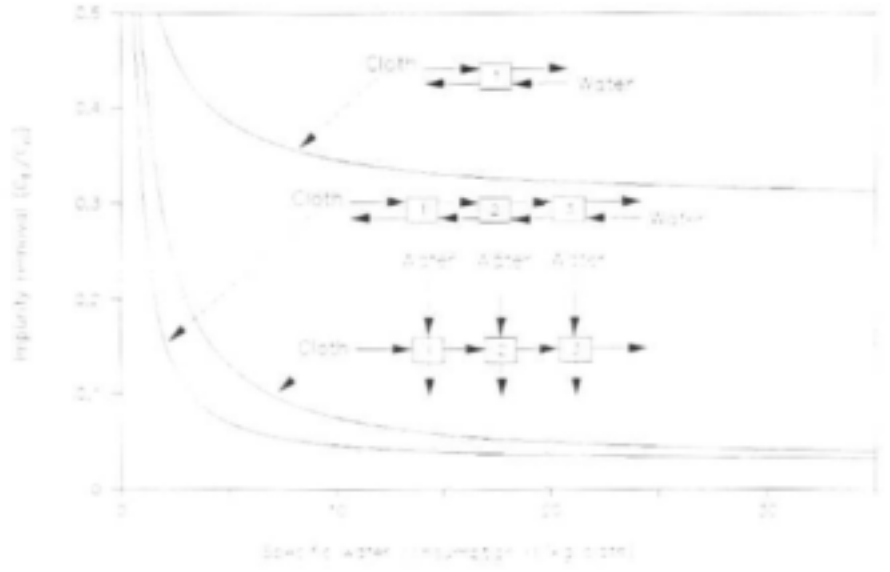


FIGURE 4.14 : IMPURITY REMOVAL DEPENDENCE ON SPECIFIC WATER USE IN COUNTER-CURRENT AND CROSS-FLOW WASHING RANGES ($k = 0.3$)(54)

<u>Example 8 : The Effect of Different Washing Parameters on the Specific Water Use</u>

Two textile mills had a similar washing duty. Mill A had two pairs of open-width washing units operated in series. Each pair of units was operated counter-currently. The washing parameter for this system was found to be 0,40. Mill B had a modern three-bowl counter-current washing range with a washing parameter of 0,24.

The relation between specific water use and impurity removal from both the washing processes is shown in Figure 4.15 (54). Also included in Figure 4.15 is the effect of converting the cross-flow counter-current range (Mill A) to a fully counter-current washing range.

Figure 4.15 indicates that for the washer in Mill A, very little improvement in impurity removal occurs with a specific water use greater than about 10 ℓ/kg cloth. If the unit were to be converted to a counter-current unit then the specific water use could be reduced by 20 % with the same impurity removal. Mill B, with the three-bowl counter-current range, could achieve the same level of impurity removal with a specific water use of 5 ℓ/kg cloth.

Advantages of the more efficient washing range are :

(i) lower specific water use leading to lower :
  (a) water and effluent charges;
  (b) steam requirements;
  (c) chemical requirements (where appropriate).

(ii) reduced floor area,

(iii) a higher degree of impurity removal.

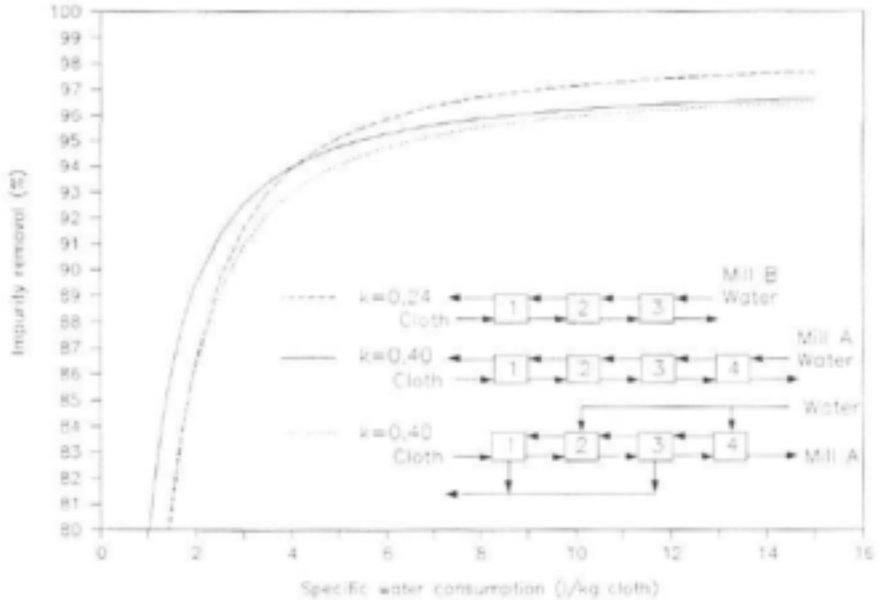


FIGURE 4.15 : THE RELATION BETWEEN SPECIFIC WATER CONSUMPTION AND IMPURITY REMOVAL FOR THREE WASHING RANGES

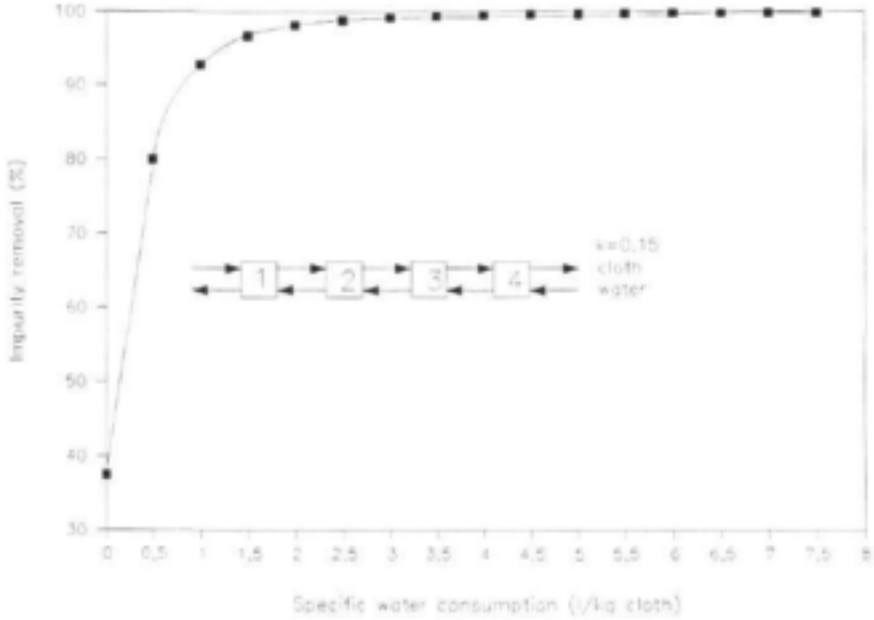


FIGURE 4.16 : PREDICTED WASHING EFFICIENCIES

Example 9 : The Relation Between Specific Water Use and Impurity Removal

A wet preparation section at a local textile mill contained a Vaporloc scouring range with a continuous four-bowl open-width washing system operated counter-currently. The cloth speed was 50 m/min and the wash water flow into the final washing bowl was 5 kℓ/h. The average specific water use was 6,5 ℓ/kg cloth. The moisture carry-over into the washing range and out of washing bowls 1 to 3 was 0,8 ℓ/kg cloth. The moisture carry-over out of the last washing bowl was 0,5 ℓ/kg cloth.

Carefully controlled trials were conducted to determine the relationship between the specific water use and impurity removal from the padded cloth. The determining criterion was the residual sodium hydroxide on the cloth leaving the washing range. A reduced water flow would have been unacceptable if it resulted in a poorer quality product.

Washing theory was used to predict the interdependence of the washing variables (18). The washing parameter (λ) was found to be 0,15. The impurity removal for the washing range was predicted as a function of specific water use (Figure 4.16) and found to be 99,8 % at a specific water use of 6,5 ℓ/kg cloth. This represented an excessive use of water if it is considered that :

(i) at high water use a small increase in washing efficiency could be obtained with an increase in water use. For example, a reduction of 62 % in the specific water use (to 2,5 ℓ/kg cloth) reduced the washing efficiency by only 2 %,

(ii) high washing efficiencies were not essential since subsequent processing at the factory usually included bleaching and mercerising, where the fabric would be subjected to high sodium hydroxide environments.

The theoretical predictions were verified experimentally (18) and the wash water use was decreased with minimal effect on the sodium hydroxide drag-out from the wash range, the washing efficiency or the final cloth quality.

4.3.3 Water and Chemical Recirculation

Large volumes of water are used in washing processes where the objective is to remove soluble impurities from the fabric. Wash water is therefore often dilute and the possibility exists for the reuse of certain waste streams as :

(i) process water in other textile operations, with or without the addition of chemicals,

(ii) rinse water for another process in which low-grade water is acceptable,

(iii) rinse water for direct use in a continuous counter-current washing system where dilute rinses are reused in successively dirtier washing bowls.

Where partially treated waste streams are reused the concentration in the recycle loop increases, requiring a constant bleed-off to maintain concentrations below a predetermined level.

The segregation and reuse of waste streams reduces the total effluent volume, often together with energy, water and chemical savings. As the cost of chemicals, water, energy and waste treatment escalates, the recirculation of and recovery from various streams becomes justified. Cascading of waste streams is common practice e.g. :

(i) Spent bleaching streams have been successfully cascaded to scouring where the residual chemicals and auxiliaries improved the efficiency of the scouring **(55)**. The spent bleaching chemicals did not affect the scouring process.

(ii) Chlorine bleaching streams have been used in the removal of starch during desizing. The chlorine aided in the degradation of the starch and the starch derivatives (**55**).

(iii) Effluent from bleaching systems is relatively clean and has been used as wash water for scouring (**10,18**).

(iv) Wash water from kiering is generally highly contaminated by soap, emulsified waxes and lubricants, since the kiering pad solution is not normally saturated with these impurities and may be reconstituted and reused (**18**).

(v) Relaxer effluent is generally weak and has been cascaded to mercerising systems as wash water.

(vi) Mercerising effluent is relatively free from impurities other than sodium hydroxide and is often concentrated for reuse as process sodium hydroxide using evaporation techniques. Where there is no such sodium hydroxide recovery the effluent may be reused for kier boiling, prescouring or dyeing (**55**). Mercerising effluent has also been used in the scouring saturator (**10**).

Example 10 : Effluent Cascading

Trials at a textile mill producing cotton and polyester/cotton woven fabrics have shown that substantial savings in water, effluent discharge costs and energy costs can result from the cascading of effluent from "clean" processes for reuse as wash water in processes which do not require high quality water (18).

A matrix of the possible cascading operations is given in Table 4.8. For each trial, effluent was pumped from the "source" process, via a holding tank, to the "destination" process to be used as process water.

In each case the process was operated for at least four hours on cascaded water before sampling to ensure that a minimum length of 10 000 m of cloth was processed under stable operating conditions.

TABLE 4.8
POSSIBLE CASCADING OPERATIONS

	Cascaded to:							
Source effluent	Oxidative desizing	Scouring	Bleaching	Mercerising 1	Mercerising 2	Relaxing 1	Relaxing 2	Treatment
Desizing								X
Scouring								X
Bleaching	X	X			X			X
Mercerising 1								X
Mercerising 2	X	X	X	X		X		
Relaxing 1		X						X
Relaxing 2	X	X	X		X	X	X	
Ox. desizing								X

Table 4.9 summarises the results of some cascading trials. Effluent from the second stage of the mercerising washing range was suitable for process water in the washing of :

(i) sodium hydroxide scoured cloth,

(ii) oxidative desized cloth,

(iii) mercerised cloth which was to be subsequently bleached.

TABLE 4.9
RESULTS OF CASCADE TRIALS

Source effluent	Destination process	Comment
1. Mercerising 2 (weak NaOH)	Scour washing range	1) Residual NaOH on cloth increased from 20 g/ℓ to 40 g/ℓ. 2) Residual TOC increased by 25 %. 3) No difficulties experienced in further processing of cloth.
2. Mercerising 2 (weak NaOH)	Oxidative desize washing range	1) Residual NaOH on cloth lower than when washed with fresh water. 2) Residual TOC increased by 25 %. 3) No difficulties experienced in further processing of cloth.
3. Mercerising 2 (weak NaOH)	Mercerising 1	1) No increase in residual NaOH on cloth. 2) Residual TOC and TDS increased by 50 %. 3) No difficulties experienced in further processing of cloth.
4. Relaxing 2 (weak sodium acetate)	Relaxing 2	1) Residual NaOH on cloth easier to control and less acetic acid required for neutralisation. 2) No deterioration in cloth quality for reasonably short runs (5 to 6 hours).

Estimated energy, water and effluent discharge savings from the reuse of effluent from the second stage of the mercerising washing range at the factory were approximately R14 000/a (1985).

Effluent from the rinsing stage of the relaxer was found to be suitable for recycling to the relaxer process.

4.3.4 Plant and Process Modifications

Modifications could include :

(i) chemical substitution by more easily treated alternatives. For example, high COD organic acids such as acetic acid should be replaced with mineral acids;

(ii) the installation of facilities for the recovery of energy from hot wastes;

(iii) the optimisation of recipes. Usually established recipes are used which are failsafe under the most extreme conditions. This leads to the use of an excess of chemicals, increased pollution and higher effluent concentrations;

(iv) the installation of chemical dosing control systems to prevent excessive use of chemicals. Redox equipment in bleaching and automatic dosing systems in scouring and mercerising would enable improved control;

(v) the installation of instrumentation which will assist with the uniformity of chemical application or provide temperature control,

(vi) the reduction in the number of processes. For example, oxidative desizing enables desizing, scouring and bleaching to be carried out in a single stage with a reduced number of textile padding and washing processes. Single stage scouring-bleaching and desizing-scouring are other examples of reduced stage operations.

4.3.5 Raw Material Modifications

Raw material modifications may result in reduced effluent discharge problems. For example :

(i) synthetic fibres may be processed instead of natural fibres,

(ii) higher quality raw materials containing less impurities may be purchased.

4.3.6 Effluent Control

Important in-plant control measures with regard to effluents and their discharge should include :

(i) identification, segregation and separate treatment of high-strength (desizing, mercerising, scouring and dyeing) and toxic effluents to avoid dilution and discharge with other weaker or less toxic effluents. Certain detergents, solvents, dyes and finishes may be toxic to biological treatment plants and should be kept separate,

(ii) dry clean-up of chemical spills,

(iii) preliminary treatment by filtration or screening to remove fibre,

(iv) identification of shock loads and a means to distribute such loads evenly in the total factory discharge,

(v) identification of foam-producing chemicals,

(vi) evaluation of process chemical substitution by alternative less toxic, aggressive or polluting chemicals,

(vii) optimisation of washing and rinsing operations,

(viii) evaluation of the reuse of chemicals, heat and water in weak effluents by the implementation of a cascading system,

(ix) a strict material control strategy. A large fraction of the pollution load in textile factories is often due to excessive use of chemicals and auxiliaries.

4.3.7 Housekeeping

Good housekeeping should entail :

(i) the prevention of the indiscriminate disposal of residual chemicals and spent liquors,

(ii) careful chemical control to prevent excess make-up,

(iii) the prevention of spills,

(iv) the maintenance of pipes and flow meters,

(v) minimum hose-pipe use for washing of equipment and floors,

(vi) the maintenance of dripping taps and self-closing valves,

(vii) the installation of water and effluent flow meters for each individual process and routine monitoring thereof.

4.3.8 Staff Motivation

An awareness and understanding of processes and resource conservation must be created amongst all staff. Regular staff management meetings would enable all parties to be involved in the chemical, water and energy use of the factory. In addition, staff should be given incentives to minimise resource use and to maximise production.

4.4 EFFLUENT TREATMENT PROCESS SELECTION

The selection of the necessary effluent treatment processes and their sequence is complex and a procedure to assist in management decision making is outlined. Both water and effluent management are affected because certain parameters are volume dependent and others are concentration dependent. Table 4.10 outlines the methodology for the improvement of the effluent characteristics with respect to volume, colour, soluble organic matter, soluble inorganic matter and settleable and suspended solids.

TABLE 4.10
METHODOLOGY FOR THE IMPROVEMENT OF EFFLUENT CHARACTERISTICS

Reduction in	Methodology
1. Volume	See Section 4.3.
2. Colour	Segregation and treatment; flocculation, adsorption, hyperfiltration.
3. Organic constituents	Segregation and treatment; process selection; control of chemical use; biological treatment, flocculation, adsorption, microfiltration, hyperfiltration, ultrafiltration.
4. Inorganic salts and alkalies	Segregation; process selection; control of chemical use; hyperfiltration, electrodialysis, electrolysis.
5. Settleable and suspended solids	Screen and settle, flocculation, dissolved air flotation, microfiltration.

Treatment options are briefly considered for effluents from the scouring of polyester (Chapter 5). Results are presented for laboratory-scale studies and no design data is presented. The discharge of this effluent has a lower impact on the environment than the discharge of sodium hydroxide scouring effluents from the processing of cotton. Particular attention is given to the treatment of these cotton scouring effluents (Chapters

6 to 11) since this effluent was identified as posing a serious pollution problem. Most factories do not treat this effluent since no suitable treatment system has been developed. This effluent contributes up to 25 % of both the volume and the COD loading of the discharge from the wet preparation section and contains 37 % of the total solids load **(13)**.

Treatment process options for scouring effluent involve either :

(i) partial treatment prior to discharge to improve the quality of the effluent, particularly with regard to pH, COD, suspended matter and organic constituents,

(ii) complete treatment for water and chemical reuse. This involves a closed loop recycle operation yielding high removals of organics and inorganic components.

The proposed options are given in Table 4.11.

General pretreatment and treatment measures for the effluents may include screening, flow balancing, water management, in-plant controls and pH adjustment.

The treatment of bleaching and mercerising effluents is not discussed further since :

(i) bleaching effluent is considered as dilute scouring effluent containing spent bleaches,

(iii) mercerising effluent may be concentrated by evaporation. Where clean sodium hydroxide is required, mercerising effluents are considered as concentrated cotton scouring effluents and treated accordingly.

TABLE 4.11
TREATMENT OPTIONS FOR SCOURING EFFLUENTS

Effluent type	Pretreatment options prior to discharge	Treatment options for reuse
Polyester, polyester/cotton scouring (weak)	(i) neutralisation. (ii) filtration.	neutralisation, microfiltration and ultrafiltration for water and partial chemical recovery (detergent, salt) (Chapter 5).
Cotton, polyester/cotton scouring (strong)	(i) neutralisation. (ii) acidification to pH 7 and flocculation. (iii) biological treatment in admixture with other effluents. (iv) flotation. (v) electro-oxidation.	(i) dynamic membrane ultrafiltration for the reuse of water and chemicals (Chapter 6). (i) evaporation for the reuse of chemicals and water (Chapter 7). (iii) neutralisation and electro-oxidation for reuse of water (Chapter 8). (iv) neutralisation, microfiltration, nano-filtration and electro-chemical processing for the reuse of water and chemicals (Chapter 9-11).

5 ULTRAFILTRATION OF WEAK POLYESTER AND POLYESTER/COTTON SCOURING EFFLUENTS

5.1 INTRODUCTION

Polyester is the main synthetic fibre used in the Southern African textile industry. The fibre may be scoured in the yarn, woven fabric or knitted fabric forms. In some applications polyester and polyester/cotton blends are scoured in weak solutions of sodium carbonate or sodium hydroxide and detergent.

5.2 POLYMERIC MEMBRANES : LOW-TEMPERATURE ULTRAFILTRATION

This section summarises the results obtained from pilot-scale ultrafiltration studies. The aim was to separate the process oils from the inorganic constituents of the effluent. The weak scouring effluent was passed through a cartridge filter prior to ultrafiltration. Design data for scale-up purposes is not included.

5.2.1 Mill Process and Effluent Characterisation

The mill from which the weak scouring effluent originated produced mostly warp and circular knit fabrics. Fibres processed were mainly polyester, cotton, nylon and blends. Scouring was achieved in the yarn or knitted fabric form using alkali and detergent to remove knitting, spinning and antistatic oils which were absorbed by the fibre during the various extruding, spinning and knitting operations. Batch machines of the jet type were used.

The chemicals consumed during scouring included :

(i) sodium hydroxide for the scouring of cotton and polyester/cotton yarn,

(ii) sodium carbonate for the scouring of cotton and polyester fabrics and fabrics consisting of cotton, polyester and nylon blends,

(iii) non-ionic or anionic detergents to enhance the emulsification action,

(iv) dye-crack prevention auxiliaries,

(v) sequestrants.

Polyester yarn was scoured in warm water (above 40 °C) and nylon fabric was scoured in a warm solution of detergent and trisodium phosphate.

The scouring liquor ratio was 30 : 1. The analysis of the untreated effluent from the scouring of fabrics containing cotton and polyester is given in Table 5.1. The effluent had the appearance of diluted milk.

5.2.2 Pilot Plant Description

The experimental plant is shown in Figure 5.1.

The ultrafiltration unit specification is given in Table 5.2.

TABLE 5.1
AVERAGE COMPOSITION OF WEAK SCOURING EFFLUENT TREATED BY LOW-TEMPERATURE ULTRAFILTRATION

Determinand	Untreated effluent		Composite permeate (at 90 % water recovery)	
	Min	Max	Min	Max
pH	7	13	7	13
Conductivity (mS/m)	20	70	20	60
TS	1 170	3 300	780	2 210
TOC	117	690	57	336
Na	199	339	182	310
Mg	7	12	<1	1
Ca	4	20	<1	2
Cl	67	92	65	89
Soap, oil and grease	300	400	0	100

(all analyses in mg/ℓ except pH and conductivity).

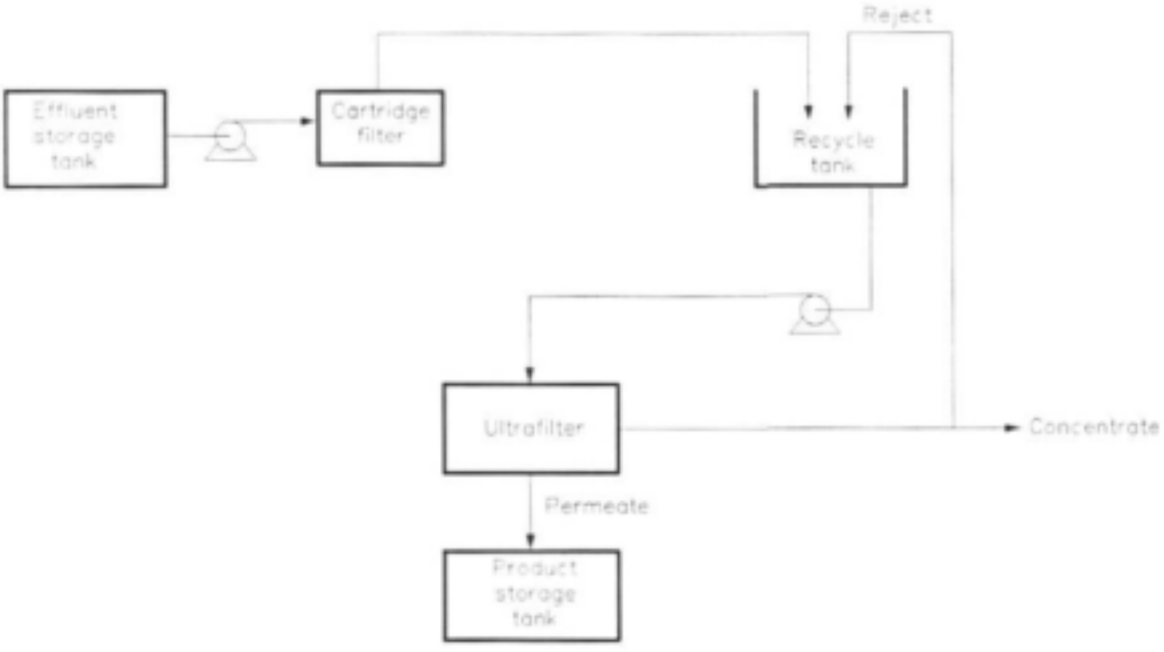


FIGURE 5.1 : FLOW DIAGRAM OF EXPERIMENTAL PLANT

TABLE 5.2
LOW-TEMPERATURE ULTRAFILTRATION UNIT SPECIFICATION

Membrane type	:	Abcor HFK 132
Molecular mass cut-off	:	3 000 to 5 000
Membrane configuration	:	Spiral wrap, one element
Membrane area	:	3,3 m^2
Operating pressure	:	Inlet 500 kPa
	:	Outlet 200 kPa
Pump type	:	Mono
Permeate rate	:	1,5 m^3/day
Recommended feed pH	:	1 to 13

5.2.3 Experimental Procedure and Results

The procedure and results of the pilot-scale ultrafiltration investigations are reported in detail elsewhere (**18**).

Ultrafiltration trials were run for one month. The trials took the form of a series of batch concentrations to a final water recovery (R) of 90 %.

After each batch concentration the concentrate was diluted to the original volume (250 ℓ) with fresh effluent. The unit was operated in the total recycle mode for two to three days in between each batch concentration.

5.2.4 Ultrafiltration Rejection Performance

In Table 5.1 the concentrations of the composite permeate after 90 % water recovery and the untreated effluent are given.

Rejections were as follows :

Monovalent inorganic ions	:	0 to 10 %
Divalent inorganic ions	:	85 to 95 %
Total organic carbon	:	60 to 80 %
Soap, oil and grease	:	40 to 60 %

The permeate was crystal clear and was of suitable quality for recycle to the scouring jets.

5.2.5 Ultrafiltration Fluxes

Fluxes at 90 % water recovery were 20 ℓ/m^2h and could be maintained by water and detergent rinses.

5.2.6 Ultrafiltration Concentrate

A concentrate, approximately 10 % of the volume of the total feed, was produced and contained :

Total solids : 10 000 mg/ℓ
Sodium : 1 255 mg/ℓ
Soap, oil and grease : 2 200 mg/ℓ
Total organic carbon : 4 500 mg/ℓ.

5.3 DYNAMIC MEMBRANES : HIGH-TEMPERATURE ULTRAFILTRATION

Dynamic (formed-in-place) membranes formed on supports (**59-62**) of porous stainless steel tubes, are capable of treating effluents at temperatures above 45 °C. Thus this technology is suitable for the treatment of hot scouring effluents.

Dynamic membrane porous stainless steel tubes are commercially available and have been used in several textile applications (**63**). The advantages include :

(i) high-temperature stability,
(ii) long service life of the support tubes,
(iii) the ability to replace the dynamic membrane *in situ* using solution chemistry,
(iv) tailor-made applications,
(v) robust systems.

The disadvantages include :

(i) high capital costs,
(ii) relatively low salt rejection (less than 30 %).

5.3.1 Mill Process and Effluent Characterisation

A treatment/recycle plant was installed and commissioned in a factory involved in weaving, preparation, dyeing and finishing of polyester viscose fabrics (**60**). Fabrics were scoured at the factory in order to remove the oil used on the warp yarn and to increase weavability. Scouring was carried out using sodium carbonate and scouring auxiliaries. The wet pick-up of the padding solution was 0,9 ℓ/kg cloth. A continuous washing machine was used and the effluent produced was hot, colourless and relatively clean. The average composition of the effluent is given in the first column of Table 5.3. The design mass balance is given in Figure 5.2.

5.3.2 Plant Description

The plant consisted of three dynamic membrane units for the treatment of scouring, weak dyeing and strong dyeing effluents (Table 5.4). The dynamic membrane units were designed to operate at 95 % water recovery and the water was reused in processing. The concentrate from the dynamic membrane plant and other high-strength wastes and concentrates from the factory were further treated in an evaporator to produce a final residue for disposal to sea. The overall water recovery was designed to be 98 % and the thermal energy recovery was over 90 %.

The design basis of the plant is given in Table 5.5. The scouring, weak dyeing and strong dyeing units contained 9, 15 and 18 modules each with an area of 6,8 m^2.

TABLE 5.3
AVERAGE COMPOSITION OF WEAK SCOURING EFFLUENT TREATED BY HIGH-TEMPERATURE ULTRAFILTRATION

Determinand	Untreated Effluent	Composite Permeate*	Point Rejection %
pH	8,1	-	-
Conductivity (mS/m)	90	80	30 to 40
TS	960	900	25
TDS	920	880	20
TIC	28	-	-
TOC	262	245	25
Ca	6	-	-
Mg	5	-	-
Colour (ADMI units)	191	105	75

(all analyses in mg/ℓ except for pH, conductivity and colour).

* Calculated from average rejections at a 95 % water recovery.

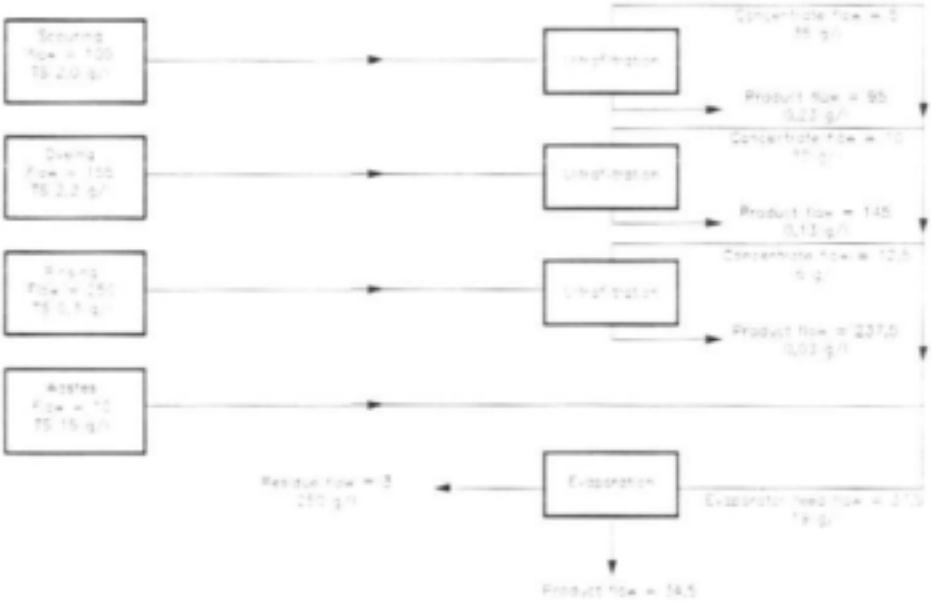


FIGURE 5.2 : PLANT LAYOUT AND MASS BALANCE (FLOW UNITS ARE RELATIVE)

TABLE 5.4
EFFLUENT CHARACTERISATION OF WEAK SCOURING EFFLUENT FOR HIGH-TEMPERATURE ULTRAFILTRATION (60)

Effluent	Flow units	TS g/ℓ	Temp °C	Main pollutants
Scouring	17	1,97	75	oil, detergent and alkali
Weak dyeing	43	0,30	25	minor contaminants
Strong dyeing	26	2,20	62	dye, organic contaminants, salt and alkali

TABLE 5.5
DESIGN BASIS OF DYNAMIC MEMBRANE PLANT FOR THE TREATMENT OF WEAK SCOURING EFFLUENTS

Effluent	Feed m^3/d	Permeate m^3/d	Concentrate m^3/d	Flux* $ℓ/m^2h$ at 6,1 MPa
Scouring	120	108	12	80
Weak dyeing	300	276	24	119
Strong dye	185	176	9	63

* based on a 22 h operation per day.

Scouring Effluent System

The system for scouring effluent consisted of nine modules in a series taper configuration of 4 : 2 : 2 : 1. Each module was 10 m long and contained 143 m of tube with an inside diameter of 15 mm. A pump with a capacity of 6 m^3/h was used to maintain a flow velocity of 1,2 m/s in the tubes.

Pretreatment using wedge wire screens for lint removal proved ineffective and these were replaced with vibrating screens.

5.3.3 Plant Performance

Severe fouling and subsequent flux decline were experienced during plant operation due to cotton waxes, microbial growth and lint.

Careful selection of scouring chemicals, control of operating temperatures and addition of biocide to the feed significantly improved the plant flux performance. However, even after the improvements the permeate production rate was 64 % below design.

The foulant(s) did not respond to a wide range of cleaning procedures. An effective cleaning procedure consisted of :

(i) two sodium carbonate rinses,

(ii) a 30-minute recirculation of a hot solution of sodium hydroxide, hydrogen peroxide, "Butyl Cellusolve" and detergent,

(iii) two water rinses,

(iv) two acetic acid and ammonia rinses,

(v) three water rinses.

Rejection performance varied depending on the pH of the feed and the time elapsed since the previous membrane clean.

A typical product composition from the high-temperature ultrafiltration of weak scouring effluent is given in Table 5.3. The average composition was calculated from the average rejections assuming a water recovery of 95 %.

6 ULTRAFILTRATION OF STRONG COTTON AND POLYESTER / COTTON SCOURING EFFLUENTS

6.1 INTRODUCTION

Batch scouring produces two effluents, one from the dumping of the scouring liquor and the other from rinsing effluent. Continuous scouring normally produces only a rinsing effluent because the scouring solution which is padded onto the cloth at high concentrations is normally not discarded.

High-temperature ultrafiltration of scouring effluent would enable the scouring padding solution to be reused indefinitely in the case of a batch process since it enables the separation of the high molecular mass organic material from the sodium hydroxide prior to reuse. In a continuous scouring process or in the case of batch rinsing effluent a concentration step such as evaporation is necessary in order to concentrate the sodium hydroxide up to reuse strength.

Polymeric ultrafiltration membranes typically have a temperature limit for solutions with a high pH whilst dynamically formed membranes (Section 5.3) can withstand high temperatures at these pH values . This chapter summarises the results of laboratory tests (**64**) in which strong scouring rinsing effluent was treated by ultrafiltration using dynamically formed membranes.

A proposed high-temperature ultrafiltration system for the treatment of strong effluents from continuous scouring is shown in Figure 6.1. The process consists of dynamic membrane ultrafiltration to produce a concentrate of organic material and a sodium hydroxide containing permeate stream. This sodium hydroxide stream may be concentrated by evaporation to enable both rinse water and process chemicals to be recycled to production. Since the concentration of clean sodium hydroxide solutions by evaporation is a commonly practiced operation in the textile industry, the evaporation stage is not discussed in this chapter.

6.2 MILL PROCESS AND EFFLUENT CHARACTERISATION

The mill from which the strong scouring effluent originated produced woven cotton and polyester/cotton fabrics. The cotton fabric was continuously scoured by padding a solution of sodium hydroxide (70 g/ℓ), reducing agent and wetting agent onto the fabric after desizing. The fabric was then steamed prior to being wound into caravans where it was rotated in a steam atmosphere for 2 h before rinsing in a four-bowl counter-current range. The pick-up of the padding solution was 89 ℓ/kg cloth and the rinse water consumption was 4 ℓ/kg cloth.

The chemical analysis of the strong scouring effluent is given in Table 6.1. The effluent was dark in colour and contained a small amount of suspended material.

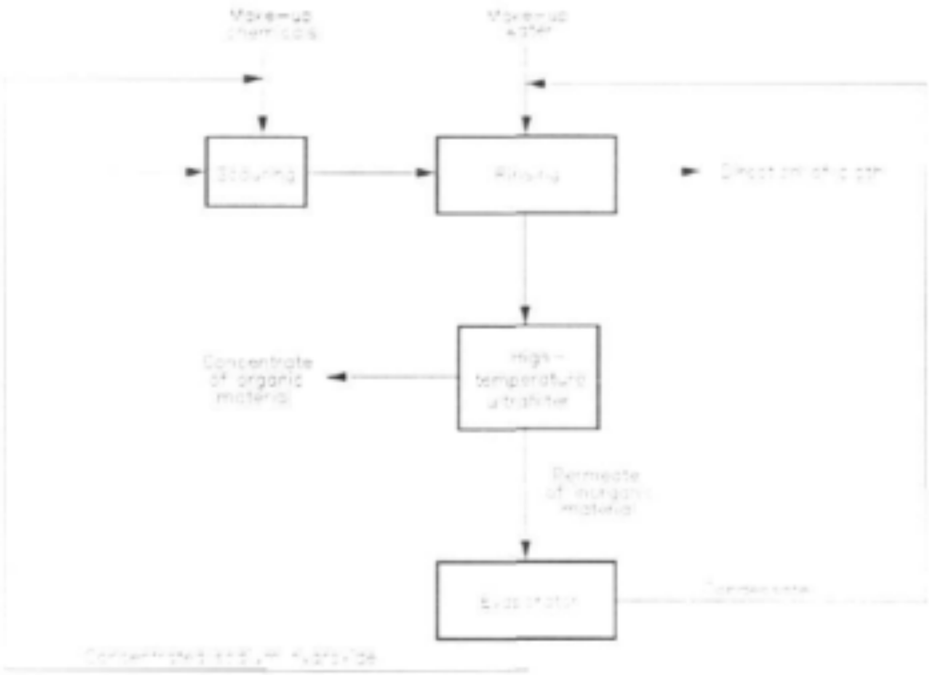


FIGURE 6.1 : HIGH-TEMPERATURE ULTRAFILTRATION OF STRONG EFFLUENT FROM CONTINUOUS SCOURING

TABLE 6.1
AVERAGE COMPOSITION OF STRONG EFFLUENT FROM CONTINUOUS SCOURING TREATED BY HIGH-TEMPERATURE ULTRAFILTRATION

Determinand	Effluent		Treated effluent (composite at 90 % R)	
	Min	Max	Min	Max
pH	12	14	12	14
Conductivity (mS/m)	400	8 600		
TS	27 000	89 000		
Na	4 000	10 000		
NaOH	5 000	14 000	4 850	13 600
TOC	2 000	26 000	1 100	14 000
COD	3 000	44 000		
OA	2 000	77 000		
Ca		80		
Mg		20		

(all analyses in mg/ℓ except for pH and conductivity).

6.3 PILOT PLANT DESCRIPTION

A flow diagram of the experimental unit is given in Figure 6.2. The effluent was stored before being pumped, at room temperature, into the ultrafiltration recycle tank. No pretreatment was required.

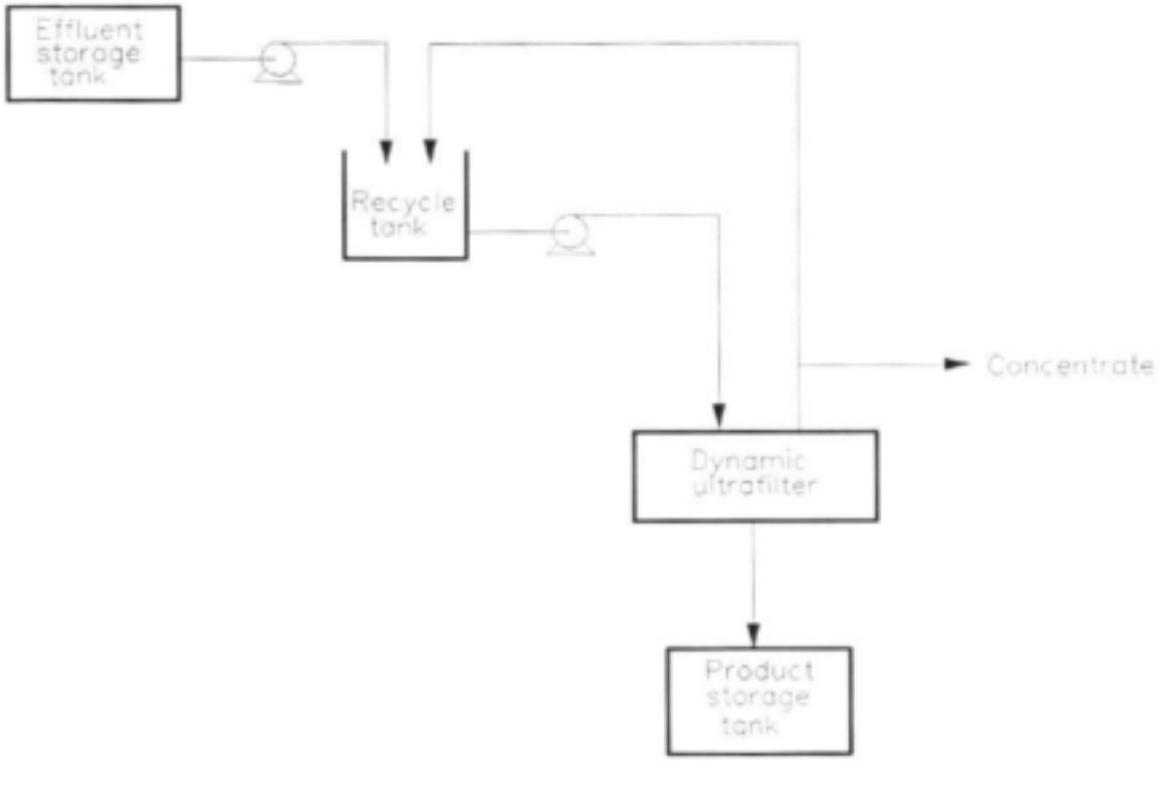


FIGURE 6.2 : FLOW DIAGRAM OF THE EXPERIMENTAL UNIT

The ultrafiltration unit comprised four sintered stainless steel tubes on which the dynamic membranes had been formed. The tube arrangement consisted of two parallel lines each containing two tubes in series. The specifications of the ultrafiltration rig are given in Table 6.2.

6.4 EXPERIMENTAL PROCEDURE AND RESULTS

Membrane formation conditions are given in Table 6.3.

The trials were conducted on a total recycle system in a series of five experiments. In total, 16 single- and dual-layer membranes with different flux characteristics were formed. Each membrane was operated continuously against scouring effluent for between 16 and 40 days.

The chemical analysis of the composite permeate predicted from point rejections for a water recovery of 90 % is given in Table 6.1.

TABLE 6.2
HIGH-TEMPERATURE ULTRAFILTRATION UNIT SPECIFICATION

Combined membrane area	0,01 m^2
Tube suppliers	CARRE, USA
Tube diameter	inside 12,7 mm outside 15,9 mm
Tube length	300 mm
Nominal pore size	0,5 μm
Pump type	Hydrocell D10 diaphragm
Fluid velocity	2,1 m/s
Product rate	2 to 6 ℓ/d
Operating pressure	4 to 5 MPa
Operating temperature	30 to 70 °C

TABLE 6.3
MEMBRANE FORMATION CONDITIONS FOR HIGH-TEMPERATURE ULTRAFILTRATION OF STRONG SCOURING EFFLUENT

Chemicals	Zr membrane Dual-layer membrane	: Zirconium nitrate : Zirconium nitrate/ Polyacrylic acid
Temperature	Ambient	
Fluid velocity	4,5 m/s	
Pressure	Zr membrane Polyacrylic acid layer	: 6 MPa : 5 MPa
pH	Zr membrane Polyacrylic acid layer	: 3 to 4 : 2 to 7
Water flux	Zr membranes Dual-layer membranes	: 150 to 400 ℓ/m^2h : 100 to 170 ℓ/m^2h

6.4.1 Membrane Rejection

Dynamically formed membrane rejection is, in general, dependent on the pH of operation since the pH value determines the ion-exchange properties of the membrane. Ionic species are most effectively rejected at :

(i) pH 4 to 5 for Zr membranes,

(ii) neutral pH for dual-layer membranes.

Results indicated that high molecular mass organic material can be separated from the sodium hydroxide under the conditions employed. Inorganic species point rejections were 10 to 20 %, while the organic carbon point rejection was 60 to 80 %.

6.4.2 Membrane Flux

Permeate fluxes underwent a three-fold increase as the operating temperature was increased from 20 to 80 °C (Figure 6.3). The permeate flux (corrected to 20 °C using a viscosity correction factor) increased with operating pressure by 2,1 ℓ/m^2h per MPa.

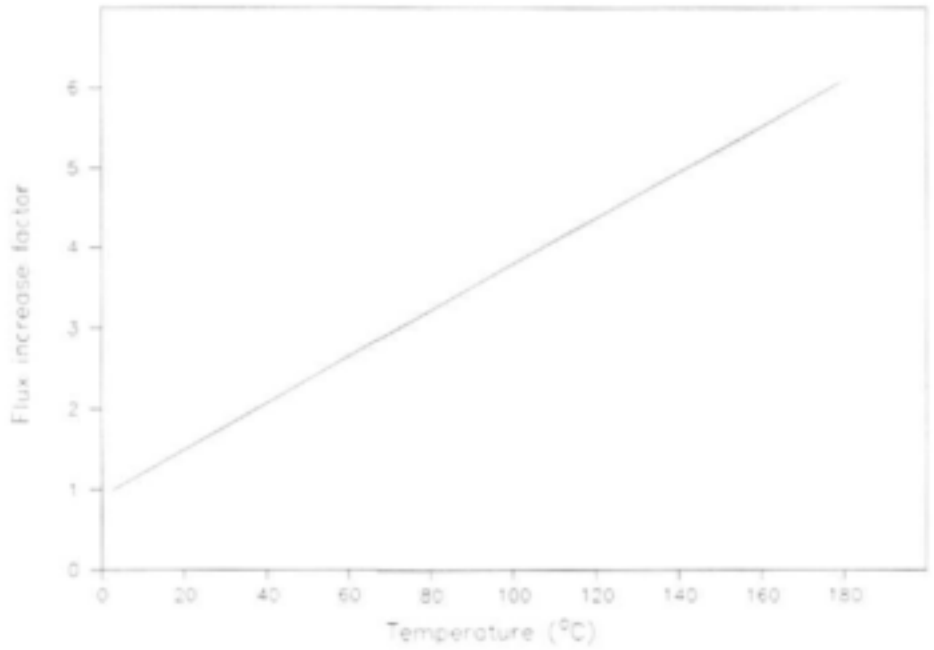


FIGURE 6.3 : CORRECTION FACTOR TO REDUCE PERMEATE FLUX TO 20 °C

Temperature corrected fluxes (20 °C) at 5 MPa on the high flux membranes were 20 to 30 ℓ/m^2h after 40 days of operation.

6.4.3 Membrane Cleaning

Permeate fluxes did not improve after hot water rinses. Detergent, sodium hydroxide and hydrogen peroxide rinses were only effective for short periods of time (1 h). The most effective cleaning solution was the caustic padding solution which consisted of wetting agent, sequestrants and sodium hydroxide. Fluxes could be maintained if rinses using the padding solution were undertaken every eight hours.

6.4.4 Membrane Stability

The Zr membrane was more stable to highly alkaline scouring effluent for longer periods of time than the dual-layer membranes. The membrane was also stable to hot sodium hydroxide, detergent and hydrogen peroxide solutions at specific pH values.

7 EVAPORATION OF STRONG COTTON AND POLYESTER/ COTTON SCOURING EFFLUENTS

7.1 INTRODUCTION

The evaporation of mercerising effluents, using various evaporator configurations, to enable the recovery and recycle of sodium hydroxide is accepted technology in the textile industry (**65**). Sodium hydroxide effluents from cotton scouring have been considered too weak and contaminated for recovery and reuse by evaporation. Since the sodium hydroxide consumption during scouring is low the ratio of non-hydroxide sodium to hydroxide sodium in the effluent is also low.

The recovery of sodium hydroxide from these scouring effluents is advantageous because of :

(i) the serious environmental impact associated with the disposal of the effluents, either neutralised or in their alkaline state,

(ii) the escalating cost associated with purchasing new chemicals and disposing of waste chemical streams.

The application of evaporative techniques to the treatment of scouring effluents results in the concentration, not only of the recoverable chemicals, but also of the contaminants. The contaminants are not considered to be a problem since :

(i) they may be concentrated above their solubility limit during evaporation and may be removed from the concentrated product by centrifugation,

(ii) if they are recycled in the sodium hydroxide they should not inhibit the scouring action since it is the sodium hydroxide fraction of the liquor which performs the scouring function.

A proposed treatment sequence involving evaporation is illustrated in Figure 7.1.

The process consists of :

(i) filtration using either cartridge filters or cloth filters to remove the lint,

(ii) evaporation to produce a condensate for reuse as rinse water and a concentrate containing the sodium hydroxide,

(iii) centrifugation to remove suspended matter from the concentrate before recycling this stream.

This chapter summarises the results obtained from the operation of a pilot plant evaporator at a textile mill to concentrate sodium hydroxide scouring effluent for reuse (**18**). The pilot plant was of the falling film type.

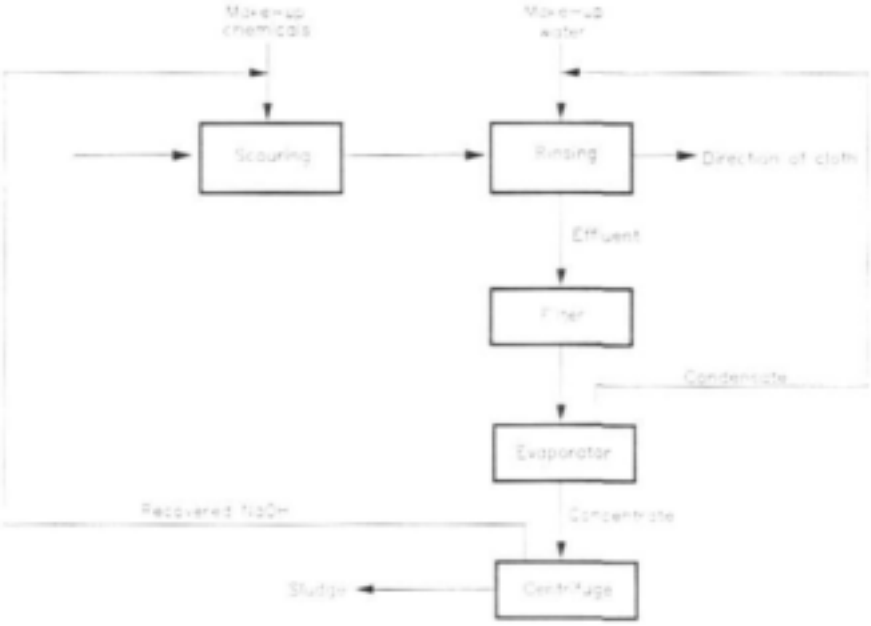


FIGURE 7.1 : FLOW DIAGRAM FOR SODIUM HYDROXIDE RECOVERY BY EVAPORATION OF STRONG SCOURING EFFLUENT

The objectives of the pilot plant operation were to determine the :

(i) degree of fouling,
(ii) heat transfer coefficients,
(iii) energy requirements,
(iv) suitability of the concentrate for reuse.

7.2 MILL PROCESS AND EFFLUENT CHARACTERISATION

The mill processed woven cotton and polyester/cotton blends. Batch scouring was carried out by padding a length of fabric with sodium hydroxide (70 g/ℓ) and detergent. The sodium hydroxide concentration in the saturator was maintained by the addition of concentrated virgin sodium hydroxide.

The cloth was steamed and wound into a caravan, which was pressurised with steam for two to six hours. Thereafter the residual sodium hydroxide and degraded impurities were rinsed from the cloth in a counter-current washing range.

Water flow rates were 5 m^3/h. Cloth was padded at a rate of 60 m/min and rinsed at a rate of 70 m/min. Pick-up from the saturator was 0,7 ℓ/kg cloth.

A chemical analysis of a sample of scouring effluent is given in Table 7.1.

TABLE 7.1
AVERAGE COMPOSITION OF SCOURING EFFLUENT TREATED BY EVAPORATION

Determinand	Effluent	Concentrate	Condensate
pH	14	14	8
TDS	40 000	172 000	100
TOC	4 550	12 300	50
TIC	450	1 800	
COD	25 000		
Na	8 000	57 500	0
Ca	40	105	0
Mg	8	13	0
K	70	171	
NaOH	16 400	96 000	0

(all analyses in mg/ℓ except for pH).

7.3 PILOT PLANT DESCRIPTION

A flow diagram of the plant is given in Figure 7.2. The manufacturers' specification for the evaporation plant and the pumps is given in Table 7.2.

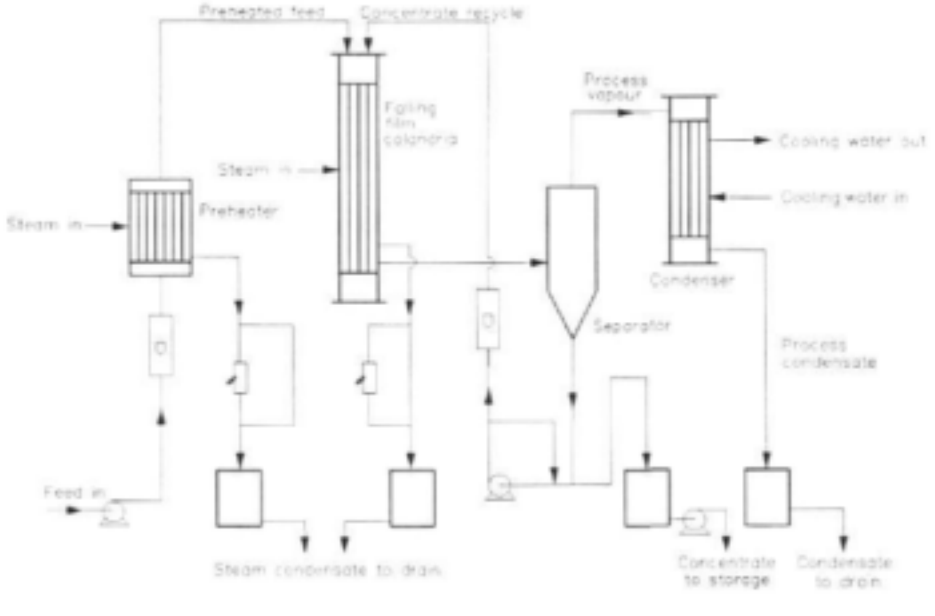


FIGURE 7.2 : FLOW DIAGRAM OF EVAPORATION PLANT

TABLE 7.2
EVAPORATOR PLANT SPECIFICATION

Vessel/Equipment	Specification
Preheater	**Test pressure: 600 kPa** **Shell: 2 of BS 1387; 25 mm NB x medium x 2 490 LG** **Tube: 2 of 316 L; 6 mm NB x SCH40 x 2 490 LG** **Area: 0,125 m^2.**
Colandria	**Test pressure shell: 600 kPa** **Test pressure tube: 150 kPa** **Shell: BS 1387; 100 mm NB heavy** **Flange: 316 SS 10 mm** **Tubes: 3 of Incaloy 825; 25 mm OD x 16 g x 2 748 LG** **32 mm triangular pitch; 25,7 mm diameter hole.** **Area 0,658 m^2**
Separator	**Test pressure: 150 kPa**
Condenser	**Test pressure shell: 175 kPa** **Test pressure tube: 400 kPa** **Shell: BS 1387, 100 mm NB x heavy** **Tube: 9 of 316 SS; 18,8 mm OD x 16 g x 2 000 LG** **19,3 mm diameter square pitch: 24 mm** **Area: 1,08 m^2.**
Feed pump	**Manufacturer: Alfa Laval model GM-2**
Recirculation pump	**Type: Centrifugal** **Manufacturer: Allis Chalmers model F4A5** **Speed 1 440 rpm.**
Concentrate pump	**Manufacturer: Mono Pump model D-40**

The design evaporative capacity of the plant was in the region of 25 ℓ/h of water for a feed of 80 to 180 ℓ/h. The utilities for the operation of the plant were as follows:

Total installed power	3 kW
Cooling water requirement (based on a 10 °C cooling water rise)	1 000 ℓ/h
Low-pressure steam	120 to 180 kPa.

The effluent from the counter-current scouring rinsing range was collected in a 20 m^3 stainless steel storage tank. It was pumped either through nylon filament filter cloth with a mean aperture of 80 μm or through 50 μm cartridge filters and passed to the evaporator through a rotameter; the flow was controlled manually using a needle valve. The feed was transferred through a preheater before entering the falling film colandria.

The temperature of the effluent entering the colandria was 80 to 85 °C. The concentrate and process vapour were then separated and the concentrate was recirculated to the colandria and the vapour condensed. For the purposes of the pilot plant trials the process condensate (from the condenser) and the steam condensate (from the preheater and the colandria) were discharged to drain. The concentrate was stored and reused in the scouring process.

To simulate a multi-effect evaporator the plant was operated in a feed and bleed mode with the concentrate from one run becoming the feed for the next run. To prevent blockage of the needle valve the liquor was pumped through the cartridge filters between passes through the evaporator.

During the operation of the evaporator the following modifications to the plant were required :

(i) To prevent foaming with resultant carry-over of process liquid into the condenser, anti-foam agents were added and the centrifugal pump was replaced with a mono pump.

(ii) The probes which gave erratic level control due to foam interference, were replaced with a successful overflow weir control system. The overflow was routed to a receiving vessel and then pumped under level control.

(iii) Heat losses were reduced by the additional insulation of various pipework on the plant.

Table 7.3 gives the conditions under which the pilot evaporator was operated.

TABLE 7.3
PILOT PLANT OPERATING CONDITIONS FOR THE EVAPORATIVE TREATMENT OF STRONG SCOURING EFFLUENT

Parameter			Preheater	Colandria	Condenser
Feed			effluent	effluent	process vapour
Feed flow	(kg/h)		65	65	30
Feed temp	(°C)		20	80	100
Steam flow	(kg/h)		9	45	
Steam pressure	(kPa)		100	100	
Steam temp	(°C)		120	120	
Cooling water flow	(ℓ/h)				1 300
Cooling water temp	(°C)	in			in 20
		out			out 30
Concentrate flow	(kg/h)			35	
Concentrate temp	(°C)			100	

7.4 EXPERIMENTAL PROCEDURE AND RESULTS

Approximately 40 m^3 of scouring effluent was concentrated to a level suitable for reuse in processing. Scouring trials using reclaimed sodium hydroxide were carried out as part of the normal factory production.

7.4.1 Prefiltration

The cartridge filters showed little tendency to foul with either the raw effluent or the concentrate which was recirculated between passes.

The flow of effluent was directed tangentially to the filter cloth. An effluent lint content of 3 mg/ℓ was effectively removed by the cloth with no blinding.

7.4.2 Evaporation

The performance of the evaporation system was assessed through a heat and material balance.

Heat Transfer Coefficients

Heat transfer coefficients are a measure of the capacity of an evaporator. A steady decrease in the heat transfer coefficient would be an indication of scaling.

Heat transfer coefficients were calculated for the falling film preheater and condenser from the relationship :

$$Q = U \, . \, A \Delta T$$

where Q is the heat transferred (kJ/h).
U is the heat transfer coefficient (kJ/m^2Cs).
A is the heat transfer area (m^2).
ΔT is the temperature driving force (°C).

The heat transferred was calculated from the specific enthalpy of the liquid entering the exchanger, the specific enthalpy of the liquid leaving the system, the specific enthalpy of the vapour produced and the mass flow rates of the vapour and the liquid.

Table 7.4 gives sample calculations and measurements which were used in the determination of the thermodynamic data.

The average heat transfer coefficients for the series of experiments were :

preheater	:	1,25 kJ/m^2Cs
colandria	:	1,44 kJ/m^2Cs
condenser	:	0,35 kJ/m^2Cs

These heat transfer coefficients were particularly low for sodium hydroxide evaporative systems and indicated one of the following :

(i) scaled heating surfaces, which was unlikely since the process condensate production rate was constant throughout,

(ii) inadequate venting. Problems with the steam valve system were experienced during trials,

(iii) poor condensate removal,

(iv) poor falling film characteristics in which the effluent did not contact the heat exchange surface for the length of the tubes.

These effects could be overcome if adequate provision was made during the design of such a plant.

Table 7.5 gives the relationship between the overall heat transfer coefficients (U) and the concentrations of the feed to the preheater and the liquor in the colandria.

Energy Consumption

The steam consumption varied from 5 000 to 8 000 kJ/kg of condensate produced. This included the energy required to preheat the stored effluent from 20 to 80 °C, which was approximately 2 700 kJ/kg of condensate.

TABLE 7.4
SAMPLE CALCULATION OF EVAPORATION THERMODYNAMIC DATA

System		Units	Value	Calculation basis
Preheater	Area	m^2	0,125	
Steam side	Steam pressure	kPa	100	Gauge pressure.
	Steam temperature	°C	120	Read from steam tables (saturated steam).
	Enthalpy	kJ/kg	2 706	Calculated from regression equation.
	Steam flow	kg/h	6	Bucket and stopwatch.
	Heat in	kJ/h	16 236	Steam flow x enthalpy of steam.
	Heat out	kJ/h	3 015	Steam condensate flow x enthalpy of condensate.
Preheater	Feed flow	kg/h	60	Calibrated rotameter measurement.
Fluid side	Feed temp in	°C	20	Assumed to be ambient.
	Feed temp out	°C	80	Measured.
	Enthalpy out	kJ/kg	335	Regression calculated from temperature.
	Heat out	kJ/h	20 104	Process of enthalpy x flow rate.
	Heat transferred	kJ/h	19 853	
	Heat (in-out)	kJ/h	-6 884	(Heat flow of steam + fluid in) - (Heat flow of condensate + fluid out).
	Delta temperature	°C	43	Log mean temperature difference.
Heat transfer coeff. [kJ/m²Cs]			1,02	Heat transferred per unit area per unit time per °C.
Colandria	Area	m^2	0.658	
Steam side	Steam pressure	kPa	100	Gauge pressure.
	Steam temperature	°C	120	Read from steam tables (saturated steam).
	Steam mass	kg	11	Volumetric measurement.
	Steam flow	kg/h	41	Volume per time.
	Enthalpy	kJ/kg	2 706	Regression calculation.
	Heat in (steam)	kJ/h	110 253	Enthalpy of steam x steam flow.
	Heat out (condensate)	kJ/h	20 507	Enthalpy of condensate at 100 °C x steam flow.
Colandria	Feed flow	kg/h	60	Calibrated rotameter measurement.
Process fluid	Preheat	°C	80	Measured.
Side	Enthalpy	kJ/kg	335	Regression calculation.
	Heat in (feed)	kJ/h	20 104	Product fluid flow x enthalpy.
	Mass vapour	kg	8	Volumetric measurement.
	Mass flow	kg/h	30	Volume per unit time.
	Vapour temp	°C	100	Boiling point of water at 1 atm.
	Enthalpy	kJ/kg	2 677	Enthalpy of steam at 100 °C from steam tables.
	Heat out (vapour)	kJ/h	79 307	Enthalpy of vapour x flow rate.
	Conc. flow	kg/h	30	Deduced from feed flow and vapour (process condensate) flow.
	Conc. temperature	°C	100	Measured.
	Recirc. flow	kg/h	960	Calibrated rotameter.
	Enthalpy	kJ/kg	419	Regression calculation (enthalpy of concentrate flow).
	Heat out (concentrate)	kJ/h	12 720	Product enthalpy x flow.
	Heat transferred	kJ/h	71 922	Heat out (conc + vapour) - Heat in (feed).

TABLE 7.4 (cont.)

System		Units	Value	Calculation basis
	Delta temperature	°C	21,38	Temp of steam - average temp of fluid.
	Heat (in-out)	kJ/h	17 823	Heat flow (steam + fluid in - conc - vapour - condensate).
Heat transfer coeff. [kJ/m^{2}Cs]			1,42	
Condenser	Area	m^2	1,08	
	Vapour flow	kg/h	30	Measured as above.
	Vapour temperature	°C	100	Boiling point of water at 100 °C.
	Enthalpy	kJ/Kg	2 677	Regression calc of enthalpy of vapour at 1 atm.
	Heat in (vapour)	kJ/h	79 307	Enthalpy of vapour x flow rate.
	Heat out (condensate)	kJ/h	3 407	Enthalpy of process condensate x flow rate.
	Cooling temp in	°C	22	Measured.
	Cooling temp out	°C	34	Measured.
	Cooling flow	kg/h	1 296,30	Volume per time.
	Enthalpy	kJ/kg	50	Enthalpy of water at temp. difference.
	Heat out (water)	kJ/h	65 206	Enthalpy x flow of cooling water.
	Heat (in-out)	kJ/h	10 694	Heat (vapour in - condensate - cooling water).
	Delta temperature	°C	52	Log mean temp difference.
Heat transfer coeff [kJ/m^{2}Cs]			0,33	Heat transferred to cooling liquid.

TABLE 7.5
HEAT TRANSFER COEFFICIENTS VS CONCENTRATION FOR EVAPORATION OF STRONG SCOURING EFFLUENT

Feed g/ℓ NaOH	Colandria g/ℓ NaOH	U Preheater kJ/m^{2}Cs	U Colandria kJ/m^{2}Cs	U condenser kJ/m^{2}Cs
16	32	0,99	1,48	0,37
21	35	1,02	1,40	0,30
21	34	0,99	1,39	0,35
28	60	1,06	1,22	0,42
34	70	0,99	1,41	0,35
52	77	1,87	1,59	0,40
58	100	1,87	1,58	0,34

Fouling of Falling Film

No decline in the rate of condensate production was observed. The colandria tubes were inspected and showed no indication of scaling.

Boiling Point Elevation

The boiling point rise of the concentrated effluent is given in Table 7.6. Boiling temperature rose by approximately 1 °C for each 10 g/ℓ increase in effluent sodium hydroxide concentration. The relatively high boiling point elevation suggests that multiple effect as opposed to vapour compression evaporation would be more suited to the present application.

TABLE 7.6
BOILING POINT ELEVATION VS CONCENTRATION FOR EVAPORATED STRONG SCOURING EFFLUENT

Conc. NaOH g/ℓ	Effluent boiling point °C
16	100
32	102
34	102
60	104
77	106
100	108

7.4.3 Centrifugation

The composition of the sludge was a function of the concentration of sodium hydroxide in the evaporated effluent. Table 7.7 illustrates this relationship. Laboratory and pilot plant studies (**18**) indicated that significant amounts of the impurities present in the raw effluent were precipitated with increasing concentration, particularly as the concentrate was cooled, and could be removed by centrifugation of the concentrate after cooling. At concentration factors of 4 to 5, the sludge (5 % of the feed) contained the following percentages of the total impurities originally present in the effluent :

Total solids	30 %
Chemical oxygen demand	30 %
Calcium	25 %
Magnesium	10 %
Sodium	5 %

The reinforcement factor required during processing determined the degree of concentration required during evaporation. This in turn determined the degree of impurity removal during centrifugation. In the event of recycle operations a steady state must be reached in which the mass of impurities removed from the fabric would be balanced by the mass of impurities removed as sludge.

7.4.4 Reuse of Process Condensate

The process condensate, which was produced at a rate of approximately 20 to 30 ℓ/h, was sampled and analysed regularly. The results given in Table 7.1 indicate that the condensate produced was of suitable quality for reuse as process water in the scouring rinse range.

TABLE 7.7
SLUDGE COMPOSITION OF CENTRIFUGED EVAPORATION CONCENTRATE

Determinand	Per cent component in sludge for concentration factors of				
	x2	x4	x8	x12	x16
Na	0	0	0		0
Ca	25	29	26	50	78
Mg	5	52	54		39
TOC	0	15	9		31
TS	0	3	23		17
NaOH	0	5	10		17

Note : Approximate NaOH concentrations for the concentration factors were :

x2 : 5 %
x4 : 9 %
x8 : 17 %
x16 : 32 %

7.4.5 Reuse of Sodium Hydroxide Concentrate

The composition of the reclaimed sodium hydroxide (concentrate) is given in Table 7.1.

Reclaimed sodium hydroxide was used as process sodium hydroxide for the scouring of approximately 10 000 m of fabric. Since detergent was removed during the evaporation and centrifugation processes, detergent was added to the reclaimed sodium hydroxide according to the recipe.

In Table 7.8 the compositions of virgin and reclaimed sodium hydroxide are compared. The reclaimed sodium hydroxide contained higher levels of organic material than the virgin sodium hydroxide. Despite the high level of organic contamination in the reclaimed sodium hydroxide, no interference with the scouring action of the sodium hydroxide on the cotton impurities occurred and the final cloth quality was not impaired (**18**). The impurity carry-overs for cloth lengths scoured in virgin and in reclaimed sodium hydroxide were not significantly different.

The cloth which was scoured in reclaimed sodium hydroxide was processed by the standard factory methods and subsequently printed and dyed as part of a normal production run. No problems were encountered with further processing and the cloth passed all quality control tests.

TABLE 7.8

CHEMICAL COMPOSITION OF VIRGIN AND RECLAIMED SCOURING LIQUORS

Determinand	Virgin sodium hydroxide	Reclaimed sodium hydroxide
pH	13,5	13,5
TS	110 to 145	140 to 150
TOC	0 to 9	13 to 23
Na	45 to 60	50 to 60
NaOH	70 to 85	70 to 80

(all analyses in g/ℓ except pH).

7.5 DESIGN CONSIDERATIONS

In summary, evaporation may be used in the treatment of strong scouring effluent from the textile industry. This treatment process :

(i) requires minimal pretreatment in the form of filtration using fine screen or wedgewire systems,

(ii) produces a good quality product water which may be reused for rinsing,

(iii) concentrates the sodium hydroxide in the effluent while at the same time it precipitates 30 to 60 % of the other impurities, allowing them to be removed by centrifugation,

(iv) produces a concentrated sodium hydroxide stream suitable for reuse in the scouring process without impairing the cloth quality.

In the specification of an evaporator unit for the treatment of strong scouring effluent consideration must be given to :

(i) solids removal. Lint should be removed using fine screen or wedge wire systems;

(ii) the removal of precipitates from the concentrated sodium hydroxide by centrifugation. This will include the removal of the waxy layer at the bottom and the sludge at the top;

(iii) minimise foaming. This should be achieved by using suitable pumps and pipework to prevent cavitation and by the addition of anti-foam;

(iv) fluctuations in the cooling water flow. These fluctuations can be caused by fluctuations in the mains supply pressure and should be avoided in order to control and maximise vapour condensation;

(v) a suitable venting system for the steam jacket. This system should prevent the build-up of non-condensable gases and the blanketing of part of the heating surface and thus minimise energy consumption;

(vi) complete size removal in the desize washing process prior to the scouring process. If size removal is not effective a gelatinous evaporator concentrate is produced.

A detailed design and a costing analysis requiring a complete heat and material balance and which are specific to each individual application, have not been prepared. Since most evaporators are supplied as package units, the economic assessment should be carried out in conjunction with evaporator suppliers.

7.5.1 Major Equipment

Major equipment would include :

Effluent Storage and Transfer Facilities

Effluent and product storage of 6 to 24 h duration is necessary to provide for heat transfer surface cleaning, minor breakdowns, maintenance and fluctuations in processing. All pipes and tanks used for transferring and storing effluent should be insulated to prevent heat loss from the effluent.

Prefiltration

The effluent should be screened to avoid clogging of the pumps and other process equipment. Wedgewire screens with apertures of 50 to 80 µm are suitable for lint removal. Screens are standard units and the size/area depends on the effluent flow.

Heat Transfer

Equipment costs are determined by heat transfer surface area, materials of construction and evaporator type.

Several types of evaporator are available. In single-effect evaporators approximately 1 kg of steam is consumed in evaporating 1 kg of water. Lower steam consumption can be achieved by using multi-effect evaporators and vapour compression.

Solids-Liquids Separation

The evaporator concentrate should be centrifuged prior to storage and reuse.

8 ELECTRO-OXIDATION OF STRONG COTTON AND POLYESTER/ COTTON SCOURING EFFLUENTS

8.1 INTRODUCTION

Strong scouring effluents contribute over 25 % of the COD in the final effluent from the wet preparation section of a mill processing cotton and cotton blends (section 2.7.1). Oxidation of the organic material in the effluent will lower the COD and make the effluent more amenable for discharge to the environment or to the sewer.

This chapter describes the oxidation of organic material in strong scouring effluent by hypochlorous acid, which is generated from effluent components during electrolysis in an electro-oxidation cell (**18**). A flow diagram of the treatment sequence is shown in Figure 8.1 and consists of :

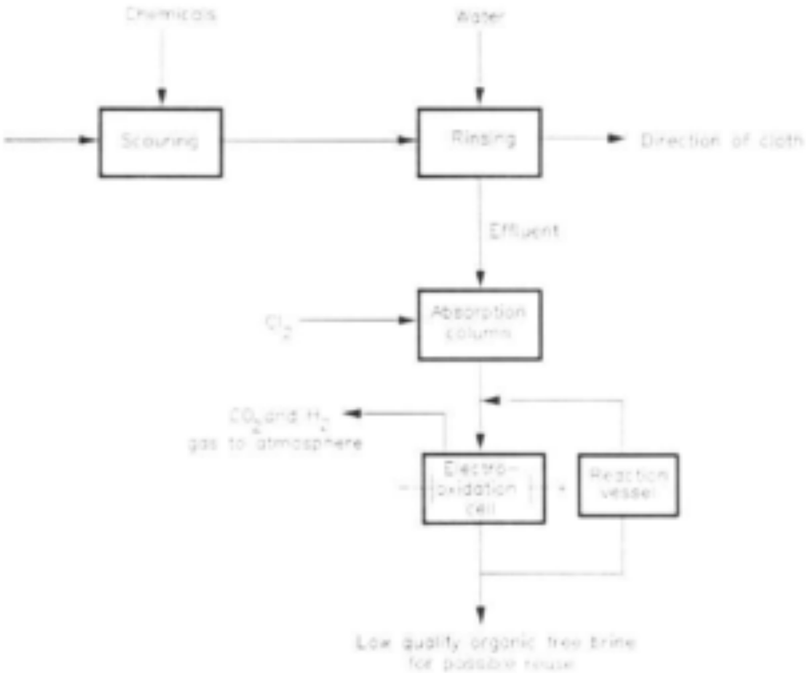


FIGURE 8.1 : FLOW DIAGRAM FOR THE ELECTRO-OXIDATION OF STRONG COTTON AND POLYESTER/COTTON SCOURING EFFLUENTS

(i) neutralisation of the sodium hydroxide in the effluent using chlorine to produce sodium chloride,

(ii) electrolysis of the sodium chloride solution in an undivided electro-oxidation cell (without a separator) to generate the oxidising agent, hypochlorous acid,

(iii) oxidation of the organic material in a reaction vessel.

A colourless, slightly alkaline and mildly oxidising brine solution is produced, which may be reused in bleaching or as low quality water. Hydrogen from the electrode reaction and carbon dioxide from the oxidation of organic material in the electro-oxidation cell are also produced.

The objectives of the electro-oxidation trials were to determine the :

(i) optimum operating conditions for the removal of COD in scouring effluent,

(ii) degree of removal of COD which could be achieved and the current efficiency at which this removal could be effected,

(iii) energy requirements of the system.

8.2 MILL PROCESS AND EFFLUENT CHARACTERISATION

The strong scouring effluent under consideration was from the same textile mill processing woven cotton and polyester/cotton blends as was the effluent used in the evaporation trials (Chapter 7).

A chemical analysis of a scouring effluent subjected to oxidation is given in Table 8.1.

TABLE 8.1
CHEMICAL ANALYSIS OF SCOURING EFFLUENT TREATED BY ELECTRO-OXIDATION

Determinand	Effluent	Chlorinated effluent	Oxidised effluent
pH	13,7	7	5 to 6
Cond (mS/m)	5 100	2 800	3 000
TS	64 000		
TOC	7 700	7 600	2 500
TIC	700	0	0
COD	26 000	23 000	1 000 to 4 000
Na	15 400	15 400	15 400
Ca	80	80	80
Mg	17	17	17
Cl	1	19 700	16 000
OCl	0	900	5 300

(all analyses in mg/ℓ except pH and conductivity)

8.3 PILOT PLANT DESCRIPTION

A flow diagram of the plant is shown in Figure 8.2.

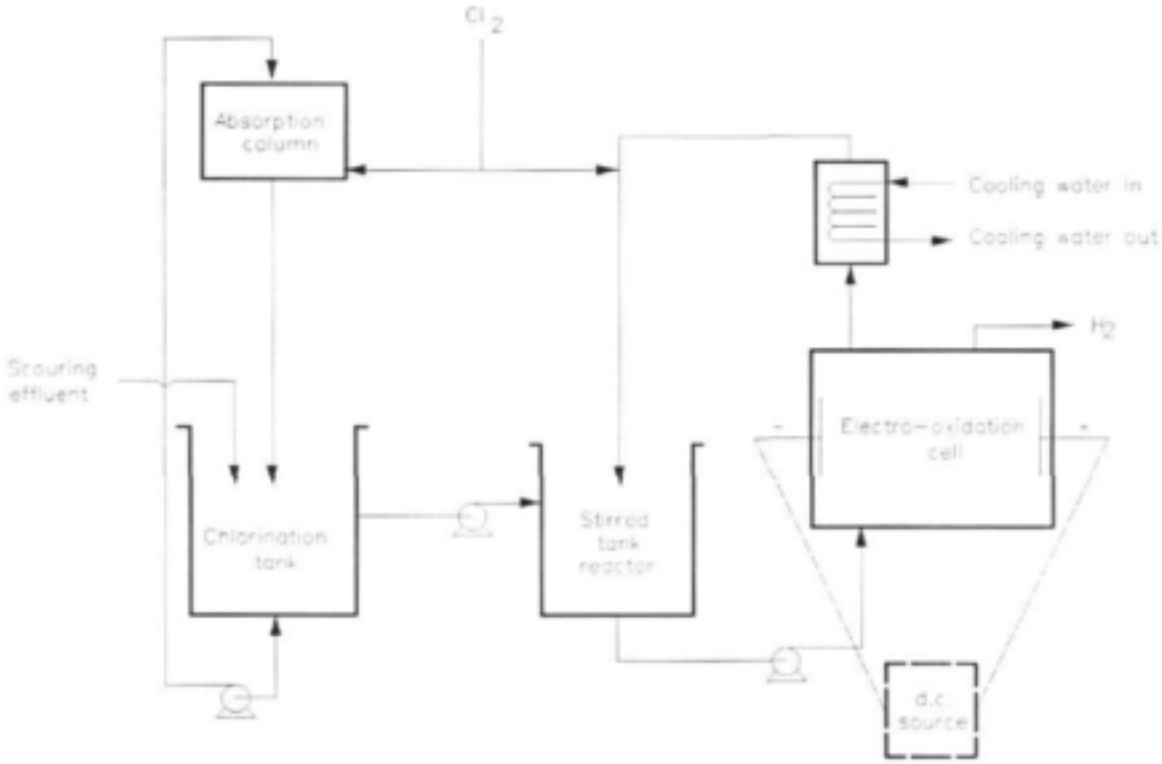


FIGURE 8.2 : FLOW DIAGRAM OF THE ELECTRO-OXIDATION PLANT

Both the chlorination and electro-oxidation functions were operated in the batch mode. Scouring effluent from the factory was chlorinated during recirculation through the adsorption column. The chlorine was either supplied from a cylinder or was generated by the electrolysis of a sodium chloride solution in a membrane cell. The chlorinated effluent was transferred to the stirred tank reactor from where it was circulated through the electro-oxidation cell until the required degree of oxidation had been achieved.

The plant specification is given in Table 8.2.

TABLE 8.2
ELECTRO-OXIDATION PLANT SPECIFICATION

Unit	Parameter	Specification
Absorption column	size	Height : 1 000 mm diameter : 150 mm
	construction material	glass
	packing	ceramic saddles
	effluent flow	5 ℓ/min
	final effluent pH	7 to 7,5
	pump type	Magnetic coupled centrifugal
Electro-oxidation cell	electrode size	0,1 m^2
	electrode separation	30 mm
	anode material	DSA (titanium base, PG oxide coating)
	cathode material	mild steel
	frame construction material	PVC
	pump type	Magnetic coupled centrifugal
	effluent flow	5 to 8 ℓ/min
	current density	2 200 A/m^2
	pH	5 to 6

8.4 EXPERIMENTAL PROCEDURE AND RESULTS

The chemical analysis of the effluent after chlorination and after electro-oxidation is shown in Table 8.1.

8.4.1 Chlorination

Chlorination of the scouring effluent :

(i) removed approximately 10 % of the COD in the effluent,

(ii) decreased the effluent pH,

(iii) resulted in the formation of chloride and hypochlorite ions.

8.4.2 Electro-oxidation

Foaming

Foaming which tends to occur during gas generation, was controlled by either decreasing the flow rate through the cell or by the addition of anti-foam.

Current Efficiency for the Removal of COD

Calculations of current efficiency for the removal of COD are based on :

(i) Faradays law i.e. a Faraday (F) of electricity produces a mole of electrons. Hence a mole of electrons would be transferred in producing 0,5 moles of chlorine or a mole of oxidising agent, which is in turn equivalent to a removal of 0,5 moles of oxygen i.e. 8 g of COD;

(ii) the following relationship :

$$F = \frac{Ah}{26,8}$$

where A = current passed.
h = hours.
F = Faradays.

(iii) the ratio between the observed COD removal and the theoretical COD removal based on the electricity consumed.

$$current\ efficiency\ (\%) = \frac{observed\ COD\ removal}{theoretical\ COD\ removal} \times 100$$

Initially current efficiency for the removal of COD was near 100 %. As the COD concentration in the effluent decreased (i.e. as the COD removal increased), the resistance to oxidation increased with COD removal efficiencies dropping rapidly as illustrated in Figure 8.3.

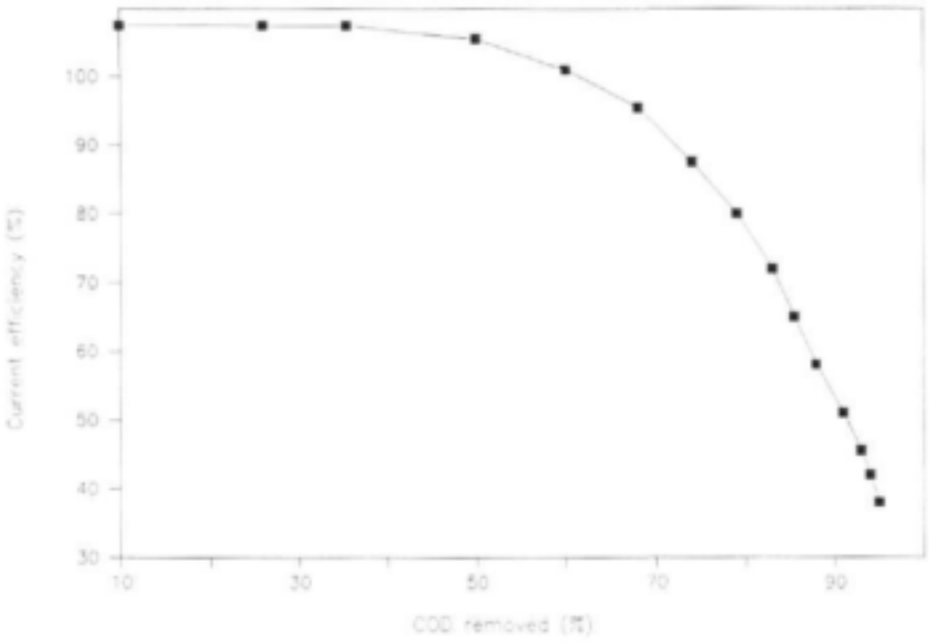


FIGURE 8.3 : CURRENT EFFICIENCY FOR THE REMOVAL OF COD AS A FUNCTION OF THE COD REMOVED

The pH range in which the effluent had to be maintained during electro-oxidation was 5,5 to 6,5. Figure 8.4 shows the relationship between current efficiency and effluent pH at a fixed COD removal of 70 %. Figure 8.5 shows the relationship between COD removal and effluent pH at a fixed current efficiency of 85 %. Figures

8.4 and 8.5 show that for high COD removals at high current efficiencies the pH should be maintained below 7. During electro-oxidation the pH increases and additional electricity was consumed in producing chlorine to control the pH at the required value.

Colour Removal

Complete colour removal occurred at approximately pH 9 during chlorination of the effluent in the absorption column. Residual turbidity was eliminated during the initial stages of electro-oxidation, after which the effluent was crystal clear.

Distribution of Chlorine Species

Figure 8.6 shows the distribution of chlorine species as a function of the amount of COD removed. Initially chloride ions existed which were converted to hypochlorite/ hypochlorous acid on application of an electric potential across the system. The hypochlorous acid ($HClO$), which is the oxidising agent predominates below pH 7,8 (Figure 8.7). After the removal of approximately 90 % of the COD, chlorate ions (ClO_3^-) are produced :

(i) chemically by the reaction of hypochlorite ions and hypochlorous acid in a 1 : 2 ratio;

(ii) electrochemically by the anodic oxidation of hypochlorite ions.

The predominant chlorate formation mechanism depends on the pH of the solution. If the electric potential is maintained across the solution after complete COD removal has been achieved, perchlorates (ClO_4^-) are formed at the expense of the other chlorine species.

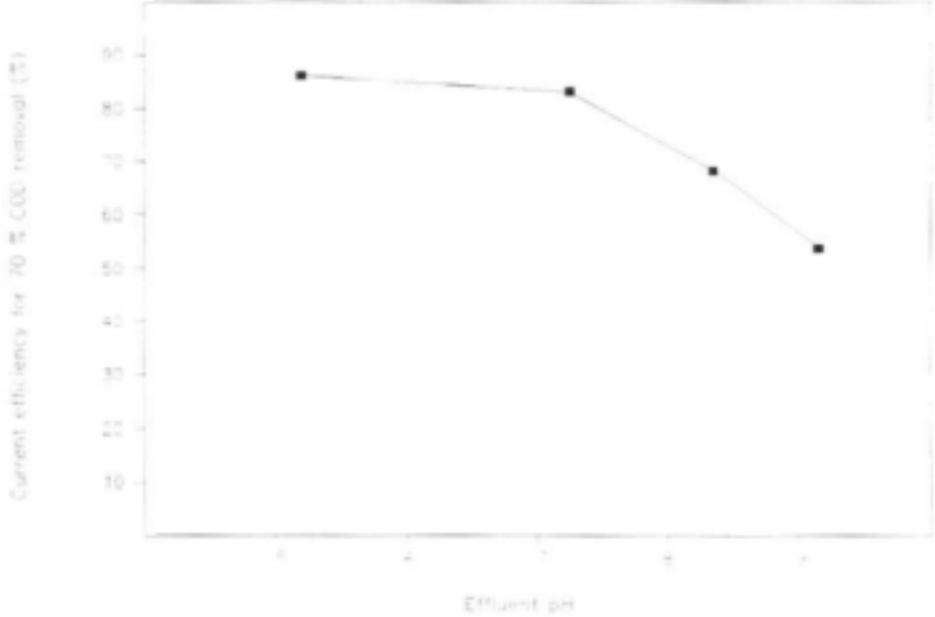


FIGURE 8.4 : DEPENDENCE OF CURRENT EFFICIENCY ON EFFLUENT pH FOR A FIXED COD REMOVAL

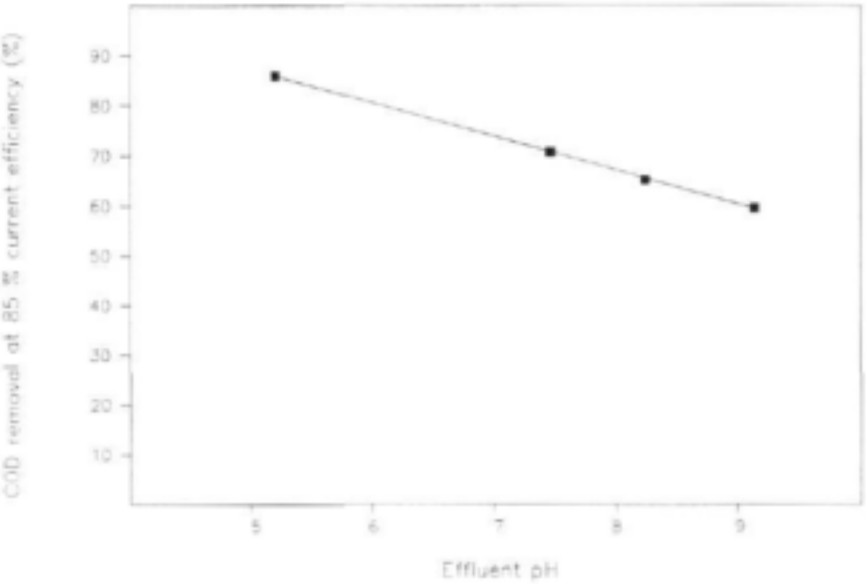


FIGURE 8.5 : DEPENDENCE OF COD REMOVAL ON EFFLUENT pH FOR A FIXED CURRENT EFFICIENCY

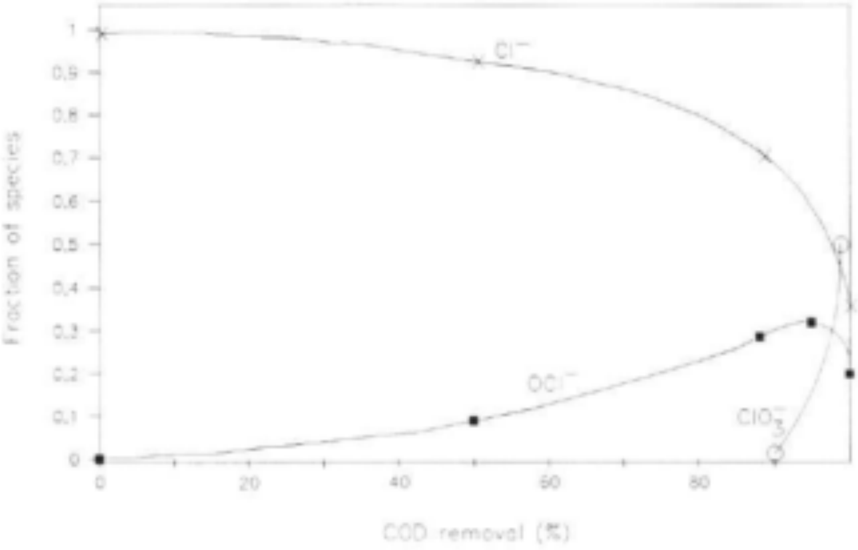


FIGURE 8.6 : DISTRIBUTION OF CHLORINE SPECIES AS A FUNCTION OF COD REMOVAL

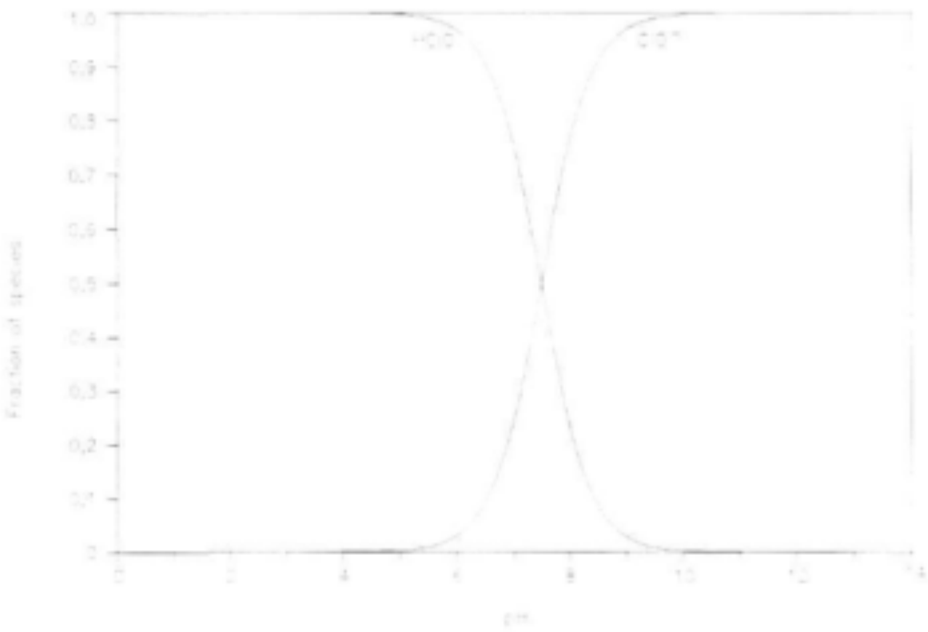


FIGURE 8.7 : DISTRIBUTION OF HYPOCHLOROUS ACID AND HYPOCHLORITE WITH pH

Power Consumption

The power consumption per kg of COD removed is plotted in Figure 8.8 as a function of the fraction of the total COD removed. Chlorination, during which the specific power consumption was below 2 kWh/kg COD removed, oxidised the most easily oxidised COD in the effluent and removed the colour. The specific power requirement for COD removal increased sharply as the total amount of COD remaining in solution decreased. All the turbidity was removed at a cumulative specific power consumption of 17 kWh/kg COD. In the case where total COD removal was achieved the specific power consumption was nearly 70 kWh/kg COD.

Thus three scenarios are possible :

colour removal,
turbidity removal,
total COD removal.

The specific power requirements are dependent on the scenario chosen and increase rapidly as greater COD removals are required.

8.5 DESIGN CONSIDERATIONS

In summary, electro-oxidation may be used in the treatment of strong scouring effluent when the discharge of colour and COD from the factory is a problem. This process :

(i) requires filtration to effect lint removal,

(ii) removes all the colour and turbidity from the effluent,

(iii) allows the degree of COD removal to be varied,

(iv) neutralises the effluent to produce a colourless, slightly acidic, brine solution. This solution may be reused as low quality water in processes such as bleaching, mercerising or scouring or may be treated and used in the electrolytic generation of chlorine for the neutralisation/chlorination stage.

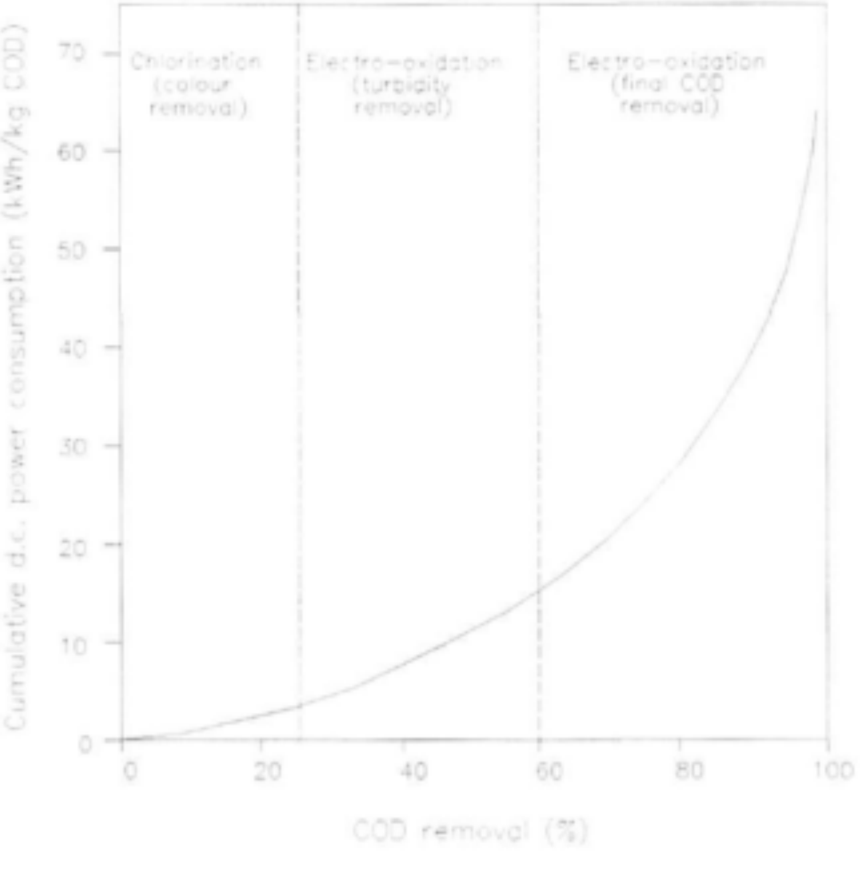


FIGURE 8.8 : CUMULATIVE POWER CONSUMPTION (ELECTROCHEMICAL MEMBRANE AND ELECTRO-OXIDATION CELLS) AS A FUNCTION OF COD REMOVED FROM THE EFFLUENT

In the design of an electro-oxidation plant for the treatment of strong scouring effluent consideration must be given to :

(i) minimising foaming by employing suitable pumps and pipework to prevent cavitation, by enabling efficient release of evolved gases and by the addition of anti-foam,

(ii) the provision of cooling facilities to ensure maximum production of hypochlorite and hypochlorous acid and to minimise the chemical conversion of these species to chlorate ions,

(iii) pH control to ensure that hypochlorous acid predominates over the hypochlorite species. Hypochlorous acid is the oxidising agent and the anodic oxidation of hypochlorite to form chlorates occurs at high hypochlorite ion concentrations,

(iv) efficient mass transfer at the anode to ensure that the oxidation of chloride ions to chlorine predominates over the oxidation of water with the evolution of oxygen. This is achieved by maintaining the current density below a predetermined level, dependent on the chloride concentration and a high fluid flow through the cell.

8.5.1 Major Equipment

The flow diagram of the treatment sequence is given in Figure 8.9 and the major equipment components are as follows :

Heat Exchanger

Heat exchangers are required to cool the liquor which circulates through the electro-oxidation cell to maintain its temperature below 20 °C, thus minimising the loss of oxidising agent consumed in the production of chlorates.

Prefilter

Wedge-wire screens or cartridge filters are used for lint and particulate solids removal from the effluent prior to chlorination.

Storage Facilities

Storage facilities are required to smooth out variations in the flow of various streams. Where the storage equipment is exposed to oxidising solutions, it must be constructed from suitably resistant materials.

Chlorine Generator

Chlorine is required to neutralise the sodium hydroxide in the incoming scouring effluent and to maintain the pH of the circulating liquor at pH 5,5 to 6,5 (this requires an additional 5 % chlorine).

Chlorine is generated electrolytically in an electrochemical membrane cell from sodium chloride using specially designed units and a direct current (d.c.) power supply. Equipment manufacturers can supply packaged units with capacities which range from 0,01 to 24 t Cl_2/d.

For a plant treating 4 m^3/h of effluent containing 25 g/ℓ NaOH (see Electro-oxidation below) the electrochemical membrane cell should be sized to produce 2,2 t Cl_2/d.

If chlorine is not generated on site, it may be purchased as a bulk chemical. On-site chlorine generation is, however, preferable since sodium hydroxide is produced simultaneously and may be used in processing.

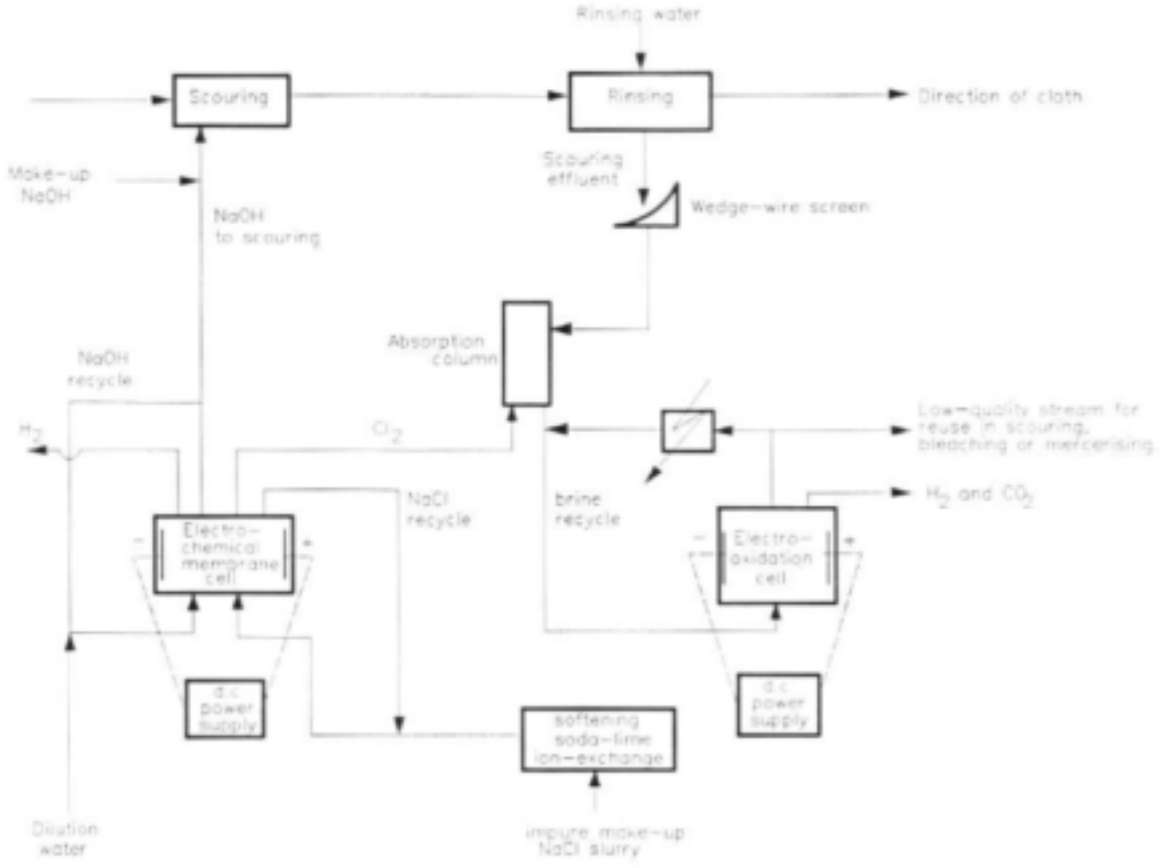


FIGURE 8.9 : FLOW DIAGRAM OF THE TREATMENT SEQUENCE FOR THE ELECTRO-OXIDATION OF STRONG SCOURING EFFLUENT

Absorption Unit

The absorption unit provides surface area for absorption of chlorine into the effluent. Chlorine gas is highly soluble, undergoing rapid hydrolysis that accelerates the rate of absorption (66). Sophisticated mass transfer equipment and excess gas recycle systems are not necessary.

pH Control systems must be installed to prevent excess chlorination of the effluent, at which stage chlorine is no longer absorbed.

Electro-oxidation Unit

The function of the electro-oxidation unit is to oxidise the chloride ions in the effluent to produce hypochlorous acid for the oxidation of organic material. The electro-oxidation stack is a standard unit supplied to comply with design specifications and consists of a series of undivided cells which may be electrically connected in either series or in parallel. Different flow configurations are available.

The electrode area of each repeating unit varies depending on the manufacturer, but would be in the order of 0,5 to 1 m^2.

An example design is based on the following specification :

Scouring effluent flow	4 m^3/h		
Scouring effluent COD concentration	25 g/ℓ, highly coloured		
Scouring effluent Na concentration	15 g/ℓ		
Scouring effluent NaOH concentration	25 g/ℓ		
Product flow	4 m^3/h		
Product COD concentration	(i)	19 g/ℓ	(colour removal)
	(ii)	10 g/ℓ	(colour and turbidity removal) (87 % COD removal)
	(iii)	3 g/ℓ	
Product NaCl concentration	35 g/ℓ.		

Table 8.3 lists the estimated electro-oxidation plant size for the three cases (for current densities of 2 200 A/m^2).

The cell frames and cell components are manufactured from materials resistant to oxidation by chlorine. The cathodes are constructed from titanium, stainless steel or any other suitable metal, while the anodes are constructed from a material which possesses a low chlorine overpotential such as platinum group metal oxide coated titanium.

TABLE 8.3
ESTIMATED ELECTRO-OXIDATION PLANT SIZE
Current density = 2 200 A/m^2

Design parameter	COD removal (%)	Current efficiency (%)	Cell area (m^2)
Colour removal	24	no electro-oxidation required	
Turbidity removal	60	80	114
Further oxidation	87	40	324

Regulated chlorine addition and pH control must be incorporated.

A reaction vessel is used to provide a residence time during which the hypochlorous acid oxidises the organic material. The residence time will be determined by the COD removal requirement and should be 0,5 to 1 h. At high COD removals the oxidation reaction proceeds more slowly and longer residence times are required.

Power Requirements

Both the electrochemical membrane cell and the electro-oxidation unit must be connected to a d.c. power supply.

The combination of volt/current requirements will be a function of the configuration of the electrical connections of the electrochemical membrane and electro-oxidation stacks.

Rectifier control is important to prevent ripple effects which destroy the anode coating.

9 ELECTROCHEMICAL RECOVERY OF SODIUM HYDROXIDE FROM STRONG COTTON AND POLYESTER/COTTON SCOURING EFFLUENTS

9.1 INTRODUCTION

Strong scouring effluents are high in sodium ion concentration. In factories where the recovery of mercerising caustic is practiced, scouring effluents are a large contributor to the cationic load in the final factory discharge. The disposal of scouring effluents is governed by effluent discharge regulations. Discharge to the sea or solar evaporation or irrigation is regarded as short-term measures.

Chapters 6 and 7 describe the treatment of strong scouring effluents by ultrafiltration and electro-oxidation techniques. These techniques may be applied where the discharge of COD is the major problem. Chapter 8 describes the evaporation and the reuse of strong scouring effluent to overcome the TDS problems associated with their discharge. In this system the water, the reusable chemicals and some of the impurities are concentrated and recycled.

This chapter describes a treatment sequence which will enable the recovery of the sodium hydroxide for recycling to the scouring process.

The proposed treatment sequence is shown in Figure 9.1 and consists of :

(i) neutralisation with carbon dioxide to convert the sodium hydroxide to sodium bicarbonate,

(ii) cross-flow microfiltration to remove suspended, colloidal and waxy contaminants from the neutralised effluent,

(iii) nanofiltration to separate the sodium bicarbonate from the soluble organic and divalent metal contaminants,

(iv) electrochemical treatment in a membrane cell (Figure 9.2) to split the sodium bicarbonate into sodium hydroxide, carbon dioxide and a dilute brine.

The pH dependence of the equilibrium which exists between the various forms of inorganic carbon in solution (Figure 9.3) is used to ensure that the desired species predominates.

The treatment sequence produces :

(i) two concentrates containing organic material and divalent metal ions from the filtration stages. These streams comprise up to 10 % of the initial volume of the scouring effluent treated,

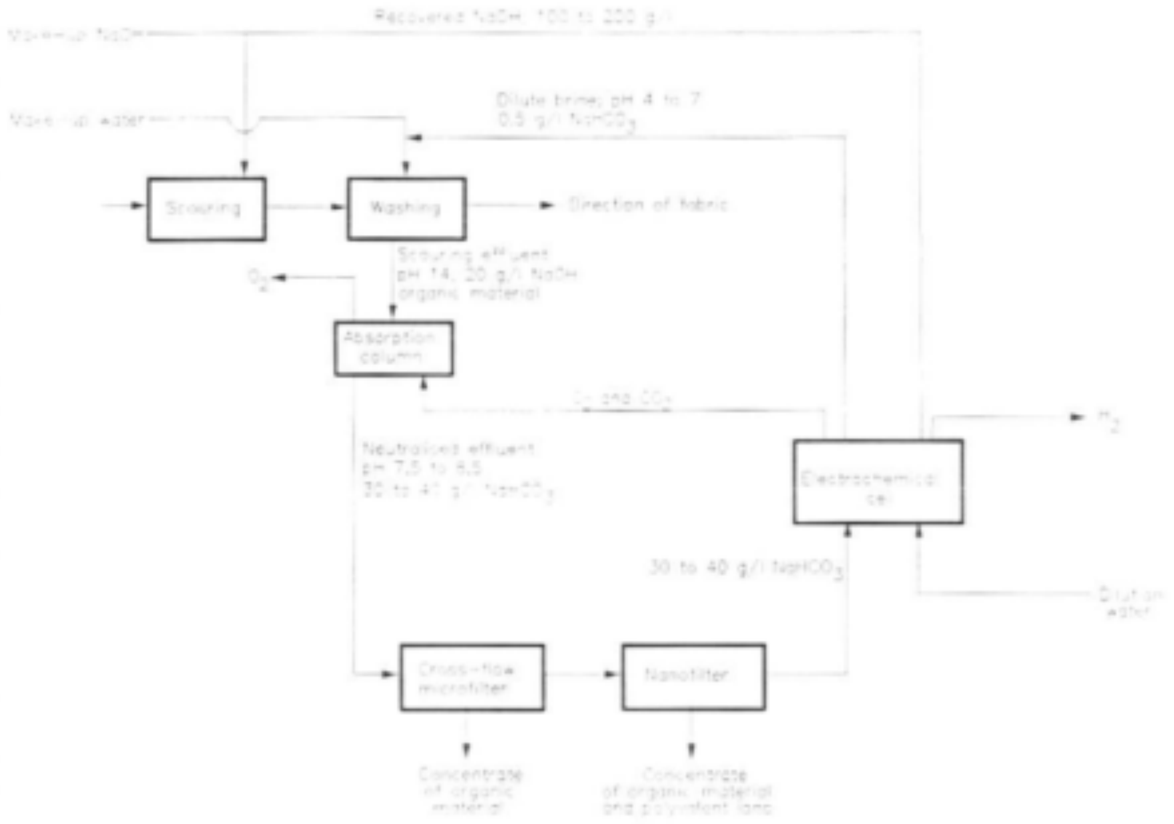


FIGURE 9.1 : TREATMENT SEQUENCE FOR THE RECOVERY AND RECYCLE OF STRONG COTTON SCOURING EFFLUENTS

(ii) hydrogen and oxygen from the electrochemical unit,

(iii) a dilute brine from the anode compartment of the electrochemical unit which could be reused in the washing section of the scouring process,

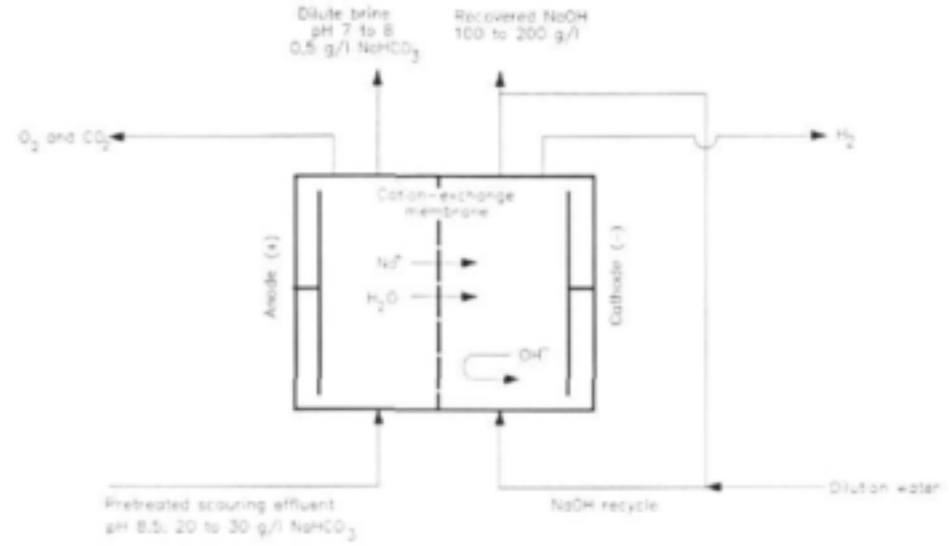
(iv) a concentrated sodium hydroxide stream for recycling to the scouring process.

The results from the operation of a pilot plant for the electrochemical recovery of chemicals and water from scouring effluent are summarised. The objectives of the trials were to :

(i) assess the technical and economic feasibility of the treatment sequence for its application to scouring effluents,

(ii) determine the purity and concentration at which the recovered products may be produced,

(iii) determine the operating parameters of the treatment stages,



Anode reaction : $H_2O - 2e \rightarrow \frac{1}{2}O_2 + 2H^+$

Cathode reaction : $2H_2O + 2e \rightarrow H_2 + 2OH^-$

Anolyte reaction : $H^+ + HCO_3^- \Leftrightarrow H_2CO_3 \Leftrightarrow CO_2 + H_2O$

FIGURE 9.2 : SCHEMATIC OF ELECTROCHEMICAL MEMBRANE CELL

(iv) determine the influence of the scouring effluent characteristics on the process,

(v) obtain data for the design of a full-scale plant.

9.2 MILL PROCESS AND EFFLUENT CHARACTERISATION

Pilot-plant trials were conducted at a textile mill processing woven cloth and polyester/cotton blends. Scouring was achieved in an open-width Vaporloc machine using a sodium hydroxide solution at 50 g/ℓ for a fabric speed of 50 m/min. Lufibrol TX112 (10 g/ℓ) and Formosol (1 g/ℓ) were also added to the saturator. A continuous counter-current four-bowl washing range was employed with a wash-water flow rate of 4 to 5 m^3/h. The wash water used was a mixture of mains water and effluent from a bleaching range at a volume ratio of 7 : 3. The effluent used in the pilot-plant trials was collected from the first washing bowl of the range. A chemical analysis of this effluent is given in Table 9.1.

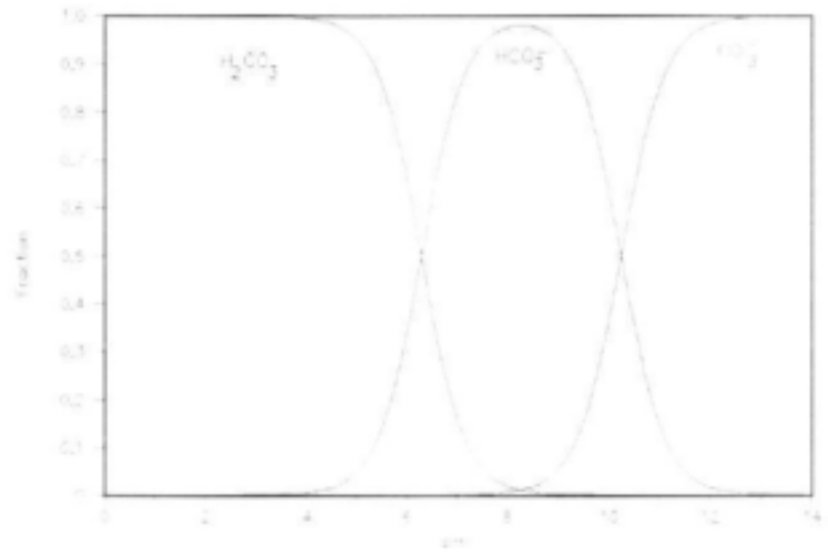


FIGURE 9.3 : DISTRIBUTION OF INORGANIC CARBON IN SOLUTION

TABLE 9.1
AVERAGE COMPOSITION AFTER EACH STAGE OF THE SCOURING TREATMENT SEQUENCE

Determinand		Raw scouring effluent	After neutralisation	After CFMF	After NF	After electrolysis	
						brine	NaOH
pH		13,5	8,6	8,4	9,0	5,2	14,0
Conductivity	(mS/m)	6 400	2 400	2 500	2 300	200	
TS	(g/ℓ)	22,0	22,0	20,0		0,5	
TC	(g/ℓ)	4,0	7,9	7,6	5,9	0,4	
TIC	(g/ℓ)	0,3	4,3	4,6	5,2	0	
TOC	(g/ℓ)	3,7	3,6	3,0	0,7	0,4	
COD	(g/ℓ)	8,3	8,3	5,3	0,5	0,5	
OH	(g/ℓ)	4,1	0	0	0	0	70,0
CO_3	(g/ℓ)	2,6	1,9	2,0	3,4	0	1,5
HCO_3	(g/ℓ)	0,0	16,1	16,5	11,5	0	0
Na	(g/ℓ)	8,4	8,2	8,8	7,2	0,3	97,0
Ca	(mg/ℓ)	45,0	45,0	3	2	2	
Mg	(mg/ℓ)	7,0	5,0	2	1	1	

Note : CFMF denotes cross-flow microfiltration and NF denotes nanofiltration.

9.3 PILOT-PLANT DESCRIPTION

Flow diagrams of the individual unit processes of the pilot plant i.e. neutralisation, cross-flow microfiltration, nanofiltration and electrolysis are given in Figures 9.4 to 9.7 respectively. A detailed design of the pilot plant is reported elsewhere (**18**). Table 9.2 contains the pilot-plant specification.

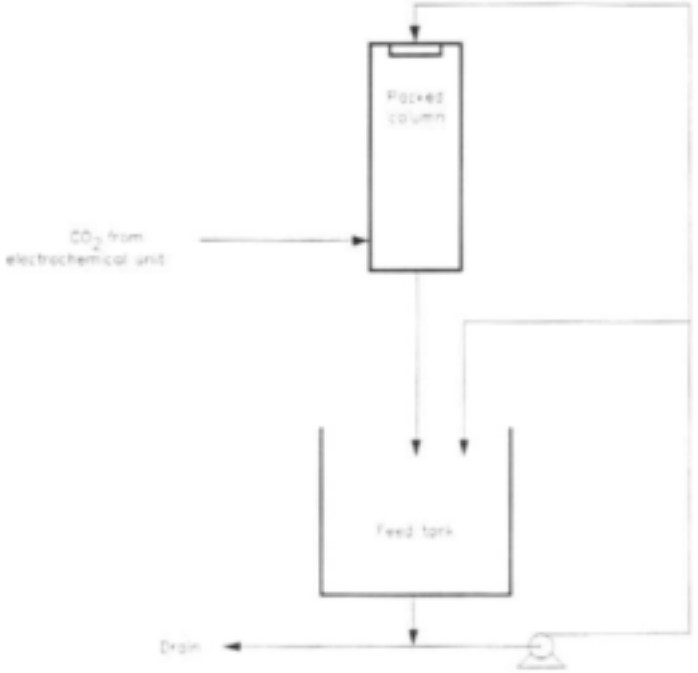


FIGURE 9.4 : FLOW DIAGRAM OF NEUTRALISATION UNIT

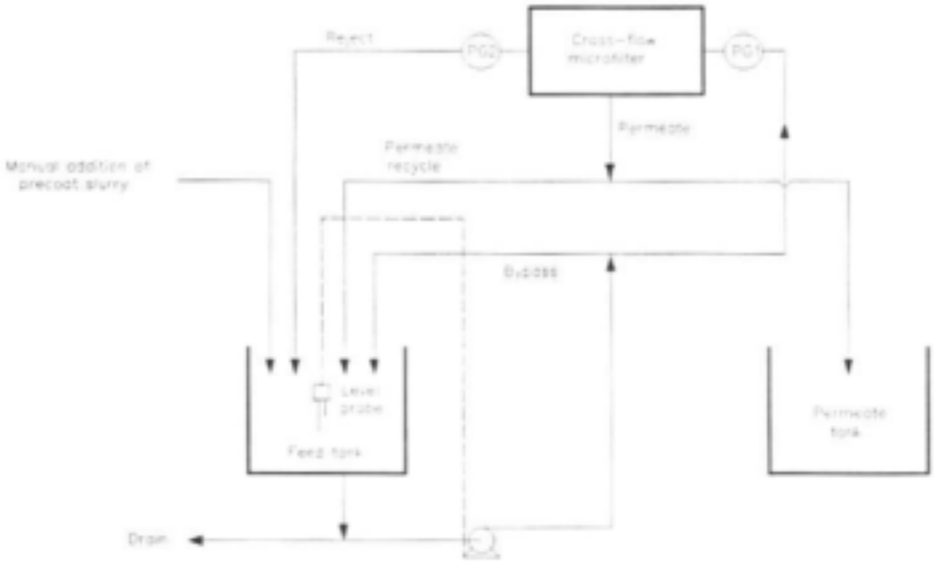


FIGURE 9.5 : FLOW DIAGRAM OF CROSS-FLOW MICROFILTRATION UNIT

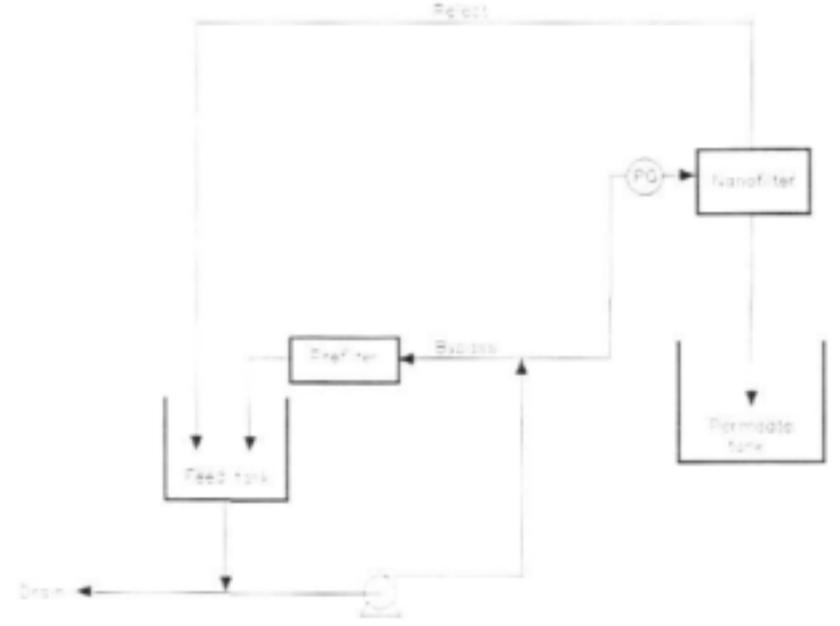


FIGURE 9.6 : FLOW DIAGRAM OF NANOFILTRATION UNIT

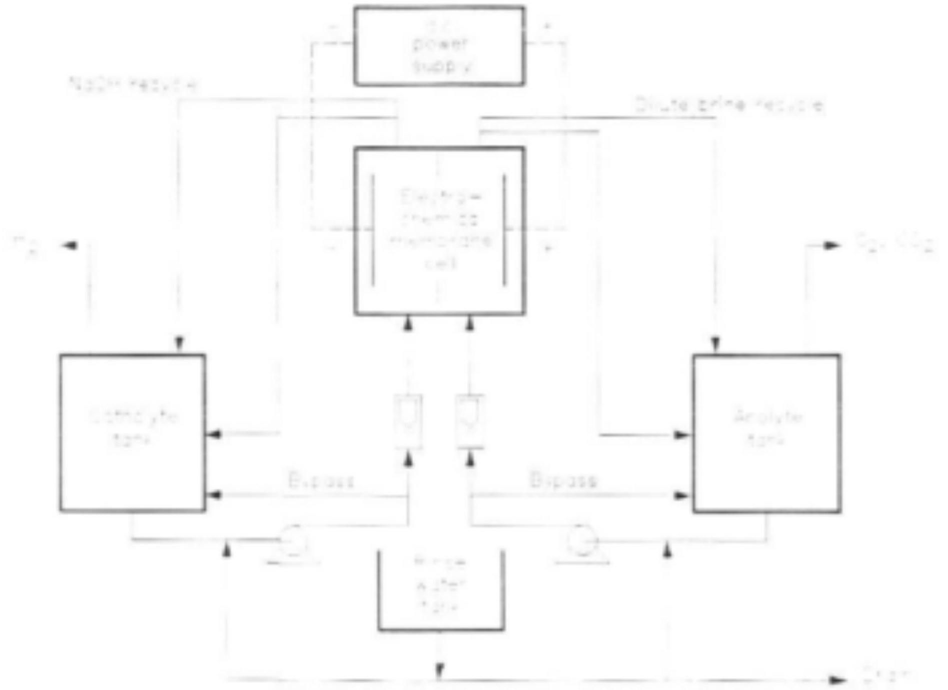


FIGURE 9.7 : FLOW DIAGRAM OF ELECTROCHEMICAL UNIT

The four stages of the pilot plant were designed for batch operation. Scouring effluent was carbonated by circulation through the absorption column where it was contacted with carbon dioxide generated in the electrolysis stage. The carbonated effluent was circulated through the cross-flow microfilter tubes until the required degree of recovery had been achieved. The filtrate from the cross-flow microfilter was then circulated through the spiral-wrap nanofiltration unit until the required degree of water recovery had been achieved. Finally, the permeate was treated in the electrochemical unit until the desired salt depletion was achieved.

9.4 PILOT PLANT EXPERIMENTAL PROCEDURE AND RESULTS

Detailed results of the pilot-plant investigation have been reported elsewhere (**18**).

The overall quality of the treated effluent and the recovered sodium hydroxide is compared to the effluent in Table 9.1. The scouring effluent contained 10 to 20 g/ℓ of sodium hydroxide and was contaminated by organic contaminants (10 g/ℓ COD) and calcium and magnesium compounds (10 to 60 mg/ℓ in total).

The treatment sequence was designed to remove colour and impurities and to recover sodium hydroxide from the effluent.

The pretreatment stages neutralised the effluent and removed approximately 85 % of the COD, all the colour, 65 % of the organic impurities and calcium compounds and 50 % of the magnesium compounds from the scouring effluent.

In the final stage the sodium hydroxide was recovered as a pure solution at a concentration between 100 and 200 g/ℓ. This stream was suitable for reuse in the scouring saturator. The depleted effluent contained low concentrations of TDS and was suitable for reuse in the scouring washing range.

The performance of each of the unit operations is summarised in the following sections :

9.4.1 Neutralisation

The flow, F_e and concentration, C_e of the effluent to the neutralisation unit is a function of wash water and fabric characteristics as follows :

$$F_e = F_w - m_i - m_o \tag{9.1}$$

$$C_e = \frac{m_i C_i - m_o C_o + F_w C_w}{F_e} \tag{9.2}$$

where F = flow (m^3/h).
C = concentration (kg/m^3).
m = cloth moisture content (m^3/t cloth).

and the subscripts are: w = wash water.
e = effluent stream.
i = drag-in stream.
o = drag-out stream.

TABLE 9.2
ELECTROCHEMICAL RECOVERY PILOT PLANT SPECIFICATIONS

Unit	Parameter	Specifications
Packed Column	Size: height	1 000 mm
	diameter	150 mm
	Construction material	Perspex
	Packing	Polyethylene saddles (25 mm length)
	Final effluent pH	8,5
	Effluent flow	10 ℓ/min
	Pump	Magnetic coupled centrifugal
Cross-flow microfilter	Tube size: diameter	12 mm
	area	2,26 m^2
	Tube fibre	Woven polyester
	Tube velocity	2 to 3 m/s
	Pump	Low-pressure, high-flow positive displacement
	Operating pressure	200 to 300 kPa
Nanofilter	Membrane type	Spiral wrap NF40 (FilmTec)
	Membrane area	0,56 m^2
	Cartridge prefilter	5 μm string wound polyester
	Pump	Positive displacement
	Operating pressure	1,6 MPa
Electrochemical cell	Cell pairs	2
	Electrode size	4 of 0,05 m^2
	Anode material	DSA
	Cathode material	Mild Steel
	Frame construction material	PVC
	Electromembrane type	Nafion 324 (du Pont)
	Pump types	Magnetic coupled centrifugal
	Electrolyte flow	10 to 15 ℓ/minute
	Electrical requirements: volt	4 to 10 V/cell pair
	current density	300 to 3 000 A/m^2
Pilot plant	Daily capacity	150 ℓ effluent used to produce: 3 kg NaOH (50 to 200 g/ℓ) 135 ℓ low quality water 75 g (850 ℓ) H_2 gas 600 g (420 ℓ) O_2 gas 15 ℓ concentrated impurities

The inorganic carbon balance across the electrochemical membrane cell and in the neutralising effluent indicated that carbon dioxide absorption was complete with no gas loss in the pH ranges 8,0 to 14,0.

Efficient recovery of sodium bicarbonate in the nanofiltration process could be achieved when the pH was lowered to between 8,0 and 8,5 where the bicarbonate ion was the predominant inorganic carbon species (Figure 9.3).

9.4.2 Cross-flow Microfiltration

Cross-flow microfiltration removed the suspended, particulate and colloidal matter from the neutralised effluent. This included saponified waxes and pectins, lint and other contaminants of the effluent. During the pilot plant study, the reduction in contamination averaged 40 % for COD, 10 % for TS and 50 % for calcium compounds. The optimum conditions for cross-flow microfiltration were :

feed velocity	:	3,0 to 3,5 m/s
pressure	:	300 kPa
precoat	:	limestone (15 μm) (100 g/m^2).

Under these conditions calcium rejections were increased to above 90 % and fluxes averaged 50 ℓ/m^{2}h at 20 °C. The method of application of the precoat was an important factor affecting the performance of the unit.

The most effective cleaning solution for the removal of waxy deposits on the surface of the cross-flow microfiltration tube was a solution containing 20 g/ℓ sodium hydroxide and 1 g/ℓ scouring detergent.

9.4.3 Nanofiltration

The nanofiltration membrane was a thin-film composite polysulphonate spiral wrap type which possessed the ability to exclude organic molecules with a molecular mass above 300 together with various inorganic species, the rejection of which was dependent on charge density. Ions of high-charge density such as carbonate, sulphate, calcium and magnesium are excluded while most monovalent ions such as sodium and bicarbonate permeate through the membrane structure.

Control of the pH of the feed to the nanofilter was important to ensure that the sodium present was predominantly associated with the monovalent bicarbonate species. In the form of sodium bicarbonate, the sodium could permeate the membrane and be separated from the effluent contaminants. Since a significant portion of the ions in the effluent were sodium and bicarbonate species, which permeated through the membrane, there was a minimum osmotic pressure differential across the membrane and consequently a high flux could be obtained at a low pressure. In the pilot-plant study, nitric acid was added to control the pH of the feed to the nanofiltration membrane at 8,0 to 8,5. This was necessary since the continued removal of bicarbonate ions in the permeate caused an increase in the ratio of carbonate to bicarbonate in the feed, and the pH of the solution increased.

The reduction in effluent contaminants during nanofiltration averaged 90 % for COD and 50 % for calcium and magnesium compounds. In addition, all the residual colour was removed.

Feed pH was a significant factor affecting the flux through the nanofiltration membrane. Average fluxes varied from 5 ℓ/m²h (1 MPa, 25 °C) at pH 9,7 to 30 ℓ/m²h (1 MPa, 25 °C) at pH 8,0.

Membrane cleaning was effected using scouring detergent.

In both cross-flow microfiltration and nanofiltration the concentrate and permeate flows (F_c and F_p) and compositions (C_c and C_p) are functions of water recovery, feed characteristics and the membrane point rejection performance. The following relationships hold :

$$F_c = F_f(1-R) \tag{9.3}$$

$$F_p = F_f - F_c \tag{9.4}$$

$$C_p = \frac{C_f(1-(1-R)^{1-r})}{R} \tag{9.5}$$

$$C_c = \frac{F_f.C_f - F_p.C_p}{F_c} \tag{9.6}$$

where F = flow (m³/h).
C = concentration (kg/m³).
R = water recovery.
r = membrane point rejection.

and subscripts c = concentrate stream.
p = permeate stream.
f = feed stream.

9.4.4 Electrochemical Membrane Cell Operation

The function of the electrochemical membrane cell was to split the sodium bicarbonate into its acid and base components.

Current Efficiency and Power

The current efficiency, η, of a particular species is based on the charge passed during electrolysis and is given by the equation :

$$\eta = \frac{moles\ of\ electrons\ used\ in\ forming\ product}{total\ moles\ of\ electrons\ consumed} \tag{9.7}$$

A mole of electrons is a Faraday, which is related to current and time by Faraday's Law.

$$Faraday = \frac{current \times time}{26.8} \tag{9.8}$$

The power consumption is normally expressed in terms of kWh/t sodium hydroxide produced :

$$Power = \frac{voltage \times current \times time}{mass\ of\ NaOH} \qquad (9.9)$$

In calculating the electrical requirements of a system the current efficiency is taken into account :

$$Faradays = \frac{mass\ of\ Na\ to\ be\ transferred}{23\,g/mol \times current\ efficiency} \qquad (9.10)$$

Up to 100 % of the sodium present in the cell feed was recovered as sodium hydroxide. Current efficiency was 70 to 80 % and the power consumption was 3 500 to 4 000 kWh/t 100 % NaOH. The decomposition voltage for the system was determined to be 2,7 V.

The current efficiency for sodium hydroxide recovery determines the plant size and the operational cost.

It is assumed that the two electrode reactions, the oxidation and the reduction of water, proceed at 100 % current efficiency. Current inefficiencies for the recovery of sodium hydroxide occur as a result of :

(i) the passage of current through the membrane by cations other than sodium, in particular hydrogen ions. This is minimised by :

- operation of the unit such that the anolyte does not have a high hydrogen ion concentration.
- ensuring that a sufficient supply of sodium ions is maintained at the membrane surface, by controlling the electrolyte flow and the current density,

(ii) the passage of current through the membrane by anions, in particular the back migration of hydroxide ions. This is minimised by :

- ensuring that the pH of the anolyte is maintained above 4,0,
- ensuring that the sodium hydroxide concentration does not exceed the limit for a particular membrane, above which the membrane loses its selectivity.

The operating parameters affecting the current efficiency and hence the specific power consumption of the electrochemical unit were :

(i) the rate and uniformity of distribution of the flow of electrolyte, in particular the anolyte, through the cell stack. Comparison of the individual cell volt drops served as an indication of the degree of gas blinding or polarisation occurring within each cell of the stack.

Gas blinding of the membrane and electrode surfaces and splitting of water at the membrane surface could be prevented by ensuring that sufficient flow of electrolyte was maintained through the system and that the current density was maintained below the limiting current density.

Figure 9.8 shows the experimentally determined relationship between the anolyte flow rate (at constant catholyte flow) and the volt drop across both cells and the cell stack. For the pilot plant, the anolyte flow rate had to be maintained above 20 ℓ/min to minimise the volt drop in the second cell, thereby reducing the specific power requirements of the system.

(ii) the current density at which the system was operated. High current densities are desirable in that the duty per unit area of cell increases, thus lowering plant size requirements. The maximum current density at which the system may operate efficiently is termed the limiting current density, which is a function of the temperature and the concentration of the electrolytes, in particular the anolyte. At current densities above the limiting value, the diffusive supply of sodium ions at the electromembrane surface becomes insufficient for the transport of electric current. As a result, water in the depleted layer is decomposed to hydroxide ions and hydrogen ions, and the electric current is partially carried by hydrogen ions. This results in a loss in current efficiency.

The combination of the limiting current density and the current efficiency determines the eventual membrane area requirements for a particular duty :

$$area = \frac{current \times time}{limiting\ current\ density} \times \frac{1}{current\ efficiency} \tag{9.11}$$

where the current required is a function of the amount of sodium to be recovered.

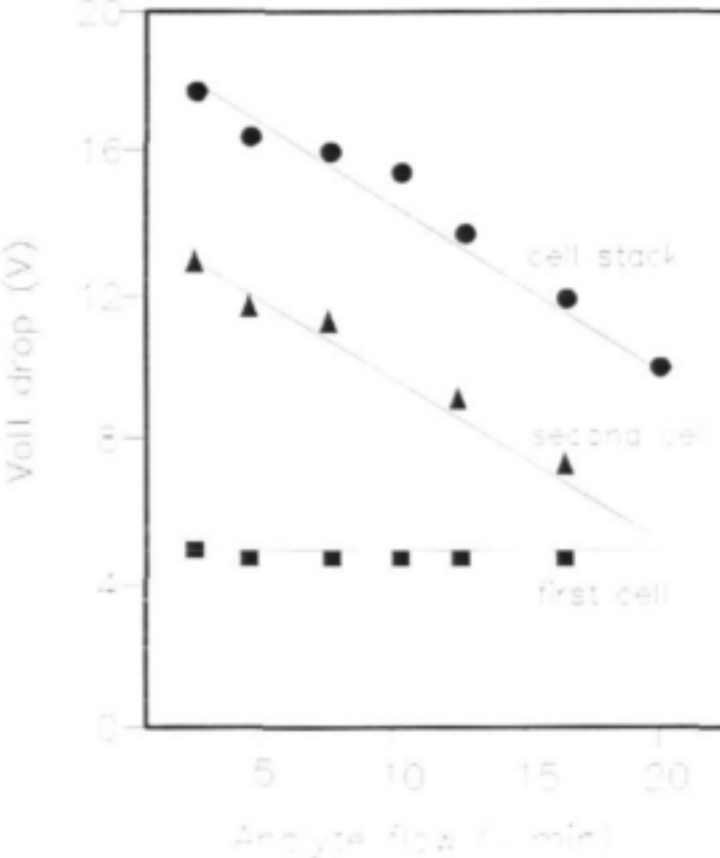


FIGURE 9.8 : RELATIONSHIP BETWEEN ANOLYTE FLOW RATE AND VOLT DROP ACROSS CELL

(iii) the temperature of the electrolytes. Elevated temperatures have a beneficial effect on the kinetics of all electrode processes, on the diffusion coefficients, the limiting current density and the rate of the chemical reactions. The pilot-plant study was conducted at temperatures ranging from ambient to 60 °C. Temperature has a significant effect on the cell volt components, in particular the volt drop through the electrolytes. The cell voltage is the sum of the volt drops across the individual components of the cell i.e. the decomposition voltage, the electrode polarisation and the ohmic drops through the membrane and electrolytes.

The experimentally determined decomposition voltage for the system was 2,7 V. The membrane volt drop is dependent on the resistance of the membrane which is in turn a function of the current density, the temperature and the ionic concentration of the solution inside the membrane. The average experimentally determined membrane volt drop was 0,3 V.

For calculation purposes the cell potential, E_t, can thus be taken as :

$$E_t = 2.7 + 0.3 + E_a + E_c \tag{9.12}$$

where E_a and E_c are the anolyte and catholyte volt drops.

The volt drop through an electrolyte is a function of the resistance of that solution, which varies inversely with the concentration or more accurately the specific conductivity of the electrolyte.

The volt drop through an electrolyte, E, may be calculated from the equation :

$$E = \frac{d.I}{\Lambda.a} \tag{9.13}$$

where Λ = conductivity

d = distance through electrolyte.

I = current.

a = area.

Figures 9.9 and 9.10 give the relationships between the concentration and the conductivity of sodium bicarbonate and sodium hydroxide solutions at various temperatures.

A relationship was developed for predicting the conductivity of the anolyte solution at any temperature and concentration :

$$Conductivity_{NaHCO_3} =$$

$$[(7.43\times^{-2}T - 6.3\times10^{-5}T^2 + 1.37)\times conc] +$$

$$[(-1.06\times10^{-3}T + 2.06\times10^{-6}T^2 - 1.78\times10^{-2}] +$$

$$[0.101T - 2.8\times10^{-3}T^2 + 2.15\times10^{-5}T^3 - 1.21] \tag{9.14}$$

Using equation 9.14 the anolyte conductivities during electrolysis may be calculated.

(iv) the interdependence of voltage, temperature, limiting current density and electrolyte conductivity.

The limiting current density, at a constant electrolyte flow, is a function of the conductivity of an electrolyte, which is in turn dependent on the concentration and the temperature of the electrolyte. The experimentally determined ratio between the limiting current density and the conductivity of the anolyte was 2,6 x 10^{-3} A/m^2 per mS/m. Using this ratio and knowing the conductivity, the limiting current density for the electrolysis of pretreated scouring effluent may be predicted at any temperature by the equation :

$$limiting\ current\ density = 2.6\times10^{-3}\times conductivity \tag{9.15}$$

(v) the membrane and electrode condition. Deposits on or degradation of electrode and membrane surfaces will cause elevated voltages. This is prevented by :

- routine acid flushing of the membrane surface, in particular the anode surface to remove deposits,
- operation of the cell under conditions which prevent water splitting and back migration. These phenomena result in a high concentration of hydroxide ions in the vicinity of the anode surface of the membrane. The potential for precipitation and scale formation will exist in such an area of alkalinity,

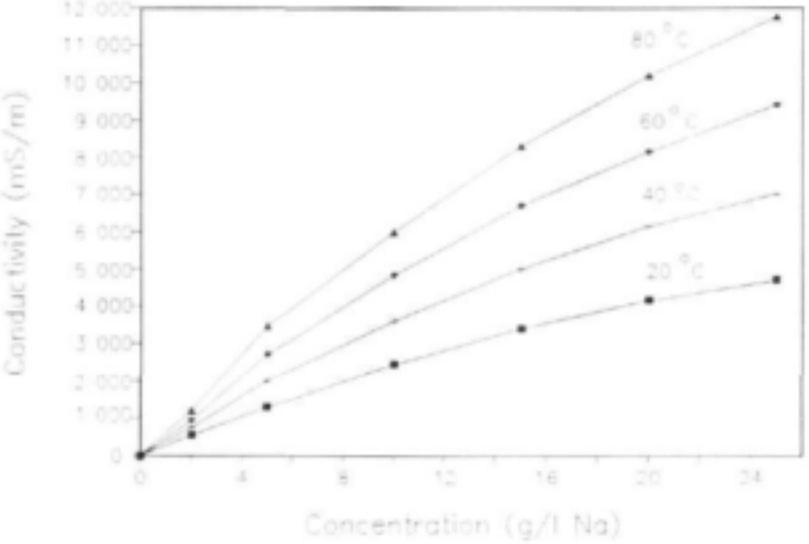


FIGURE 9.9 : RELATIONSHIP BETWEEN THE CONDUCTIVITY, CONCENTRATION AND TEMPERATURE OF SODIUM BICARBONATE IN SOLUTION

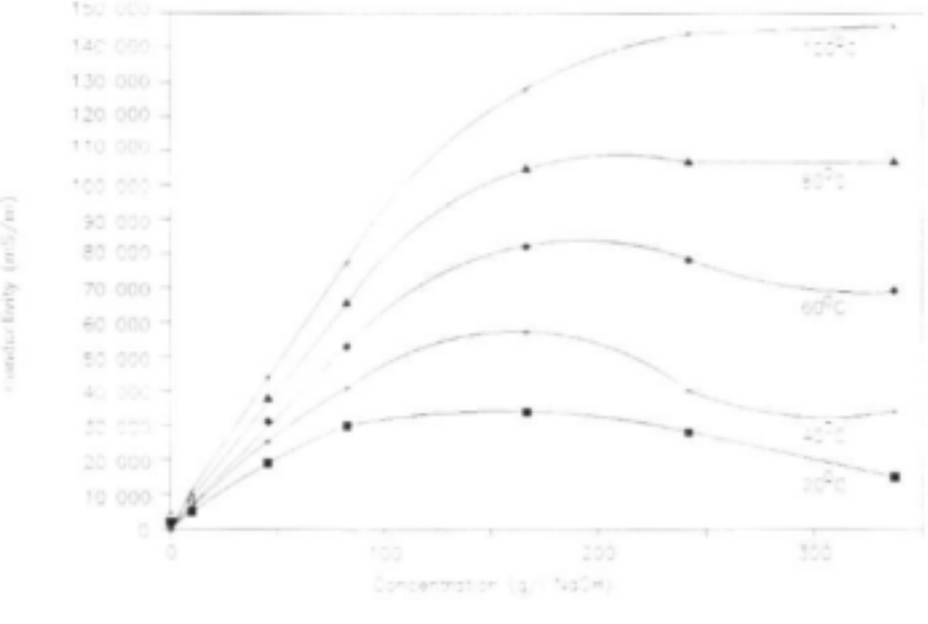


FIGURE 9.10 : RELATIONSHIP BETWEEN THE CONDUCTIVITY, CONCENTRATION AND TEMPERATURE OF SODIUM HYDROXIDE IN SOLUTION

- maintaining correct flow conditions in the cell such that physical abrasion of the electrode surfaces by the membrane does not occur;

(vi) the pH and concentration of the anolyte. Under the pilot-plant conditions listed below :

anolyte pH	5 to 12.
catholyte concentration	100 to 200 g/ℓ NaOH.
anolyte concentration	0,5 to 30 g/ℓ Na.

back migration of sodium and hydroxide ions or transport of current by hydrogen ions accounted for the 20 % loss in current efficiency of the process.

The pH of the final brine is a function of the degree of depletion of the effluent stream (Figure 9.11). At brine concentrations above 3 g/ℓ Na the evolution of carbon dioxide during electrolysis buffers the pH; at low sodium concentrations the buffer capacity is reduced and the pH decreases steeply.

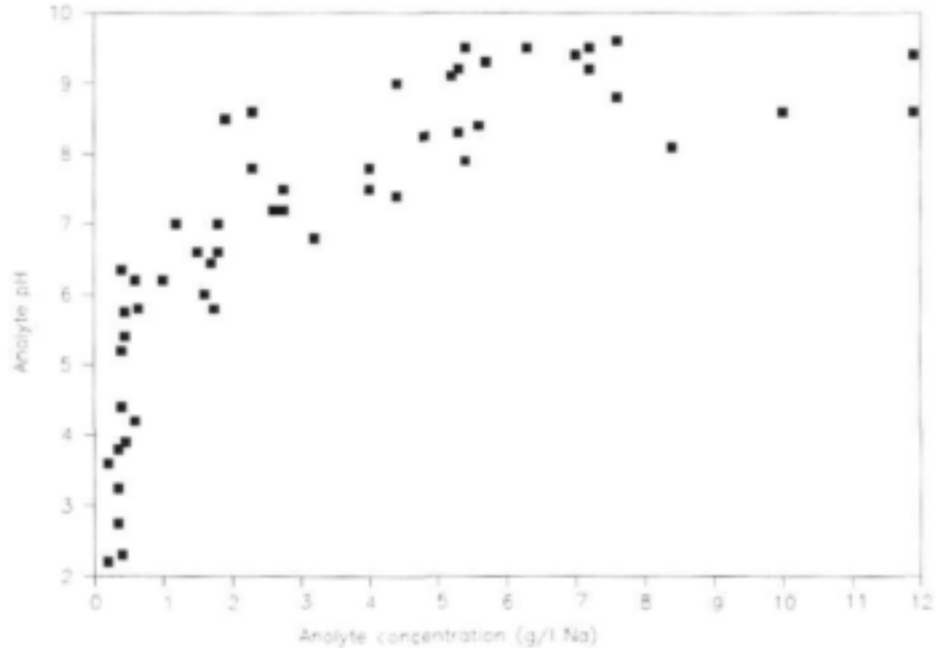


FIGURE 9.11 : RELATIONSHIP BETWEEN THE ANOLYTE CONCENTRATION AND pH

Electrode and Electromembrane Life Expectancy

An anode coating life in excess of four years was predicted if mechanical abrasion by the electromembrane was prevented.

No change in the resistance of the electromembrane was observed. However, a white deposit of calcium carbonate formed on the anode surface of the electromembrane. This precipitate formed in the areas where electrolyte flow distribution had been poor and localised polarisation resulted in zones of high pH at the surface of the membrane. This lowered the electromembrane area, adversely influencing current efficiencies. The electromembrane was descaled by contact with a 600 g/ℓ solution of nitric acid (18,67,68). The current efficiencies were restored to 100 %.

Water Transport Number

Water transport across ion-exchange membranes is caused by hydrostatic and osmotic pressure differences across the membrane and by electro-osmosis during electrolysis.

The water transport number (n_w) is the number of moles of water transported through the membrane per mole of sodium ions and is a function of the anolyte and catholyte concentration, in particular the former. In electro-osmosis, the water is transferred either as water of hydration of ions or by the momentum imparted to "free" water molecules by migrating hydrated ions. It is desirable to operate composite membranes at a low water transport number to prevent accumulation of water and subsequent blistering within the membrane. The membrane type used in the pilot plant trials was not a composite membrane.

The relationship between the anolyte sodium concentration and the water transport number is exponential and is shown in Figure 9.12. Regression of this curve gives the following relationship :

$$n_w = 6,5\times10^{-6}C^5 + 6,6\times10^{-4}C^4 - 2,5\times10^{-2}C^3 + 0,4C^2 - 3,5C + 17,8 \qquad (9.16)$$

where C is the anolyte sodium concentration (g/ℓ) and
n_w is in g water/g sodium.

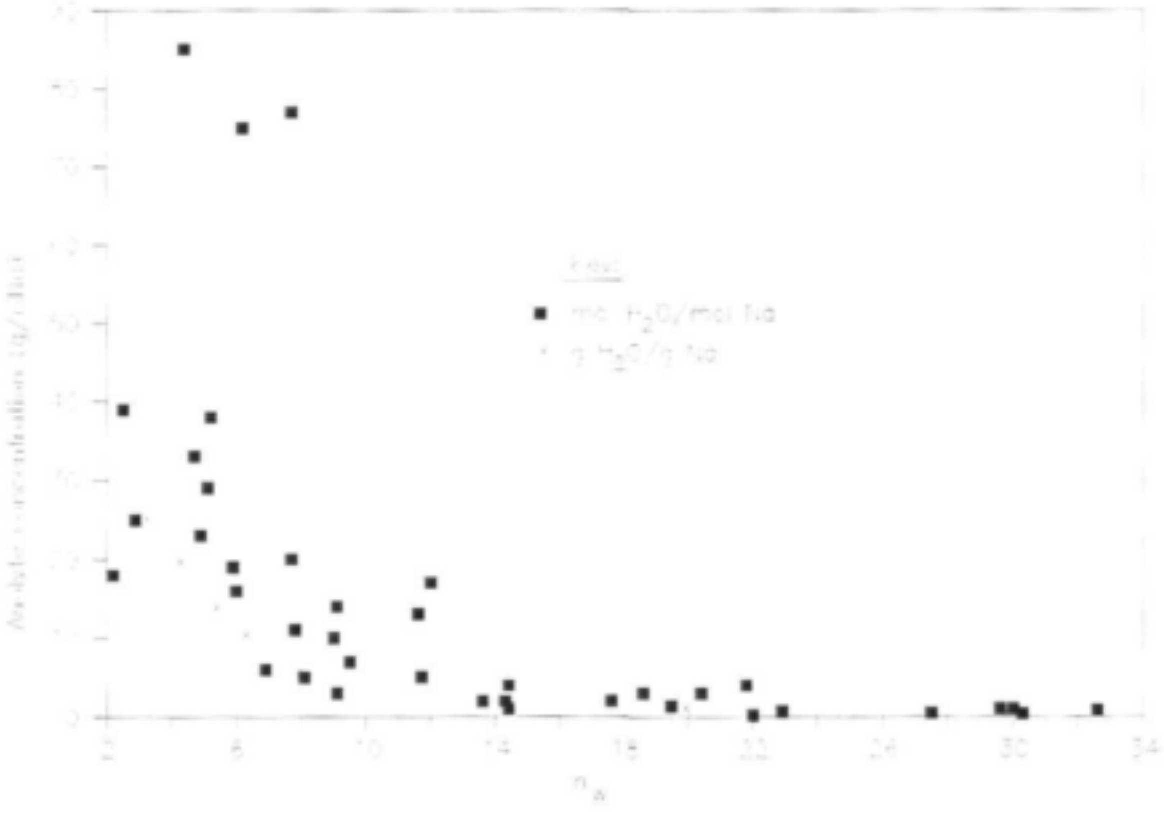


FIGURE 9.12 : EFFECT OF ANOLYTE SODIUM CONCENTRATION ON WATER TRANSPORT NUMBER. n_w

The transport of water from the anolyte to the catholyte during electrolysis dilutes the sodium hydroxide.

Sodium Recovery

The fraction of sodium which may be recovered from the scouring process is a function of the :

(i) drag-out on the fabric after rinsing,

(ii) water recovery achieved during cross-flow microfiltration,

(iii) water recovery achieved during nanofiltration,

(iv) degree of depletion of salt in the anolyte during electrolysis.

The fraction lost by drag-out is a function of sodium mass on the cloth entering and leaving the wash range :

$$loss\ by\ drag\text{-}out = \frac{m_e C_e}{m_i C_i} \tag{9.17}$$

The fraction lost in the cross-flow microfiltration and nanofiltration stages is a function of the mass in the concentrate ($C_c F_c$) and the mass in the feed ($C_f F_f$):

$$loss\ in\ concentrate = \frac{[C_c F_c]}{[C_f F_f]} \tag{9.18}$$

The fractional sodium hydroxide make-up to the system is equal to the sodium losses and is given by the equation :

$$\frac{loss\ by\ drag\text{-}out + loss\ in\ concentrates}{m_i C_i} \tag{9.19}$$

The make-up water requirement is equal to the water loss from the system.

The flow and concentration characteristics of the depleted brine and sodium hydroxide streams are given by the following equations :

$$N_r = N_i - N_e - N_c - N_s \tag{9.20}$$

$$F_r = N_r \times n_w \tag{9.21}$$

$$C_r = \frac{N_r}{F_r} \tag{9.22}$$

$$F_b = F_f - F_r \tag{9.23}$$

$$C_b = \frac{F_f C_f - N_r}{F_b} \tag{9.24}$$

$$N_b = C_b . F_b \tag{9.25}$$

where N = sodium mass flow, kg/h.
F = flow, m^3/h.
C = concentration, kg/m^3.

and the subscripts f = feed (anolyte) stream.
r = recovered sodium hydroxide stream.
b = depleted brine stream.
i = moisture of cloth into wash range.

o = moisture of cloth out of wash range.
c = mass in cross-flow microfiltration concentrate.
n = mass in nanofiltration concentrate.

and n_w = water transport number (g water/g sodium).

10 DESIGN OF A PLANT FOR THE ELECTROCHEMICAL RECOVERY OF STRONG COTTON AND POLYESTER/COTTON SCOURING EFFLUENTS

10.1 INTRODUCTION

The installation of the electrochemical system described in Chapter 9 for the treatment of textile scouring effluent for water and chemical reuse may be necessary for two main reasons :

(i) compliance with effluent discharge regulations,

(ii) economic benefit.

The pilot-plant investigations have demonstrated the technical feasibility of the four stage treatment system of neutralisation, cross-flow microfiltration, nanofiltration, and electrochemical recovery to produce reusable water and sodium hydroxide.

A factory considering the implementation of a system for treating scouring effluent must develop an overall chemical, water and effluent management strategy as outlined in Chapter 4. In terms of scouring this includes :

(i) water, heat energy, chemical and effluent pollution load balances over the scouring process,

(ii) identification of the minimum water quality requirements for scouring,

(iii) minimisation of water use during rinsing,

(iv) investigations into direct reuse of other factory effluents for rinsing e.g. bleaching effluent,

(v) minimisation of sodium hydroxide carry-over and maximisation of its removal from the cloth with minimal wash-water flow,

(vi) determination of the extent of the treatment/recycle programme necessary to meet the particular requirements of the factory. Depending on various site specific factors, the extent and the type of purification of the scouring effluent will vary from factory to factory,

(vii) development of a phased programme and a basis of decision-making (economics, reduction of water use, reduction of pollution load, elimination of environmentally unacceptable chemicals).

The design details of a treatment plant are specific to each factory and depends on the :

(i) particular characteristics of the factory's scouring process and of the cloth,

(ii) washer efficiency and water use,

(iii) purity of the rinse water,

(iv) efficacy of the individual units of the treatment process,

Chapter 11 examines the overall economics of the system. The present chapter considers a particular design example, in which the development of a treatment programme for the electrochemical recovery of scouring effluent is described.

10.2 GENERAL CONSIDERATIONS

The electrochemical recovery of sodium hydroxide and water from scouring effluents is detailed in Chapter 9. In summary, the following unit processes are required :

(i) an absorption column in which the scouring effluent is neutralised by contact with carbon dioxide to produce an impure sodium bicarbonate solution,

(ii) a cross-flow microfilter in which the suspended, colloidal and particulate matter is removed from the neutralised effluent,

(iii) a nanofilter which separates the sodium bicarbonate salt from the soluble organic and other soluble inorganic contaminants of the neutralised effluent,

(iv) an electrochemical membrane cell stack in which the sodium bicarbonate is converted into carbon dioxide and sodium hydroxide. This deionises the effluent to produce reusable water and reusable chemicals (Figure 10.1).

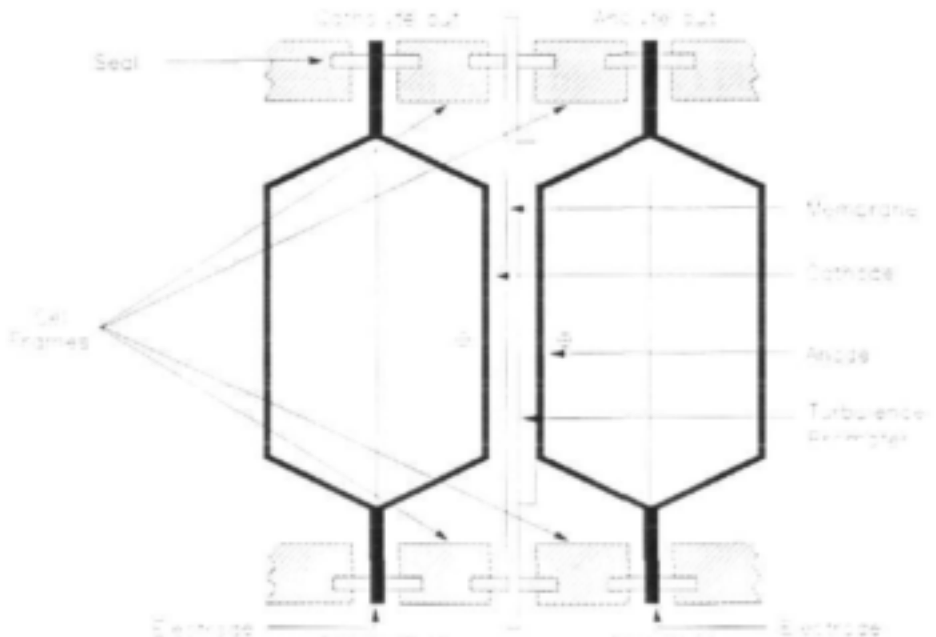


FIGURE 10.1 : ELECTROCHEMICAL MEMBRANE CELL (69)

The area requirement of the electrochemical membrane cell stack depends on the concentration of the anolyte which may be increased in one of the following process configurations :

(i) process configuration 1 : by the closed-loop recycle of rinse water with a background concentration (Figure 10.2).

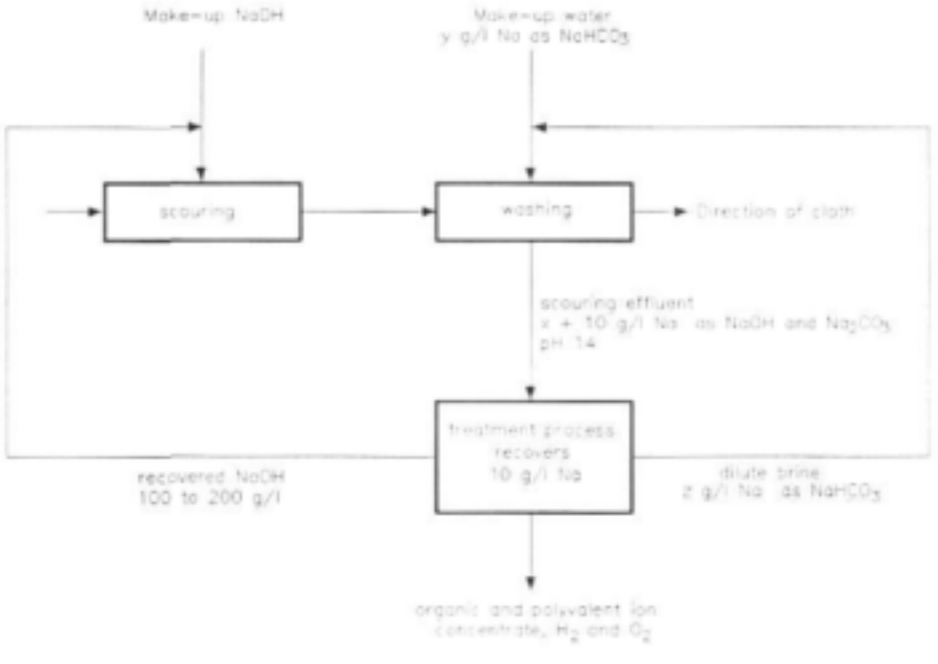


FIGURE 10.2 : PROCESS CONFIGURATION 1

In this system a sodium bicarbonate solution is used to wash cotton fibre after scouring, in place of mains water. Only the pick-up sodium, say 10 g/ℓ, will be recovered in the treatment process. Experimentally determined results indicated that the operation of such a recycle loop containing background sodium would substantially decrease the required membrane area.

Where a background concentration is employed, two options for making up the sodium short-fall exist :

1. sodium may be added to the washing section as sodium bicarbonate,
2. sodium may be added to the scouring section as sodium hydroxide.

The option chosen will be primarily determined by the relative economics of each and will in turn determine the degree of depletion of the effluent in the electrochemical unit. The design examples assume case (ii) above in which electrochemical depletion is achieved to the extent where the final effluent stream contains an equivalent amount of sodium required to yield a wash water of the chosen background concentration after additional make-up of water.

(ii) process configuration 2 : by employing an evaporation stage as the first step in the process, in which the effluent is concentrated and water is recovered (Figure 10.3). Preheating requirements for evaporation would be minimal since the effluent is discharged at 95 to 100 °C. The anolyte would be depleted to a predetermined concentration and combined with the condensate, of a high volume by comparison, for reuse as wash water.

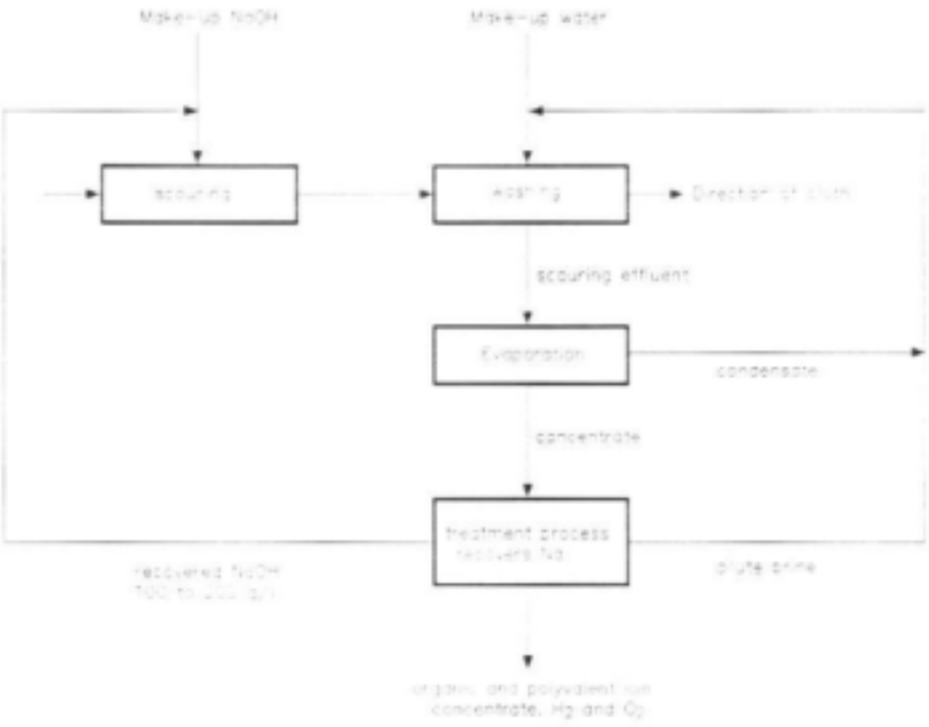


FIGURE 10.3 : PROCESS CONFIGURATION 2

(iii) process configuration 3 : by employing a reverse osmosis stage to concentrate the cross-flow microfiltration permeate prior to nanofiltration. The reverse osmosis, nanofiltration and electrochemical stages would be operated continuously in batch mode (Figure 10.4).

The advantages of options (ii) and (iii) over the background closed-loop system (i) is that sodium loss from the system by carry-over on the washed cloth will be maintained at lower levels since the wash water will contain lower ionic concentrations.

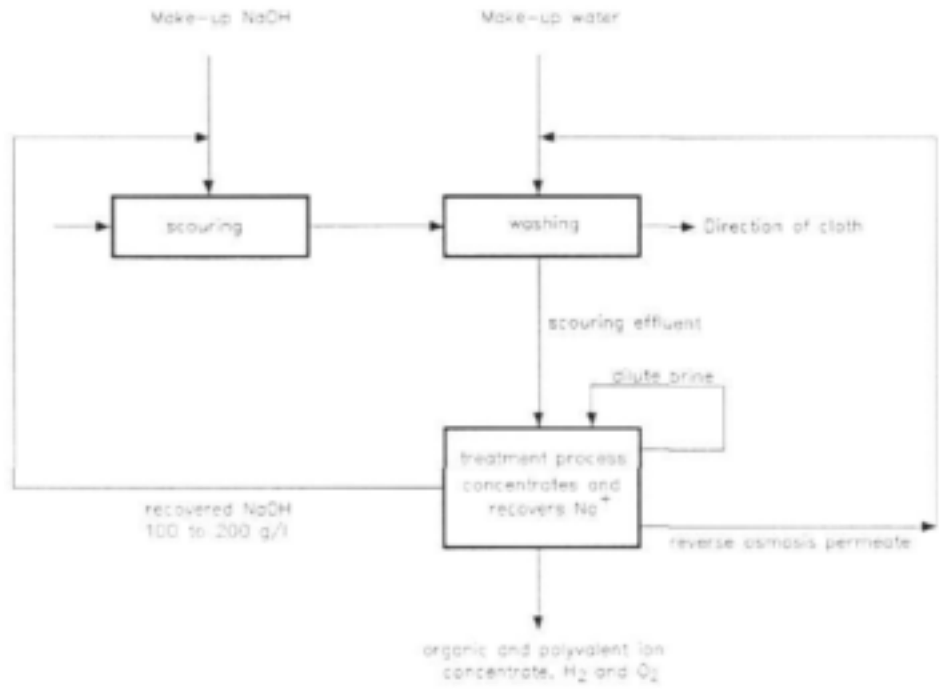


FIGURE 10.4 : PROCESS CONFIGURATION 3

In process configurations 1 and 2 the recycled wash water will have a residual sodium content since the depleted brine from the electrochemical unit partially or completely constitutes the recycled water and there is a minimum practical limit to the degree of depletion which can be attained. Where an evaporator is used (process configuration 2) the depleted brine is combined with the low TDS evaporator condensate before recycle to the wash range and hence the residual sodium content in the wash water is lower than in process configuration 1.

In process configuration 3 the depleted brine stream is recycled within the treatment system. The recycled wash water is reverse osmosis permeate which contains only trace amounts of sodium.

The design factors to be considered for the electrochemical recovery of sodium hydroxide from scouring effluents are :

process configuration selection,
textile processing considerations,
pretreatment requirements,
scaling prevention,
membrane selection and module arrangement.

10.2.1 Process Configuration Selection

Consideration must be given to the selection of either process configuration 1, 2 or 3. The selection depends on the individual factory's situation with regard to washing characteristics, effluent regulations and effluent reuse possibilities.

The incorporation of an evaporation stage into the process (process configuration 2) requires high capital expenditure. The advantages of evaporation over the use of a background concentration wash water (process configuration 1) to maintain high current densities in the electrochemical unit are as follows :

(i) The conductivity of the wash water is reduced resulting in a smaller loss of chemicals by drag-out on the cloth after washing. A larger fraction of the spent chemicals can therefore be recovered,

(ii) Since chemical drag-out is reduced after washing, chemical carry-over into subsequent wet preparation processes is lowered,

(iii) The volume of the effluent to be treated in the final four stages of the treatment process is reduced.

The implementation of reverse osmosis prior to nanofiltration (process configuration 3) :

(i) requires minimal additional capital expenditure since the reverse osmosis and nanofiltration membranes can be mounted in the same unit. One pump would be required and nanofiltration would operate using the pressure remaining in the feed after the reverse osmosis unit,

(ii) entails a concentration/recycle stage within the treatment process which is independent of the scouring process i.e. high purity wash water will be recycled from the reverse osmosis unit,

(iii) results in a small loss of sodium from the system by drag-out. Thus a larger fraction of the sodium may be recovered.

The implications of producing a washed cloth with a high sodium loading, as would be the case if the wash water contained significant amounts of sodium, must be assessed on the basis that the effluent from subsequent wet processes would contain proportionally higher amounts of sodium. The final option selected i.e. process configurations 1, 2 or 3 should be such that the chemical nature of any effluents produced elsewhere in the factory is not altered to such an extent that their present manner of discharge becomes unacceptable.

10.2.2 Textile Processing Considerations

All nanofiltration and electrochemical membranes have pH and temperature limits, operation outside of which may permanently damage the membrane. Consideration should also be given to the limits of the materials of construction of the plant.

Chemicals used during scouring should be tested for compatibility with the reverse osmosis, nanofiltration and electrochemical membranes. Chemicals such as solvents, chlorine and other oxidising agents, which will cause membrane damage are generally not used in sodium hydroxide scouring. However, particular attention must be paid to :

(i) polymeric substances,

(ii) textile auxiliaries and detergents, in particular the cationic and non-ionic types which may foul or damage the membranes,

(iii) sizing chemicals which must be removed efficiently during desizing. The carry-over of size into the scouring process results in a viscous scouring effluent. This effluent is not easily pumped and causes blockages of equipment.

10.2.3 Pretreatment Requirements

Screening to remove fibre and gross solids is essential to avoid pumping problems and blockage of the neutralisation unit. Other treatment considerations are flow balancing, pH control to suit the selected membranes, temperature, the removal of any chemicals which cause damage to the various membranes, the removal of colloidal and suspended solids for some module types of nanofiltration membranes and the removal of potential scale-forming compounds.

The following chemical analysis should be carried out to characterise the scouring effluent stream :

Temperature
Total dissolved solids
Suspended solids (>0,45 μm)
Sodium
Calcium
Magnesium
Iron
Detergent (all types)
pH
Chloride
Sulphate
Silica
Carbonate
Hydroxide
Solvents
Organic chemicals which may be incompatible with the selected membranes.

Balancing is required to avoid wide fluctuations in the flow, temperature and concentration of scouring effluent to the treatment plant.

Volume requirements depend on the production of scoured fabric and generally two to six hours storage is adequate. Additional storage may be required to provide for plant maintenance.

Pretreatment requirements for the removal of colloidal and suspended solids prior to reverse osmosis and nanofiltration are module type dependent. In general, to avoid blockage :

hollow fine fibre modules require extensive filtration to 1 to 2 μm,
spiral modules require extensive filtration to 5 to 10 μm,
plate and frame modules require minimal filtration (100 μm),
tubular modules require coarse screening for lint removal (500 μm).

Calcium and magnesium ions must be removed from the feed to the electrochemical unit.

10.2.4 Scaling Prevention

Sparingly soluble compounds such as the carbonates, hydroxides and sulphates of calcium, magnesium, iron and aluminium in the absence of sequestrants will form scale on the evaporator heat exchange surfaces and on the reverse osmosis, nanofiltration and electrochemical membranes. The precipitation of these species is a complex function of composition, pH, temperature and the type of sequestrant present. Laboratory tests should be undertaken to access the different pretreatment methods (70).

10.2.5 Membrane Selection and Module Arrangement

The basis on which the cross-flow microfiltration precoat, the reverse osmosis, the nanofiltration and the electrochemical membranes are chosen depends on various factors including :

(i) rejection and flux characteristics,

(ii) robustness,

(iii) compatibility with scouring chemicals and textile auxiliaries,

(iv) temperature,

(v) water recovery,

(vi) fouling and cleaning.

The concentration of the electrolyte streams in the electrochemical unit determines the choice of electrochemical membrane.

10.3 DESIGN EXAMPLE

The design of an effluent treatment plant requires in-house plant management as described in Chapter 4 as well as possible modifications to textile processing. Since the process is a closed-loop recycle system the treatment process must be integrated with the factory operations.

10.3.1 Textile Process Modifications

A mill processing 30 to 40 million metres per annum of woven cotton and polyester/cotton is considered.

Scouring at the mill is achieved continuously in an open-width Vaporloc machine, using an impregnation solution containing 50 g/ℓ sodium hydroxide and a sodium hydroxide reinforcement factor of four. The cloth speed is 50 m/min and the average cloth mass is assumed to be 260 g/linear m. A four-bowl counter-current washing range was used and had a specific water consumption of 6,5 ℓ/kg cloth. The effluent was produced at 100 °C. One high-nip expression roller was installed after the final washing bowl resulting in a moisture content of 0,5 ℓ/kg cloth. The moisture content of the cloth after the other nip rollers averaged 0,8 ℓ/kg cloth.

Washing theory (example 9, section 4.3.2), in combination with an experimental analysis of the washing range was used to :

(i) determine the washing parameter, k,

(ii) predict the effect of the nip expression at each washing bowl on the final washing efficiency and on the effluent concentration,

(iii) predict the washing performance variation with specific water consumption,

(iv) determine the most suitable combination of washing variables for the given application.

Following the washing analysis it was recommended that the roller before the washing range be replaced with a high-expression nip roller, giving a system with two high expression nip rollers.

For the four-bowl counter-current washing range, Figures 10.5 and 10.6 show the dependence of the washing efficiency and of the effluent concentration on the specific wash-water flow for the existing and recommended nip expression combinations. At specific water consumption above 1,5 ℓ/kg cloth the relative improvement in washing efficiency with water flow is small and the concentration factor needed for sodium hydroxide reuse is high.

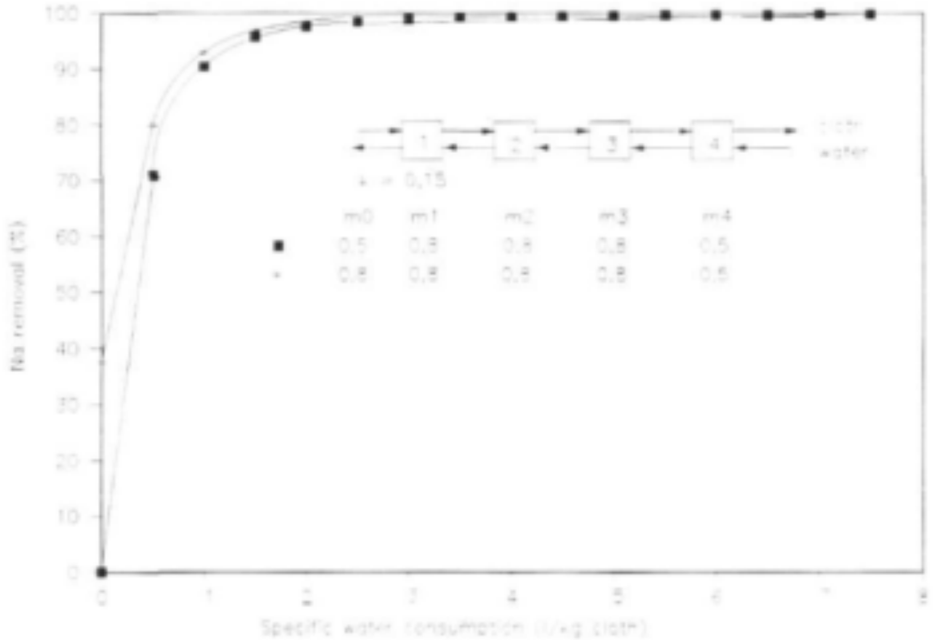


FIGURE 10.5 : PREDICTED WASHING EFFICIENCY

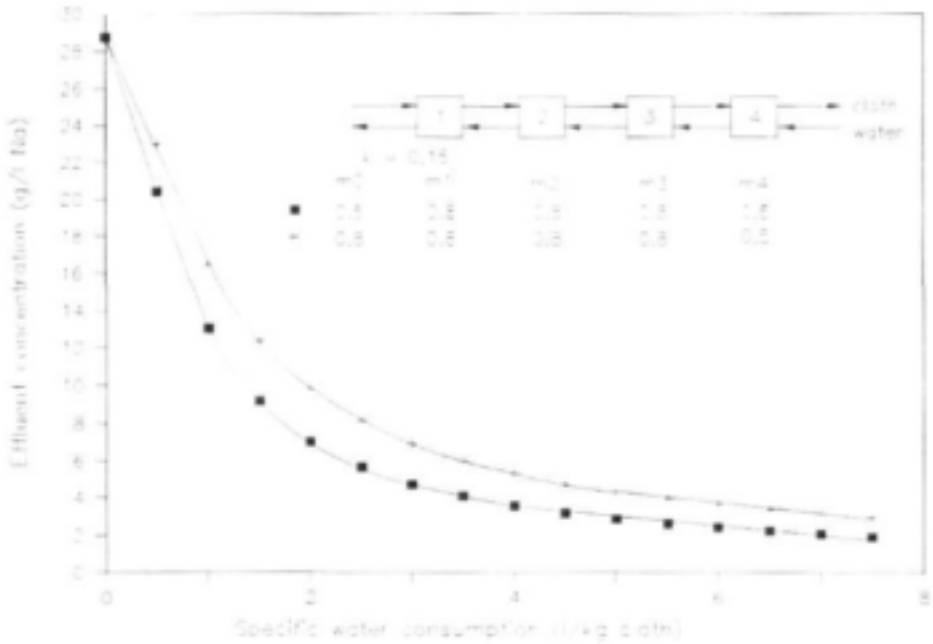


FIGURE 10.6 : PREDICTED EFFLUENT CONCENTRATION

It was recommended that the specific water flow at the factory be reduced from 6,5 ℓ/kg cloth to 1,5 ℓ/kg cloth with a decrease of 3 % in the washing efficiency. The increased cloth loading, from 0,1 to 0,7 g Na/kg cloth, was expected to have minimal effect on final cloth quality since the cloth was subsequently both bleached and mercerised.

Table 10.1 compares the washing variables of the existing process, the existing process at reduced water flow and the recommended process. At the expense of a small loss in washing efficiency the effluent concentration may be significantly decreased.

The recommended modifications amount to savings of 77 % of the water intake to this machine, reducing the annual consumption from 38 000 m^3 to approximately 8 000 m^3. The modifications also provide an annual savings of approximately 80 t of 100 % sodium hydroxide as well as savings in heat energy.

TABLE 10.1
COMPARISON OF WASHING PROCESSES

Washing variable		Existing process	Existing process reduced flow	Recommended process
Specific wash-water flow	(ℓ/kg cloth)	6,5	1,5	1,5
Number of high-expression nips		1	1	2
Washing efficiency	(%)	99,8	96,7	95,7
Effluent concentration	(g/ℓ Na)	3,4	12,4	9,2
Cloth chemical loading	(g Na/kg cloth)	0,1	0,8	0,6
Effluent chemical loading	(g Na/kg cloth)	22,9	22,2	13,8

10.4 DESIGN OF THE TREATMENT PLANT

The three process configurations (section 10.2) are :

process configuration 1 : 4-stage process employing a wash water containing a high level of sodium.

process configuration 2 : 5-stage process employing evaporation.

process configuration 3 : 5-stage process employing reverse osmosis.

The design basis for each case is given in Table 10.2 with reference to Figures 10.7, 10.8 and 10.9.

The specific design basis for the individual unit processes of the design example is discussed in the sections below.

TABLE 10.2
DATA FOR THE DESIGN OF THE ELECTROCHEMICAL TREATMENT OF STRONG SCOURING EFFLUENTS

Determinand		Value
1. Scouring variables		
average cloth mass	(g/linear m)	260
cloth speed	(m/min)	50
	(kg/h)	780
production time		20 h/d, 340 d/y
moisture content of cloth into wash range	mi	0,5 ℓ/kg cloth
moisture content of washed cloth	mo	0,5 ℓ/kg cloth
saturator concentration	Ci	50 g/ℓ NaOH
washing parameter	k	0,15
specific water use	Q	1,5 ℓ/kg cloth
total wash-water flow		1,17 m^3/h 24 m^3/d
General		
effluent total dissolved solids		25 g/ℓ
effluent chemical oxygen demand		12 g/ℓ
effluent calcium		45 mg/ℓ
effluent magnesium		8 mg/ℓ
Process configuration 1 (4-stage)		
background wash-water concentration	Cq	5 g/ℓ Na
effluent concentration	C1	12,6 g/ℓ Na
effluent mass loading	L1C1	18,9 g/kg cloth
washing efficiency		79,0 %
Process configuration 2 (5-stage with evaporation)		
effluent concentration	C1	9,7 g/ℓ Na
effluent mass loading	L1C1	14,6 g/kg cloth
washing efficiency		93,0 %
recycled wash-water concentration	Cq	0,8 g/ℓ Na
Process configuration 3 (5-stage with reverse osmosis)		
effluent concentration	C1	9,2 g/ℓ Na
effluent mass loading	L1C1	13,8 g/kg cloth
washing efficiency		95,7 %
recycled wash-water concentration	Cq	0 g/ℓ Na

Standard membranes are available and have been assumed in the design where necessary. The standard sizes chosen are :

(i) cross-flow microfiltration tubes, each 25 mm in diameter and assembled in a curtain arrangement containing 31 tubes in parallel (surface area = 2,43 m^2/linear m).

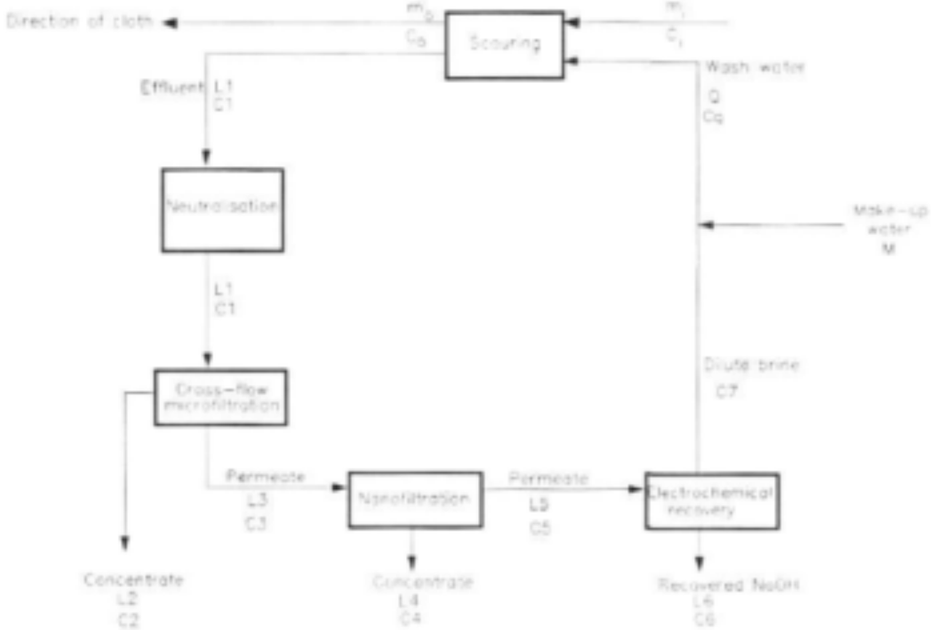


FIGURE 10.7 : PROCESS CONFIGURATION 1: MASS BALANCE BASIS FOR RECOVERY PROCESS USING BACKGROUND SODIUM CONCENTRATION

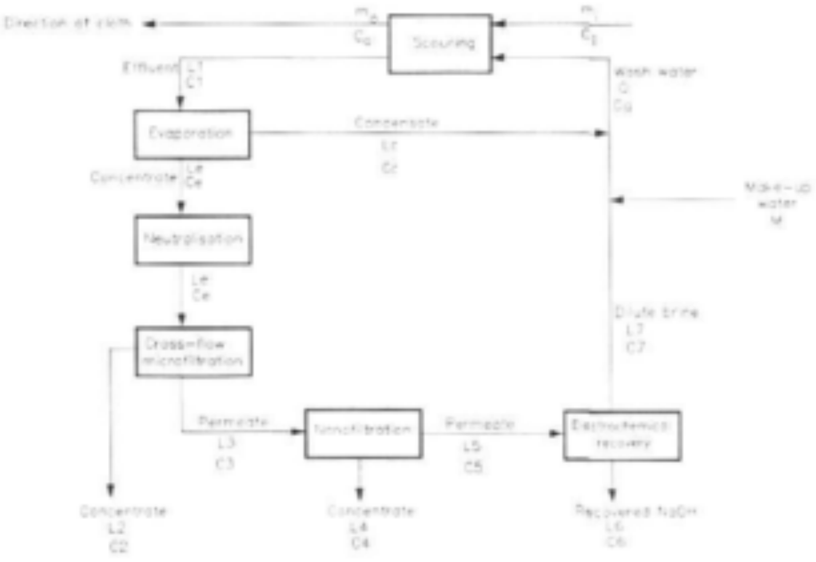


FIGURE 10.8 : PROCESS CONFIGURATION 2: MASS BALANCE BASIS FOR RECOVERY PROCESS USING AN EVAPORATION STAGE

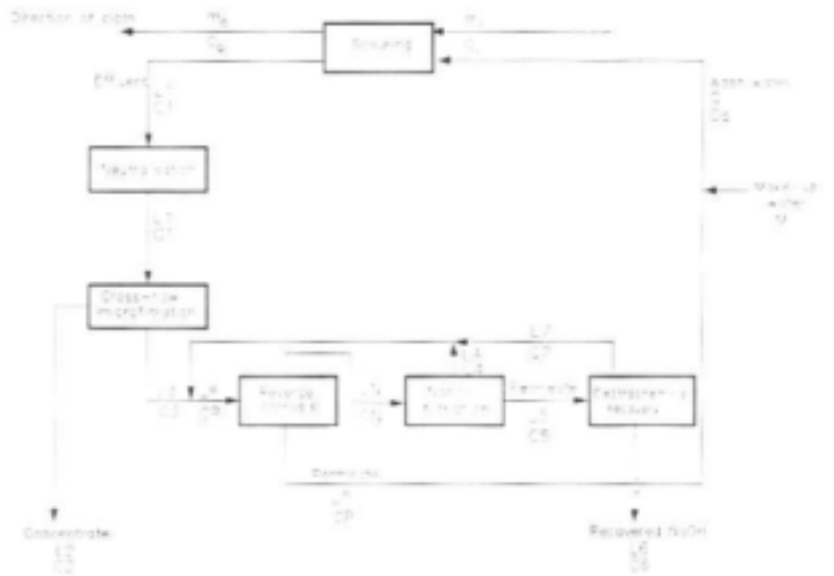


FIGURE 10.9 : PROCESS CONFIGURATION 3: MASS BALANCE BASIS FOR RECOVERY PROCESS USING A REVERSE OSMOSIS CONCENTRATION STAGE

Note on Figures 10.7 to 10.9 :

(i) L represents the flow of the streams in the treatment process (ℓ/kg cloth).
(ii) Q represents the wash-water flow to the scouring range (ℓ/kg cloth).
(iii) M represents the make-up water (ℓ/kg cloth).
(iv) C represents the sodium ion concentration of the streams (g/ℓ).
(v) m_o and m_i represent moisture content of the fabric (ℓ/kg cloth).
(vi) c_o and c_i represent the sodium ion concentration in the moisture or the fabric (g/ℓ).

(ii) spiral reverse osmosis and nanofiltration elements, each 100 mm in diameter and 1 000 mm in length (approximate membrane area = 6,5 m^2). Elements of 62 mm, 150 mm and 200 mm diameter are also available (approximate membrane areas are 2, 13 and 26 m^2 respectively).

(iii) electrochemical stack of individual cells in a plate and frame arrangement, each cell containing 1 m^2 of membrane area.

Ancillary requirements for the treatment plant would include :

(i) a pump sump within the factory,

(ii) pipeline and valves for transfer from the factory,

(iii) coarse screening to remove dirt, lint and gross suspended solids,

(iv) steam, electrical and water supplies,

(v) suitable housing facilities,

(vi) effluent handling during breakdowns,

(vii) drains.

10.5 SPECIFICATION OF EVAPORATOR

Evaporation for the concentration of scouring effluent in process configuration 2 is discussed in Chapter 7. Evaporators are purchased as unit items from a manufacturer who will size and design the unit according to the effluent characteristics and the specific evaporative requirements. In the design example a forced circulation system is assumed, in which boiling does not occur on the heat exchange surfaces, thus lowering the potential for scaling. Materials of construction are stainless or mild steel.

The specification of the evaporator is given in Table 10.3.

TABLE 10.3
EVAPORATOR SPECIFICATION

Parameter		Value
Evaporation factor		4
Feed flow	(m^3/h)	1,2
Evaporative capacity	(m^3/h)	0,9
Feed concentration	(g/ℓ Na)	9,7
Concentrate concentration	(g/ℓ Na)	38,8
Feed temperature	(° C)	95

Ancillary requirements for the evaporator include a centrifuge, preferably situated after the heat exchanger to remove suspended and colloidal matter from the concentrate.

The data in section 7.4.3. has been used to calculated the concentrate composition, which is given in Table 10.4.

10.6 SPECIFICATIONS OF BATCH NEUTRALISING UNIT

10.6.1 Equipment

Table 10.5 gives a detailed list of equipment. Figure 10.10 gives the flow diagram of the neutralisation unit.

Due to the caustic nature of the effluent careful selection of materials of construction, particularly for valves, seals and pump components is needed.

TABLE 10.4
EVAPORATOR CONCENTRATE COMPOSITION

Parameter		Value
Evaporator concentrate flow	(m^3/h)	0,295
Centrifuge sludge flow	(m^3/h)	0,015
Centrate flow	(m^3/h)	0,28
Centrate composition:		
Na	(g/ℓ)	38,8
TDS	(g/ℓ)	66,5
COD	(g/ℓ)	32
Ca	(mg/ℓ)	128
Mg	(mg/ℓ)	27

TABLE 10.5
BATCH NEUTRALISATION EQUIPMENT REQUIREMENTS

1. Effluent transfer and storage
1.1 piping and valves for transfer to absorption unit.
1.2 feed tank.
1.3 product storage tank.
1.4 transfer piping and valves from the reticulation tank to the column.
1.5 transfer piping for the oxygen and carbon dioxide from the electrochemical unit to the packed bed.
1.6 transfer piping for make-up gases from waste flue gas emissions.
1.7 transfer piping to cross-flow microfiltration unit.

2. Packed bed absorber
2.1 packed column.
2.2 dispersed liquid inlet facilities and an off-gas vent at the top.
2.3 gas inlet facilities at the base.

3. Pumps
3.1 pump for effluent transfer from the factory.
3.2 low-pressure pump for recirculation through the packed bed.
3.3 low-pressure pump for transfer to the cross-flow microfilter.

4. Controls
4.1 flow and pressure measurement.
4.2 pH control during batch carbonation.
4.3 pump motors, starters and interlocks.
4.4 level sensors and low-level alarm.
4.5 malfunction control interlocks.
4.6 interlock with electrochemical cell.

5. Ancillaries
5.1 heat exchanger on effluent feed line to cool effluent to 35 °C.
5.2 suitable break tank between electrochemical cell and absorption tank.

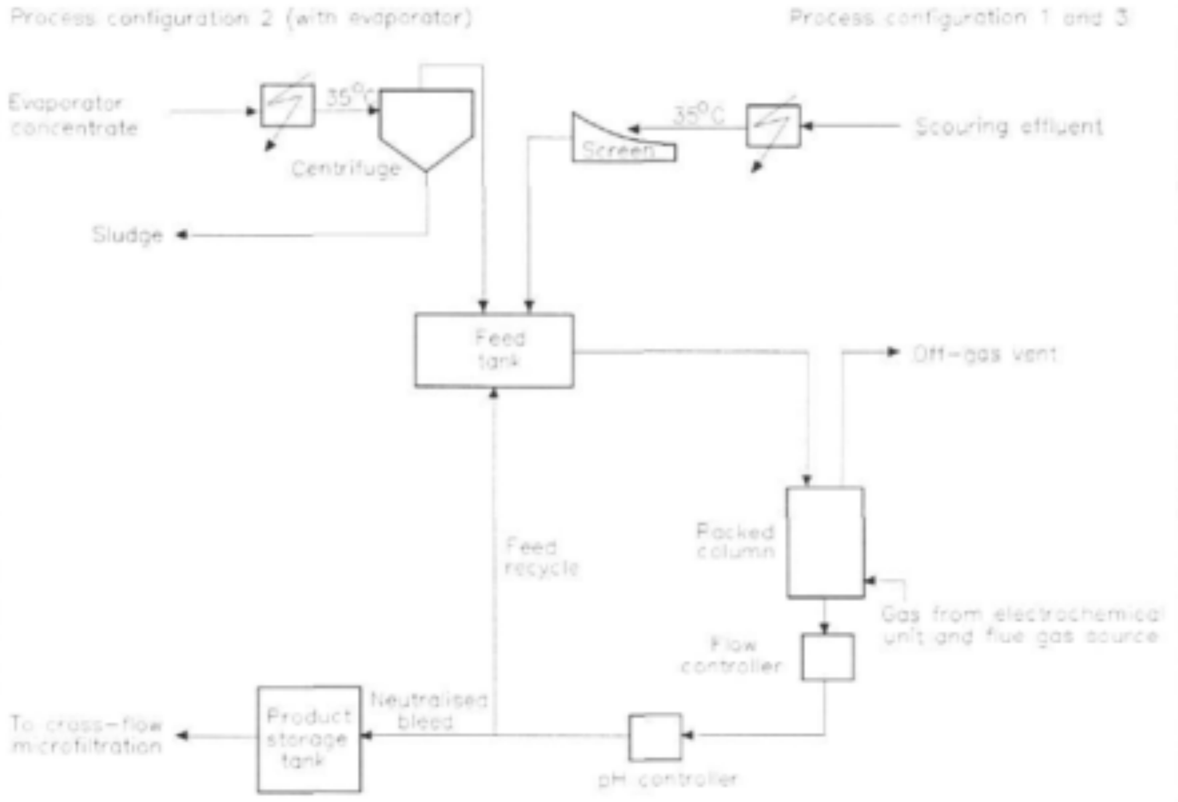


FIGURE 10.10 : FLOW DIAGRAM OF BATCH NEUTRALISATION UNIT

The residence time is controlled by a flow control valve. A pH controller on the return line controls the bleed from the system to the cross-flow microfiltration unit and prevents over-neutralisation, at which stage carbon dioxide is no longer absorbed.

Control instrumentation for temperatures and tank levels are required. Sampling ports should be provided.

The carbon dioxide for neutralisation is evolved in the electrochemical unit, which operates in a batch mode and hence the rate of neutralisation will be dependent on the operation of the electrochemical unit.

The effluent storage and sump facilities should provide approximately 6 to 12 h storage to provide for minor breakdowns and maintenance. The feed tank to the absorption column must accommodate the batch requirements of the treatment system.

10.6.2 <u>Sizing of Neutralisation Unit</u>

Carbon dioxide undergoes hydrolysis in sodium hydroxide solutions to form various soluble anions. Because efficient transfer occurs, specially designed gas transfer facilities and off-gas recycle systems are not necessary. With proper mixing and adequate gas dispersion, complete absorption is achieved and minimum retention time within the vessel is required. The oxygen associated with the carbon dioxide is vented.

To avoid excessive pressures in the electrochemical cell the pressure drop in the absorber should be taken into account in the sizing of the neutralisation unit.

For the design basis in Table 10.3 approximately 19 kg of sodium hydroxide (474 mol) must be neutralised per hour in either 1,17 m^3/h or 0,28 m^3/h of effluent (dependent on the option chosen i.e. 4-stage or 5-stage treatment). An equivalent amount of 475 mol/h of carbon dioxide would be required to transform the sodium hydroxide to sodium bicarbonate. For start-up purposes and in order to compensate for losses of inorganic carbon species from the system, a carbon dioxide make-up stream must be provided. The flue gas from LPG fired equipment is a clean and convenient source of carbon dioxide.

10.7 SPECIFICATION OF BATCH CROSS-FLOW MICROFILTRATION UNIT

10.7.1 Equipment

Table 10.6 gives a detailed list of the equipment requirements.

The neutralised effluent is not corrosive to most materials of construction.

Three main types of pumps are available : multi-stage centrifugal, high-speed centrifugal and positive displacement. Pumping duties are 500 to 600 kPa for the tubular cross-flow microfiltration membranes. The temperature of the neutralised effluent would be in the range of 30 to 40 °C.

The detrimental effect of pump vibration on the system must be considered.

The process control system is dependent on the module type and pump. In general, the process is required to produce a predetermined water recovery in a batch mode (Figure 10.11).

For a centrifugal pressure pump, the normal control arrangement is a flow control valve or a back pressure valve on the reject line.

For a positive displacement pump, discharge flow is not a function of the discharge pressure and the control system is a flow controller on the reject line (this alters the system pressure to compensate for changes in flux) and a high-pressure alarm or a pressure relief valve on the pump discharge (to protect the cross-flow microfiltration module).

Effluent, product and concentrate storage of the duration of a batch is necessary to provide for microfilter cleaning, minor breakdowns and maintenance.

TABLE 10.6

BATCH CROSS-FLOW MICROFILTRATION EQUIPMENT REQUIREMENTS

1.	Effluent transfer and storage
1.1	two feed tanks.
1.2	concentrate storage tank.
1.3	precoat slurry and cleaning chemicals recirculation and storage tanks.
1.4	product storage tank.
1.5	transfer piping and valves for effluent transfer from neutralisation.
1.6	transfer piping and valves for feed reticulation in the cross-flow microfiltration unit.
1.7	transfer piping and valves for final concentrate storage and disposal.
1.8	transfer piping and valves for product to the nanofiltration unit.
1.9	transfer piping for waste flue gas addition to the system.
2.	Cross-flow microfiltration modules
2.1	tubular curtains and assemblies.
2.2	module racks/hangers.
2.3	piping and valves for feed, final concentrate and permeate.
2.4	collection tray for permeate.
3.	Pumps
3.1	high-flow pump for recirculation of feed through modules and for precoating and cleaning.
3.2	pumps for transfer of final concentrate and product (permeate).
3.3	flow and pressure measurement, indication and control of all streams.
4.	Controls
4.1	pump motors, starters and interlocks.
4.2	feed recycle from controller.
4.3	permeate flow measurement.
4.4	high- and low-pressure alarms.
4.5	low-flow alarm.
4.6	permeate turbidity measurement and high alarm.
4.7	malfunction and alarm control interlocks.
4.8	pH control of feed to ensure maintenance of desired equilibrium.
4.9	control panel.
5.	Ancillaries
5.1	on-line cooling of recycled streams to maintain feed temperatures of 35 °C.
5.2	sampling ports.

10.7.2 Sizing of the Cross-flow Microfiltration Unit

Although several types of microfilter are available, good results were obtained during the pilot investigations (Chapter 9) using woven tubular polyester units. These are considered in the design example.

The pressure limitation of the tubular system is 600 kPa and a design pressure drop of 400 kPa has been used. During the pilot investigations, tube velocities in the range 2,5 to 3 m/s gave good fluxes on a limestone (15 μm) precoated tube. Fouling by solids on the tube was minimal.

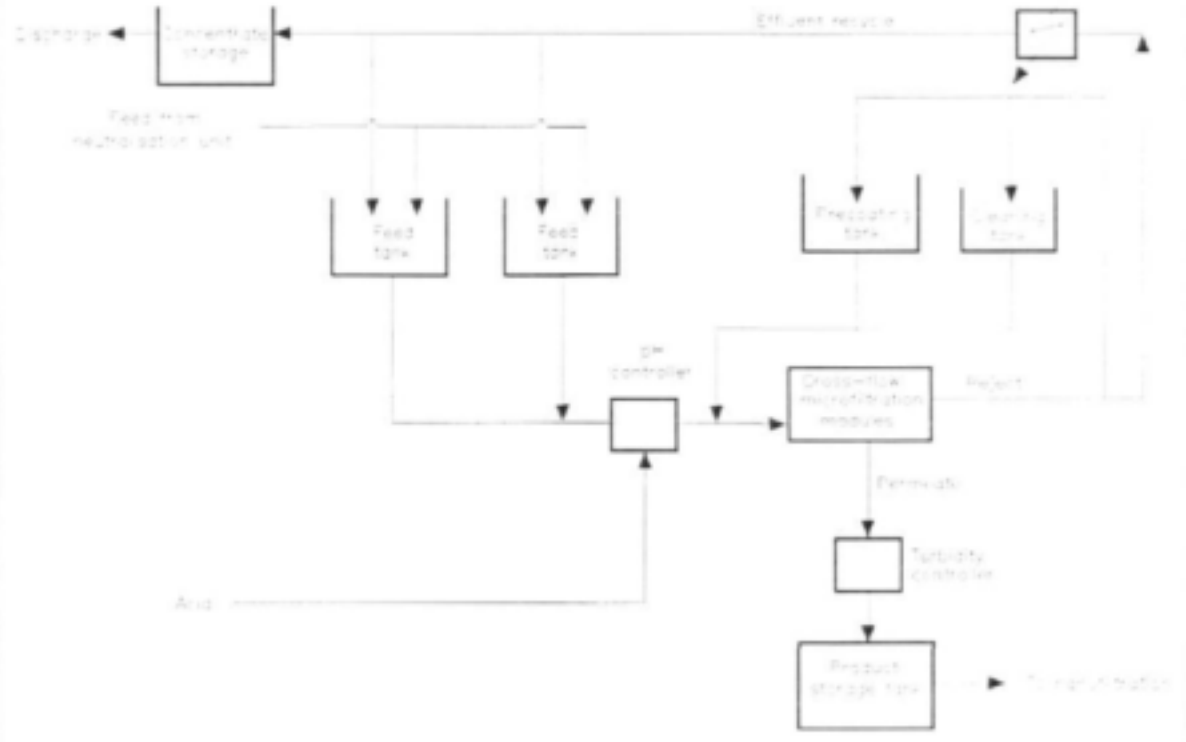


FIGURE 10.11 : FLOW DIAGRAM OF BATCH CROSS-FLOW MICROFILTRATION UNIT

Table 10.7 gives the design specifications for both the 4- and 5- stage treatment plants in the design example with reference to Figures 10.6, 10.7 and 10.8.

TABLE 10.7
BATCH CROSS-FLOW MICROFILTER SPECIFICATION

Parameter				Process configuration 1 (4-stage)	Process configuration 2 (5-stage with evaporator)	Process configuration 3 (5-stage with reverse osmosis)
Feed flow:	daily		(m^3)	24	6	24
	hourly		(m^3)	1,17	0,28	1,17
	specific	L1	(ℓ/kg cloth)	1,5	0,36	1,5
Feed sodium concentration		C1	(g/ℓ)	12,6	38,8	9,2
Tube diameter			(mm)	25	25	25
Tube velocity			(m/s)	2,5 to 3	2,5 to 3	2,5 to 3
Design flux			(ℓ/m^2h)	45	20	45
Temperature			(° C)	35	35	35

The pressure drop/velocity correlation for water, assuming an absolute roughness factor of 0,5 mm and 25 mm diameter tubes, is :

$$\Delta P = 0.93 \quad V^2 L_p$$

where ΔP is the pressure drop measured in kPa at ambient temperature, L_p is the length in m, and V is the velocity in m/s.

For a limestone precoat experimental results (**18**) suggest that

(i) at constant velocity, the flux is independent of pressure above values of 250 kPa,

(ii) at constant pressure, flux is proportional to velocity.

The membrane area of a 25 mm diameter tube is 0,0785 m^2 per m of length.

The allowable lengths per parallel pass, from pressure drop considerations, for the range of velocities are :

Velocity 2,5 m/s

$$L_p = \frac{400 \quad kPa}{(0.93 \quad kPas^2/m^3)(2.5 \quad m/s)^2}$$

$$= 69 \quad m$$

Velocity 3,0 m/s

$$L_p = \frac{400 \quad kPa}{(0.93 \quad kPas^2/m^3)(3.0 \quad m/s)^2}$$

$$= 48 \quad m$$

The velocity down the tube drops below the entrance velocity due to permeation of liquid through the tube.

The pressure drop depends on several factors including temperature and solids concentration. For the design example, a linear length of tube is assumed to be 60 m, which will provide for an exit velocity of 2,5 m/s. Table 10.8 summarises the design calculations.

Since the water recovery of each length is a function of the inlet velocity and the production rate, the water recovery will increase at higher production rates and lower inlet velocities.

TABLE 10.8
SUMMARY OF CROSS-FLOW MICROFILTER DESIGN CALCULATIONS

Design parameter		Process configuration		
		1	2	3
Membrane area[1]	(m^2)	26	14	26
Total tube length[2]	(m)	331	178	331
Tube length/pass[3]	(m)	60	60	60
Production rate/pass[4]	(ℓ/h)	212	94	212
Flow in/pass[5]	(m^3/h)	5,3	5,3	5,3
Flow out/pass[6]	(m^3/h)	5,1	5,2	5,1
Water recovery/pass[7]	(%)	4	2	4

Note:

1 (flow (ℓ/h)) x (flux (ℓ/m^2h)).
2 (membrane area (m^2)) x (0,0785 m^2/m of tube).
3 calculated in text.
4 (length per pass (60 m)) x (0,0785 m^2/m of tube) x (flux (ℓ/m^2h))
5 given.
6 (flow in) - (product rate).
7 (production rate) - (flow in).

10.7.3 Design Configuration

Several design configurations are possible and these are :

(i) batch concentration,
(ii) continuous feed and bleed,
(iii) series taper.

For the present application the batch concentration configuration is described.

This is the simplest configuration but requires at least two batch storage tanks. Figure 10.11 is a flow diagram of this system.

The number of parallel tubes, at 60 m per pass, required for a total tube length of :

331 m is 6 (process configurations 1 and 3).
178 m is 3 (process configuration 2).

The pump flow required for an inlet tube velocity of 3 m/s and for 6 and 3 passes is 32 m^3/h and 16 m^3/h respectively.

The water recovery is set by the difference in tank levels at the start and end of each batch. The concentrate is discharged on completion of the batch.

10.7.4 Overall Performance : Cross-flow Microfiltration

The overall performance of the cross-flow microfiltration unit is given in Table 10.9.

TABLE 10.9
OVERALL PERFORMANCE OF CROSS-FLOW MICROFILTRATION UNIT

Parameter		Process configuration 1 (4-stage)			Process configuration 2 (5-stage with evaporator)			Process configuration 3 (5-stage with reverse osmosis)		
Feed flow	(m^3/h)	1,17			0,28			1,17		
Feed COD	(g/ℓ)	12			32			12		
Feed Ca	(mg/ℓ)	45			128			45		
Feed Mg	(mg/ℓ)	8			27			8		
Design COD rejection	(%)	40			45			40		
Design Ca rejection	(%)	90			95			90		
Design Mg rejection	(%)	40			50			40		
Design Na rejection	(%)	0			0			0		
Water recovery	(%)	90	95	98	90	95	98	90	95	98
Product	(m^3/d)	21,06	22,23	22,93	5,04	5,32	5,49	21,06	22,23	22,93
Reject	(m^3/d)	2,34	1,17	0,47	0,56	0,28	0,11	2,34	1,17	0,47
Product COD	(g/ℓ)	8,1	10,0	10,6	20,7	26,2	28,3	8,1	10,0	10,6
Product Ca	(mg/ℓ)	10,0	12,0	15,0	12,5	16,9	22,2	10,0	12,0	15,0
Product Mg	(mg/ℓ)	5,4	6,3	7,1	16,6	19,9	22,7	5,4	6,3	7,1
Product Na	(g/ℓ)	12,6	12,6	12,6	38,8	38,8	38,8	9,2	9,2	9,2
Reject COD	(g/ℓ)	47	50	78	133	140	215	47	50	78
Reject Na	(mg/ℓ)	360	610	1 445	1 168	2 240	5 410	360	660	1 445
Reject Mg	(mg/ℓ)	31	40	50	120	161	240	31	40	50
Reject Na	(g/ℓ)	12,6	12,6	12,6	38,8	38,8	38,8	9,2	9,2	9,2

10.8 SPECIFICATION OF THE BATCH NANOFILTRATION UNIT (PROCESS CONFIGURATIONS 1 AND 2)

10.8.1 Equipment

Table 10.10 gives a detailed list of equipment requirements. Figure 10.12 gives the layout of the nanofiltration unit.

The cross-flow microfiltration product is neither abrasive nor corrosive to most materials of construction.

The comments made in section 10.7.1 apply regarding pumps, control systems and storage. Pressure pumping duties are about 1,6 MPa for nanofiltration membranes. The temperature of the effluent will be maintained at 35 °C by a cooling system on the recycle line. During the course of the concentration the pH of the feed will increase, hence acid addition (flue gas or nitric acid) is required.

TABLE 10.10
BATCH NANOFILTRATION EQUIPMENT REQUIREMENTS

1. Effluent Transfer and Storage
1.1 feed tank.
1.2 trial concentrate storage tank.
1.3 product storage tank.
1.4 cleaning solution tank.
1.5 transfer piping for effluent from cross-flow microfiltration.
1.6 transfer piping for feed reticulation in the nanofiltration unit.
1.7 transfer piping to concentrate storage and disposal.
1.8 transfer piping for product to electrochemical recovery.
1.9 transfer piping for flue gas addition to the system to maintain the desired equilibrium position.

2. Nanofiltration Modules
2.1 cartridge filters and associated pressure controller and control interlock.
2.2 membrane elements and assemblies.
2.3 module housings and racks.
2.4 piping and valves for feed, final concentrate and permeate.

3. Pumps
3.1 high-pressure pump for recirculation of effluent and cleaning solutions through modules.
3.2 pump for transfer of final concentrate to discharge.
3.3 pump for transfer of product to electrochemical recovery.
3.4 flow and pressure measurement, indication and control of all streams.

4. Control
4.1 pump motors, starters and interlocks.
4.2 feed recycle flow controller.
4.3 permeate flow measurement.
4.4 high- and low-pressure alarms.
4.5 low-flux alarm.
4.6 permeate colour measurement and high alarm.
4.7 malfunction and alarm control interlocks.
4.8 pH controller on feed line.
4.9 control panel.

5. Ancillaries
5.1 on-line cooling facilities to maintain recycled feed at 35 to 40 °C.
5.2 sampling port.

Although various membrane configurations are available the design method for the nanofiltration unit is outlined using spiral-wrap membranes as the module type. The design specification is given in Table 10.11. A cross-flow microfiltration water recovery of 95 % is assumed.

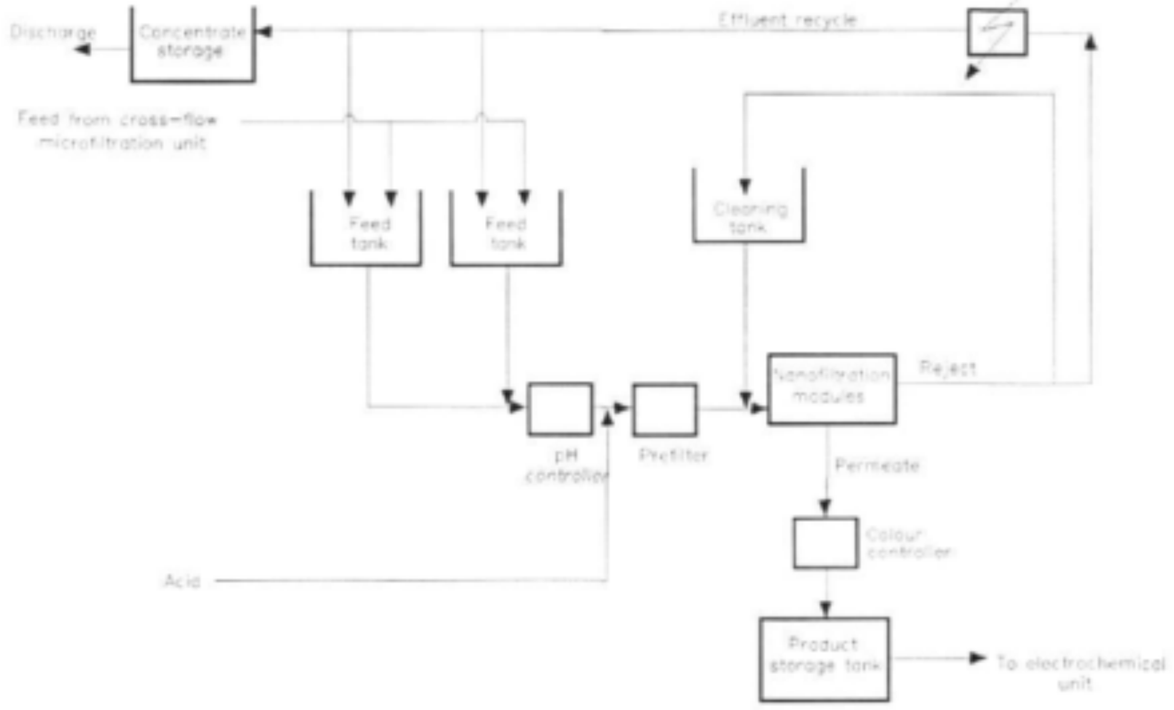


FIGURE 10.12 : FLOW DIAGRAM OF BATCH NANOFILTRATION UNIT

TABLE 10.11
BATCH NANOFILTRATION SPECIFICATION

Parameter				Process configuration 1 (4-stage)	Process configuration 2 (5-stage with evaporator)
Feed flow	daily		(m^3)	22,2	5,32
	hourly		(m^3)	1,11	0,27
	specific	L3	(ℓ/kg)	1,43	0,34
Feed sodium content		C3	(g/ℓ)	12,6	38,8
Feed pH				8	8
Membrane element area			(m^2)	6,5	6,5 and 2
Design flux			(ℓ/m^2h)	43	32
Pressure			(MPa)	1,6	1,6
Temperature			(°C)	35	35

The relationship between membrane flux and the major operating variables is :

$$J = A(P - \Delta\pi)$$

where A is the membrane permeability and is a product of the design membrane permeability (ℓ/m^{2}h.MPa) and the temperature correction factor, ($1{,}03^{(T-25\ ^\circ C)}$),

P is the pressure differential across the membrane (MPa), and

$\Delta\pi$ is the osmotic pressure differential across the membrane (MPa).

If the pressure of the permeate is assumed to be zero, then P is equal to the average of the inlet and outlet pressures of each element.

The concentration of ionised species in the feed is an important flux design parameter in any membrane process because of its relationship with osmotic pressure. The major ions present during nanofiltration will be sodium and bicarbonate which are not rejected by the nanofiltration membrane. The osmotic pressure differential across the membrane will be a function of the osmotic pressure of the rejected organic ions and the divalent ions. This will be minimal and flux decline as a result of increased osmotic pressure differentials will be insignificant.

The maximum achievable water recovery is a function of the applied pressure and the osmotic pressure differential across the membrane, which is in turn a function of the rejection characteristics of the membrane for the ionised species. Since most of the ionised species permeate the nanofiltration membrane in the present application, high water recoveries can be achieved.

10.8.2 Sizing of the Nanofiltration Unit

For the design example the inlet pressure is below the maximum pressure of the membrane to accommodate flux decline during the life-time of the membrane.

In the pilot plant investigations (Chapter 9) the membrane permeability of the nanofilter feed at pH 8 was 20 ℓ/m^{2}h.MPa at 25 °C. Considering the effects of increased TDS on membrane permeability (71) a value of 15 ℓ/m^{2}h.MPa at 25 °C has been predicted for nanofiltration of cross-flow microfilter product from process configuration 2 where evaporation has been used. These values are specific to the membrane used and to the feed pH. Other membranes and different feed pH values will result in different permeability characteristics.

The membrane area requirements are calculated from the membrane permeability using the temperature correction factor :

Process configuration 1

$$Membrane\ area = \frac{1110\ \ l/h}{42\ \ l/m^2h} = 26\ \ m^2$$

Process configuration 2

$$Membrane\ area = \frac{270\ \ l/h}{32\ \ l/m^2h} = 8.5\ \ m^2$$

The 100 mm diameter and 1 000 mm long spiral elements have approximately 6,5 m^2 of membrane area each. Thus four membrane elements of these dimensions would be required for process configuration 1. For process configuration 2, one 6,5 m^2 element is recommended together with one 2 m^2 element.

10.8.3 Overall Performance : Nanofiltration

The composite permeate quality, C_p , is a function of membrane rejection and water recovery as is given by equation 9.5.

The membrane rejection is a function of :

(i) pH: variations in the pH shift the equilibrium position of the inorganic carbon species and hence change the membrane rejection,

(ii) concentration: rejections of organic molecules and sequestered cations sometimes appear to increase at high water recoveries due to the removal of most of the permeable fraction during initial concentration,

(iii) temperature: equilibrium positions and hence membrane rejections are a function of temperature,

(iv) foulants: the build-up of foulants in the vicinity of the membrane surface alters the chemical nature of the rejection surface.

Assuming a 95 % water recovery during cross-flow microfiltration, the overall performance of the nanofiltration unit is summarised in Table 10.12.

10.8.4 Nanofiltration Module Configuration

Spiral modules are normally configured as a staged series-taper plant as illustrated in Figure 10.13. The modules are arranged to achieve approximately 50 % water recovery per stage. Thus the membrane area per stage is reduced successively by 50 % and this provides for the flow to each stage, in relation to the number of parallel modules per stage, to remain constant.

The basic configuration for a three-stage series taper plant is 4/2/1, giving approximately 50 %, 25 % and 12 % of the overall water recovery in the three stages respectively. The first stage consists of four parallel modules, the second two, and the third one.

Each membrane element has a recommended minimum and maximum flow rate. For example the 100 mm diameter nanofiltration membrane element has a feed rate specification of approximately 0,03 to 0,04 $m^3/h.m^2$.

The design example is considered in more detail.

TABLE 10.12
OVERALL PERFORMANCE OF NANOFILTRATION UNIT

Parameter		Process configuration 1 (4-stage)			Process configuration 2 (5-stage with evaporator)		
Feed flow	(m^3/h)	1,11			0,27		
Feed COD	(g/ℓ)	10,0			26,2		
Feed Na	(g/ℓ)	12,6			38,8		
Feed Ca	(mg/ℓ)	12,0			16,9		
Feed Mg	(mg/ℓ)	6,3			19,9		
Design COD rejection	(%)	97			97		
Design Na rejection	(%)	15			15		
Design Ca rejection	(%)	80			80		
Design Mg rejection	(%)	70			70		
Water recovery	(%)	90	95	98	90	95	98
Product	(m^3/d)	20,00	21,12	21,79	4,79	5,05	5,21
Reject	(m^3/d)	2,23	1,11	0,44	0,53	0,27	0,11
Product COD	(g/ℓ)	0,6	0,8	0,1	1,6	2,1	2,9
Product Na	(g/ℓ)	9,7	11,0	11,9	30,0	34,0	36,7
Product Ca	(mg/ℓ)	4,0	5,1	6,4	5,6	7,2	9,0
Product Mg	(mg/ℓ)	2,8	3,5	4,3	8,8	11,2	13,5
Reject COD	(g/ℓ)	94	185	500	252	483	1 144
Reject Na	(g/ℓ)	39	43	44	125	142	171
Reject Ca	(mg/ℓ)	83	143	288	121	202	401
Reject Mg	(mg/ℓ)	38	60	105	122	187	333

Process configuration 1 : 4-stage

The design feed flow is 1,1 m^3/h and four spiral elements of 100 mm diameter were required. A 3/1 configuration is closest to the basic configuration above.

This is a two-stage plant and the flow to each parallel element in the first stage will be 1,1 / 3 = 0,37 m^3/h, which is within the manufacturer's specification.

A design calculation has to be carried out for each element in the system to assess flow specifications and to allow for module pressure drop.

Allowable water recovery is determined by the flow requirements of the last element of the system. In the design case, the minimum is 0,2 m^3/h and hence the maximum allowable water recovery from this design parameter is 1 - (0,2 m^3/h / 1,1 m^3/h) = 82 %. Higher water recoveries may be achieved by reducing the element diameter on the last stage of the plant.

Alternatively the membranes may be arranged in four parallel sets with a flow rate of 1,1 / 4 = 0,28 m^3/h to each element.

Process configuration 2: 5-stage

The design flow is 0,27 m^3/h and one spiral element of 100 mm diameter with two spiral elements of 62 mm diameter were required (this incorporates a safety factor). This is a two-stage plant with the flow to the first stage operated intermittently in batch mode as required.

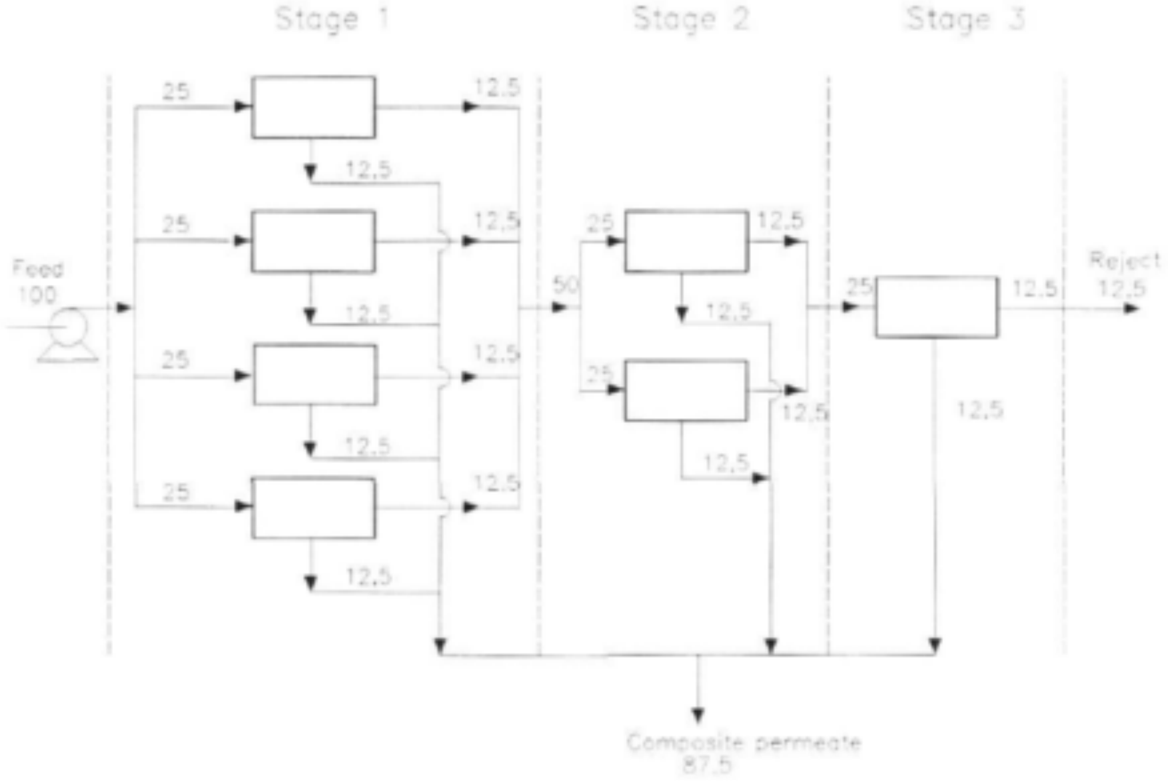


FIGURE 10.13 : BASIC CONFIGURATION OF SPIRAL ELEMENTS SHOWING FLOWS IN ARBITRARY UNITS

10.9 SPECIFICATIONS OF THE ELECTROCHEMICAL UNIT

Electrochemical cell stacks, in a plate-and-frame construction, are supplied, with or without the ancillary pumps, tanks, piping and power source, by a number of manufacturers according to their own design. Particular attention must be paid to :

(i) mass transport effects which relate to different aspects of cell performance, including the uniformity of current density over the electrode surface and the limiting current density,

(ii) fluid mechanics of the pipework between the cells, and between the cell stack and other units to minimise pumping costs,

(iii) the distributor design such that fluid enters each cell with minimal creation of dead zones and that flow becomes uniform as quickly as possible,

(iv) the relative positions of the anode and cathode which determines the uniformity of potential distribution,

(v) the electrode geometry which, together with the local concentration of electroactive species determines the current distribution. Electrodes may be constructed with slits or louvres, from expanded metal or from metal sheets, in such a way as to minimise gas collection,

(vi) the availability of a high-voltage direct current which is transmitted around the cell stack with minimum energy loss,

(vii) the inclusion of switches which permit individual cells to be isolated for maintenance without disturbing the rest of the stack,

(viii) the arrangement of the cells, to ensure that the plant is electrically and chemically safe,

(ix) the type of electrical connection; monopolar or bipolar.

In a monopolar cell there is an external electrical contact to each electrode and the cell voltage is applied between each cathode and anode in parallel. Bipolar connection requires only two external electrical contacts to the two end electrodes and it recognises that the cell reaction will occur wherever there is appropriate potential difference. Table 10.13 (72) compares the two configurations. Where bipolar cells are used, attention must be given to minimising shunt current, or current leakages, by using insulating barriers in the electrolyte flow passage.

Table 10.14 gives a detailed list of equipment requirements. Figure 10.14 gives the flow diagram of the electrochemical unit.

Materials of construction must be resistant to the electrolytes. Particular attention must be given to gasket and other rubber components which are susceptible to sodium hydroxide deterioration or embrittlement. The effluent is not abrasive or corrosive to most materials. Suitable tank, piping and cell framework materials would be polypropylene, polyvinyl chloride, poly (vinylidine fluoride) and stainless steel. The former two are cheap but operation is restricted to 60 °C.

Careful selection of the type and material used in the manufacture of the valves and flow meters on the sodium hydroxide line is required to prevent blockages or malfunction resulting from solid sodium hydroxide precipitation.

The anodes should be constructed from a non-corroding material, totally stable in the electrolysis medium and possessing a low overpotential for oxygen generation, with a high current efficiency. Typical materials include the titanium substrate electrode to which a coating of precious metal oxides has been applied. Nickel and stainless steel are not suitable for the application.

The cathode should be stable under reducing conditions and in the presence of caustic. Suitable materials include nickel and stainless and mild steel.

TABLE 10.13
CHARACTERISTICS OF BIPOLAR CELLS IN COMPARISON WITH MONOPOLAR CELLS (10 V) (72)

	Bipolar cells	Monopolar cells
Conditions of electricity	small current and high voltage	large current and low voltage
Cell-to-cell current distribution	uniform	not uniform
Bus bars	between electrolyzers (less)	between electrolyzers and between cells (more)
Number of nozzles	more	less
Current leaks	more	less
Capacity of electrolyzer	easy to enlarge	not easy to enlarge
Floor area for electrolyzer	small	large
Assembling and disassembling of electrolyzer	simple	complicated
Electric resistance of conductor	small	large
Switch required	high voltage DC circuit breaker	low voltage, large current by-pass switch
Preventing of gasket leaks	easy	complicated

The tank used for storing and recirculation of cleaning chemicals must be nitric acid resistant.

The membrane employed must be stable in sodium hydroxide and selective to the transport of cations in the applicable concentration range.

High-flow pumps with low-pressure duties for electrolyte transfer are required. The flow rate of the sodium hydroxide through the catholyte compartments must be slightly higher than the flow of effluent through the anolyte compartments to maintain an elevated pressure on the cathode side of the membrane.

A cooling system must be installed on the electrolyte feed line to control the temperature in the cell stack below a certain level, generally dependent on the materials of construction of the cell stack, piping and valves. If stainless steel is employed the maximum temperature will depend on the membrane tolerance. Higher temperature operation is desirable to increase membrane swelling but temperatures must be controlled to prevent boiling within the membrane.

TABLE 10.14
BATCH ELECTROCHEMICAL EQUIPMENT

1. Electrolyte transfer and storage
1.1 feed tanks.
1.2 caustic make-up, storage and batch reticulation tanks.
1.3 depleted brine storage tank.
1.4 concentrated caustic storage tank.
1.5 flushing solution tank.
1.6 transfer piping for effluent from nanofiltration.
1.7 transfer piping for effluent, caustic and flushing solutions in the electrochemical unit.
1.8 transfer piping to liquid product storage (brine and caustic) and to factory for reuse.
1.9 transfer piping for carbon dioxide and oxygen gas stream to neutralisation unit.
1.10 transfer piping for hydrogen gas disposal.

2. Electrochemical cell stack
2.1 stack frames and gasket assemblies.
2.2 anode, cathode and membrane elements and assemblies.
2.3 electrolyte flow and pressure controllers.
2.4 piping and valves for electrolytes and flushing solutions.
2.5 gas-liquid separation facilities.
2.6 electrical connection points for application of the potential across the stack.

3. Electrical power supply
3.1 rectified power facilities sized according to the output required.
3.2 ripple prevention facilities such as tap change to enable control on the primary side of the rectifier.
3.3 battery operated invertor pack for background voltage back-up during power failures.
3.4 electrical output measurement and recording.
3.5 electrical programming to correlate current output to effluent concentration.
3.6 constant voltage operation facilities.

4. Pumps
4.1 low-pressure pumps for circulation of electrolytes and flushing solutions through cell stack.
4.2 pumps for transfer of concentrated caustic and depleted brine products to storage and factory processing.
4.3 flow and pressure measurement, indication and control of all streams.

5. Control
5.1 pump motors, starters and interlocks.
5.2 electrolyte flow controllers.
5.3 electrolyte concentration and density controllers, with alarms.
5.4 low-flow alarm.
5.5 high-pressure alarm.
5.6 malfunction and alarm control interlocks.
5.7 electrical input control with high alarm.
5.8 electrolyte temperature control with high alarm.
5.9 sodium hydroxide density controller.
5.10 depleted brine concentration and electrical input control interlocks.
5.11 control panel.

6. Ancillaries
6.1 cooling facilities to maintain the temperatures of the recycled electrolytes below the maximum stable limit of the materials used for cell construction.
6.2 sampling ports.

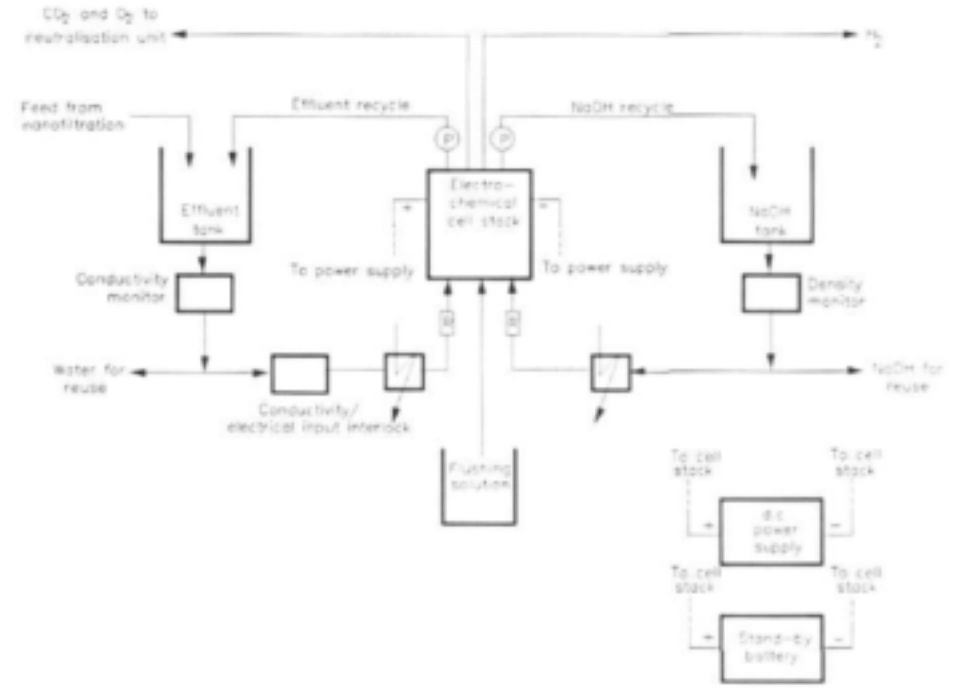


FIGURE 10.14 : FLOW DIAGRAM OF BATCH ELECTROCHEMICAL UNIT

The process is required to produce a fixed ratio of feed anolyte to dilute brine conductivity.

Effluent and dilute sodium hydroxide storage of 6 to 12 h duration is necessary to provide for electromembrane cleaning, minor breakdowns and maintenance. Depleted brine and concentrated sodium hydroxide storage facilities of approximately 12 h are necessary to allow for factory scheduling. No gas storage facilities are required provided the neutralisation unit is operated simultaneously. If the neutralisation unit is shut down, the anolyte gases may be vented to the atmosphere provided that flue gas is available on commencement of the operation of the neutralisation unit.

Although various electric current and flow configurations are possible the design method for the electrochemical unit is outlined using a plate and frame arrangement of individual cells in a cell stack, in which electrolyte flow to each cell is in parallel and in which the electric current to each cell is in series (bipolar). For this application high-flow pumps are required and a rectifier producing a high-voltage - low-current output.

The specification for the electrochemical unit in the design example is given in Table 10.15.

TABLE 10.15
BATCH ELECTROCHEMICAL UNIT SPECIFICATION

Determinand				Process configuration 1 (4-stage)	Process configuration 2 (5-stage with evaporator)
Feed flow	daily		(m^3)	20,4	5,1
	hourly		(m^3)	1,02	0,26
	specific	L5	(ℓ/kg cloth)	1,3	0,3
Feed effluent Na content		C5	(g/ℓ)	11,1	32,3
Na hydroxide concentration		C6	(g/ℓ)	150 to 200	150 to 200
Temperature			(°C)	60	60
Individual cell area			(m^2)	1	1
Membrane - electrode gap			(mm)	2	2

The optimum operating parameters for a given duty are a function of the design of the stack and will vary from stack to stack. The specification gives typical conditions based on the data in Chapter 9, assuming :

(i) a 95 % water recovery in both filtration stages i.e. an overall water recovery of 90 %,

(ii) a background wash-water concentration of 5 g/ℓ Na, (process configuration 1) and 0,8 g/ℓ Na (process configuration 2).

(iii) the washing variables specified in Table 10.2

10.9.1 Sizing of the Electrochemical Unit Area and Power Facilities

Assuming a scouring and washing range operating at a steady state, the performance of the electrochemical unit is a function of many inter-related variables including :

(i) the composition and flow of the effluent feed, which in turn depends on the rejection and water recovery of the filtration stages,

(ii) the degree of sodium removal, which depends on both the background concentration of sodium in the wash water and the sodium losses from the system,

(iii) the operating characteristics of the unit including the current density, current efficiency, temperature and voltage which are all, in turn, related to each other and to the effluent feed characteristics.

The relationships between the variables affecting the electrochemical unit operating performance are described in Chapter 9 and have been used for predicting the design requirements of the design examples (Table 10.16). The area requirements are a function of the variables and are calculated in Table 10.16 for the design examples using the procedure detailed in Chapter 9.

TABLE 10.16
ELECTROCHEMICAL UNIT OPERATING CHARACTERISTICS

Determinand			Design Calculations		
			Process configuration 1 (4-stage)	Process configuration 2 (5-stage with evaporator)	Equation
Anolyte conductivity range		(mS/m)	3 000 to 5 700	2 000 to 11 000	9-14
Limiting current density range		(A/m^2)	777 to 1 489	529 to 2 857	9-15
Average anolyte volt drop		(V)	0,52	0,52	9-13
Average catholyte conductivity		(mS/m)	82 000	82 000	Figure 9.10
Average catholyte volt drop		(V)	0,03	0,03	9-13
Average cell potential		(V)	3,6	3,6	9-12
Electrical requirements		(A.s/kg cloth)	13,9	16,9	9-10
Recovered Na hydroxide mass,	N6	(g/kg cloth)	9,0	10,9	9-25
Depleted brine flow,	L7	(ℓ/kg cloth)	1,28	0,31	9-23
Depleted brine concentration,	C7	(g/ℓ)	5,86	3,91	9-24
Area		(m^2)	9,3	7,5	9-11
Power		(kWh/t NaOH)	3 169	3 181	9-9

10.10 SPECIFICATION FOR INTEGRATED REVERSE OSMOSIS, NANOFILTRATION AND ELECTROCHEMICAL UNITS (PROCESS CONFIGURATION 3)

The combination of reverse osmosis, nanofiltration and electrochemical units in process configuration 3 is operated continuously in a single batch circuit until 95 % water recovery from the reverse osmosis unit has been achieved.

The equipment requirements of the individual units are similar to those described for the nanofiltration and electrochemical units for process configurations 1 and 2 (Sections 10.8 and 10.9). It is envisaged that the reverse osmosis and nanofiltration membranes will be mounted in the same module holder and that the pressure requirements for nanofiltration will be met by the residual pressure of the reverse osmosis reject stream.

Figure 10.15 gives the flow diagram of the integrated system of reverse osmosis, nanofiltration and electrochemical units for process configuration 3.

Conceptually the mass balance over this process is computed by assuming a constant sodium concentration in the feed to the electrochemical cell and by assuming that the increase in concentration during reverse osmosis equals the decrease in concentration in the electrochemical cell. These assumptions will enable the equipment at each stage to be sized and will determine the duty required. Depending on the flow requirements of the cell a buffer tank holding nanofiltration permeate may be required, with a portion of the depleted brine being recycled to the anolyte compartment of the cell.

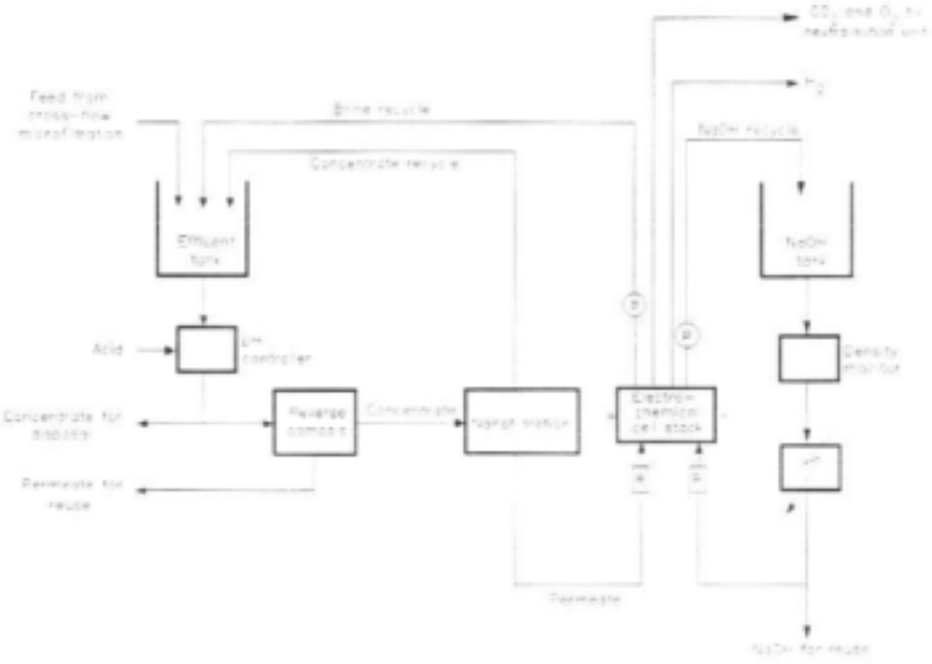


FIGURE 10.15 : FLOW DIAGRAM OF THE INTEGRATED REVERSE OSMOSIS, NANOFILTRATION AND ELECTROCHEMICAL UNITS (PROCESS CONFIGURATION 3)

10.11 SYNOPSIS OF DESIGN SPECIFICATIONS

10.11.1 Process Configuration 1 (4-stage)

Process configuration 1 is a four-stage process, utilizing a high background wash-water concentration. The design example has been presented for the case where the background sodium concentration in the wash water is 5 g/ℓ and the anolyte is depleted to a sodium concentration of 5,9 g/ℓ. A spreadsheet (Appendix 1) was used to compile an example worksheet (Table 10.17) for the extension of the calculations to include a range of background concentrations. Table 10.17 presents the effect of changing the background concentration on :

(i) effluent characteristics

The effluent and cloth characteristics are a function of the wash-water concentration. Figure 10.16 shows the effect of wash-water concentration (in the range 0 to 6 g/ℓ Na) on effluent concentration and on effluent and cloth mass loading.

TABLE 10.17

PROCESS DATA ON A DRY FABRIC MASS BASIS FOR PROCESS CONFIGURATION 1 (4-STAGE) - VARIABLE WASH-WATER CONCENTRATION

Temperature of cell operation = 60 °C;

Background wash-water Na = *0 to 6 g/l* (C_q)

Note : Where figures are not shown values are equal to value in first column.

Determinand	Symbol	Unit	Value for C_q (g/l Na)						
			0	1	2	3	4	5	6
1. WASHING VARIABLES									
Moisture content of cloth into wash range	mi	l/kg cloth	0,5						
Na conc of moisture on cloth into wash range	ci	g/l Na	28,8						
Moisture content of cloth out of wash range	mo	l/kg cloth	0,5						
Na conc of moisture on cloth out of wash range	co	g/l Na	1,3	2.2	3,2	4,1	5,1	6,0	7,0
Average cloth mass	fm	kg/m	0,3						
Cloth speed	fs	m/h	3000						
Up-time of scouring wash range	tm	h/d	20,0						
2. TREATMENT PLANT VARIABLES									
Cross-flow microfiltration water recovery	Rc	%	95,0						
Nanofiltration water recovery	Rn	%	95,0						
Nanofiltration point Na rejection	r	%	15,0						
Electrochemical cell current efficiency	E	%	75,0						
Electrochemical cell temperature	T	C	60,0						
Electrochemical cell water transport number	nw	g/g	8,1						
Electrochemical cell electrolyte length	*l*	m	0,002						
Electrochemical cell average catholyte conductivity	CONDC	S/m	82,0						
Electrochemical cell decomposition, polarisation & membrane voltage	Vd	V	3,0						
Up-time of treatment plant	tp	h/d	20,0						
3. WASH-WATER AND EFFLUENT CHARACTERISTICS									
Na conc in total wash water	Cq	g/l Na	0,0	1,0	2,0	3,0	4,0	5,0	6,0
Total wash-water flow	Q	l/kg cloth	1,5	1,5	1,5	1,5	1,5	1,5	1,5
Effluent flow	L1	l/kg cloth	1,5	1,5	1,5	1,5	1,5	1,5	1,5
Na conc in effluent	C1	g/l Na	9,2	9,9	10,5	11,2	11,9	12,6	13,3

TABLE 10.17 (cont. i)

Determinand		Symbol	Unit	Value for C_φ (g/l Na)						
				0	1	2	3	4	5	6
4. <u>MASS BALANCE CALCULATIONS</u>										
Wash Range :	Mass Na in on cloth	Ni	g/kg cloth	14,4	14,4	14,4	14,4	14,4	14,4	14,4
	Mass Na out on cloth	No	g/kg cloth	0,6	1,1	1,6	2,1	2,5	3,0	3,5
	Mass Na in effluent	N1	g/kg cloth	13,8	14,8	15,8	16,8	17,8	18,9	19,9
Cross-flow microfiltration:	Concentrate flow	L2	l/kg cloth	0,1	0,1	0,1	0,1	0,1	0,1	0,1
	Na conc in concentrate	C2	g/l Na	9,2	9,9	10,5	11,2	11,9	12,6	13,3
	Mass Na in concentrate	N2	g/kg cloth	0,7	0,7	0,8	0,8	0,9	0,9	1,0
	Permeate flow	L3	l/kg cloth	1,4	1,4	1,4	1,4	1,4	1,4	1,4
	Na conc in permeate	C3	g/l Na	9,2	9,9	10,5	11,2	11,9	12,6	13,3
	Mass Na in permeate	N3	g/kg cloth	13,1	14,0	15,0	16,0	16,9	17,9	18,9
Nanofiltration:	Concentrate flow	L4	l/kg cloth	0,1	0,1	0,1	0,1	0,1	0,1	0,1
	Na conc in concentrate	C4	g/l Na	14,4	15,4	16,5	17,6	18,6	19,7	20,8
	Mass Na in concentrate	N4	g/kg cloth	1,0	1,1	1,2	1,3	1,3	1,4	1,5
	Permeate flow	L5	l/kg cloth	1,35	1,35	1,35	1,35	1,35	1,35	1,35
	Na conc in permeate	C5	g/l Na	8,9	9,6	10,2	10,9	11,5	12,2	1,9
	Mass Na in permeate	N5	g/kg cloth	12,0	12,9	13,8	14,7	15,6	16,5	17,4
Electrochemical cell	Mass Na in Recovered NaOH	N6	g/kg cloth	12,0	11,4	10,8	10,2	9,6	9,0	8,4
	Recovered NaOH	L6	l/kg cloth	0,1	0,1	0,1	0,1	0,1	0,1	0,1
	Na conc in recovered NaOH	C6	g/l Na	123,5	123,5	123,5	123,5	123,5	123,5	123,5
	Depleted brine flow	L7	l/kg cloth	1,3	1,3	1,3	1,3	1,3	1,3	1,3
	Na conc in depleted brine	C7	g/l Na	0,0	1,2	2,4	3,5	4,7	5,9	7,0
	Mass Na in depleted brine	N7	g/kg cloth	0,0	1,5	3,0	4,5	6,0	7,5	9,0
Make-up Na as NaOH		N8	g/kg cloth	2,3	2,9	3,5	4,2	4,8	5,4	6,0
Make-up water		L8	l/kg cloth	0,2	0,2	0,2	0,2	0,2	0,2	0,2
5. <u>Na LOSSES</u>										
Na loss from drag-out		loss 1	%	4,3	7,7	11,0	4,3	17,6	21,0	24,3
Na loss in cross-flow microfiltration concentrate		loss 2	%	4,8	5,1	5,5	5,8	6,2	6,6	6,9
Na loss in nanofiltration concentrate		loss 3	%	7,1	7,7	8,2	8,7	9,2	9,8	10,3
Na loss from system		S	%	16,3	20,4	24,7	28,9	33,1	37,3	41,5
Savings on existing Na make-up		N9	g/kg cloth	12,0	11,4	10,8	10,2	9,6	9,0	8,4
			%	83,7	79,6	75,3	70,8	67,0	62,7	58,5
6. <u>WATER LOSSES</u>										
Water loss from system		W	%	16,3	15,9	15,6	15,3	14,9	14,6	14,3
Savings on existing water make-up		L9	l/kg cloth	1,3	1,3	1,3	1,3	1,3	1,3	1,3
			%	84,0	84,3	84,7	84,7	85,0	85,3	86,0

TABLE 10.17 (cont. ii)

Determinand	Symbol	Unit	Value for C_q (g/l Na)						
			0	1	2	3	4	5	6
7. <u>ELECTROCHEMICAL UNIT OPERATING PARAMETERS</u>									
Maximum anolyte conductivity	CONDA1	S/m	4,4	4,7	4,9	5,2	5,5	5,7	6,0
Minimum anolyte conductivity	CONDA2	S/m	0,0	0,6	1,2	1,8	2,4	3,0	3,5
Maximum limiting current density	CD1	A/m^2	1 137	1 211	1 283	1 353	1 422	1 489	1 555
Minimum limiting current density	CD2	A/m^2	-13	158	322	480	631	777	916
Average limiting current density	CD3	A/m^2	562	685	802	917	1 027	1 133	1 236
Minimum anolyte volt drop	VA1	V	0,5	0,5	0,5	0,5	0,5	0,5	0,5
Maximum anolyte volt drop	VA2	V	0,5	0,5	0,5	0,5	0,5	0,5	0,5
Average anolyte volt drop	VA3	V	0,5	0,5	0,5	0,5	0,5	0,5	0,5
Average catholyte volt drop	VC	V	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Average cell potential	Vc	V	3,5	3,5	3,5	3,5	3,5	3,5	3,6
Electrical requirements	F	F/kg cloth	0,7	0,7	0,6	0,6	0,6	0,5	0,5
8. <u>ELECTROCHEMICAL UNIT AREA AND POWER REQUIREMENTS</u>									
Specific area requirements	As	m^2/kg cloth	0,002	0,001	0,001	0,001	0,001	0,001	0,001
Total area requirements	At	m^2	25,0	19,5	15,7	13,0	10,9	9,3	7,9
Power requirements for NaOH production	P	kWh/t NaOH	3 157	3 159	3 162	3 165	3 167	3 169	3 171

See Annexure to Table 10.17

ANNEXURE TO TABLE 10.17

Temperature of cell operation = 40 to 100 °C;

Background wash-water Na concentration (C_a) = 5 g/ℓ.

Determinand		Symbol	Unit	Temperature			
				40	60	80	100
1.	<u>ELECTROCHEMICAL UNIT OPERATING PARAMETERS</u>						
	Electrochemical cell temperature	T	°C	40,0	60,0	80,0	100,0
	Electrochemical cell average catholyte conductivity	CONDC	S/m	55,0	82,0	100,0	130,0
	Maximum anolyte conductivity	CONDA1	S/m	4,3	5,7	7,2	8,8
	Minimum anolyte conductivity	CONDA2	S/m	2,3	3,0	3,8	4,7
	Maximum limiting current density	CD1	A/m^2	1 128	1 489	1 863	2 277
	Minimum limiting current density	CD2	A/m^2	592	777	978	1 222
	Average limiting current density	CD3	A/m^2	860	1 133	1 421	1 750
	Minimum anolyte volt drop	VA1	V	0,5	0,5	0,5	0,5
	Maximum anolyte volt drop	VA2	V	0,5	0,5	0,5	0,5
	Average anolyte volt drop	VA3	V	0,5	0,5	0,5	0,5
	Average catholyte volt drop	VC	V	0,0	0,0	0,0	0,0
	Average cell potential	Vc	V	3,6	3,5	3,5	3,5
	Electrical requirements	F	F/kg cloth	0,5	0,5	0,5	0,5
2.	<u>ELECTROCHEMICAL UNIT AREA AND POWER REQUIREMENTS</u>						
	Specific area requirements	As	m^2/kg cloth	0,001	0,001	0,000	0,000
	Total area requirements	At	m^2	12,2	9,3	7,4	6,0
	Power requirements for NaOH production	P	kWh/t NaOH	3 172	3 169	3 170	3 169

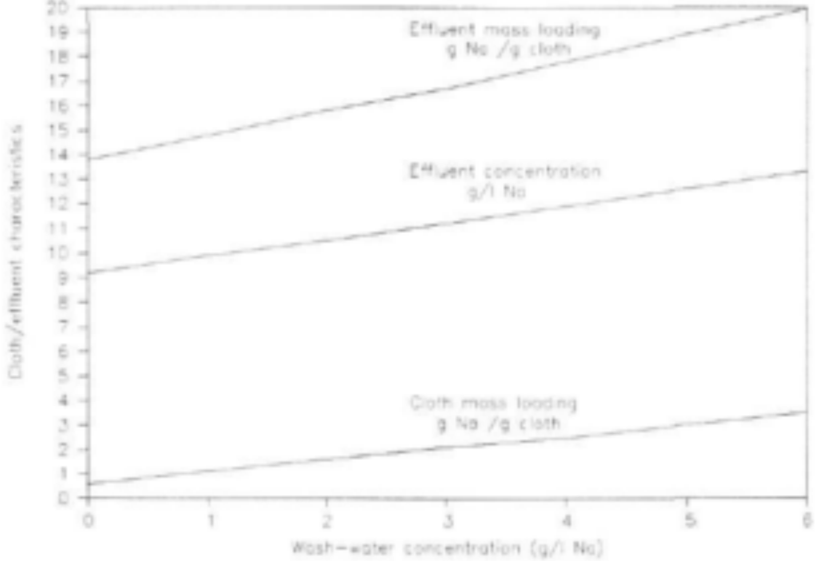


FIGURE 10.16 : DESIGN EXAMPLE: PROCESS CONFIGURATION 1: DEPENDENCE OF EFFLUENT AND CLOTH CHARACTERISTICS ON WASH-WATER CONCENTRATION

(ii) <u>electrochemical membrane area requirements</u>

The duty per unit area of electromembrane increases as the final concentration of the depleted brine is increased i.e. as the background concentration in the wash water is increased. Figure 10.17 is plotted from data in Table 10.17 and illustrates that the electromembrane area requirements decrease as the background concentration is elevated.

(iii) <u>sodium hydroxide make-up requirements</u>

Sodium losses from the system occur in the :

drag-out from the washing range.
cross-flow microfiltration concentrate.
nanofiltration concentrate.

These losses must be balanced by an equivalent make-up of sodium hydroxide to the saturator.

Although elevated background wash-water concentrations are advantageous in terms of the operation of the electrochemical unit, sodium loss from the system increases substantially as the background concentration in the wash water is increased. The sodium hydroxide make-up to the system is thus also increased significantly (Figure 10.18).

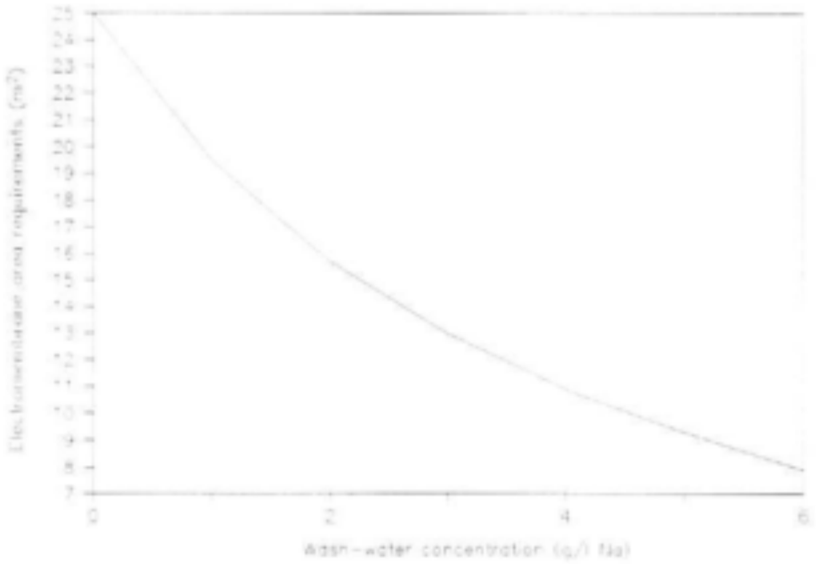


FIGURE 10.17 : DESIGN EXAMPLE: PROCESS CONFIGURATION 1: DEPENDENCE OF ELECTROMEMBRANE AREA REQUIREMENTS ON WASH-WATER CONCENTRATION. NOTE: OPERATION AT 60 °C

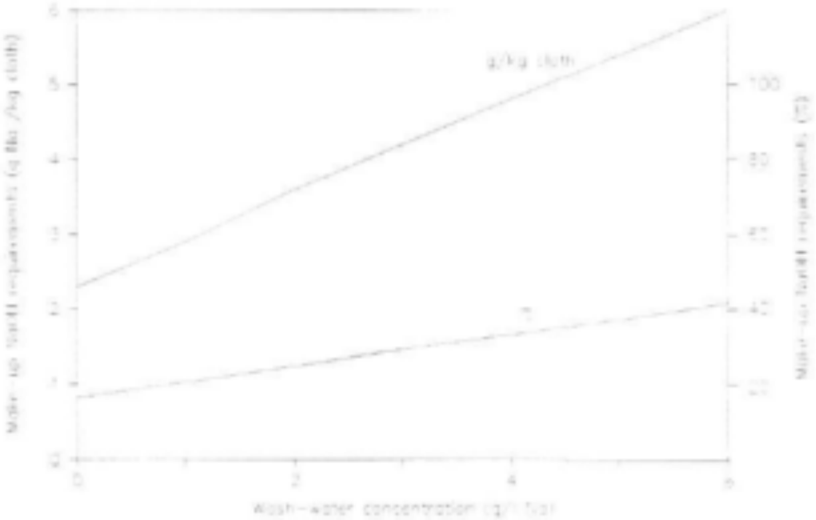


FIGURE 10.18 : DESIGN EXAMPLE: PROCESS CONFIGURATION 1: DEPENDENCE OF SODIUM LOSSES ON WASH-WATER CONCENTRATION

Table 10.17 contains an annex which presents a further extension of the design calculations to cover a range of temperatures between 40 °C and 100 °C for a background concentration of 5 g/ℓ Na. Figure 10.19 illustrates the effect of the temperature at which the electrochemical process is operated on the total area requirements of the system.

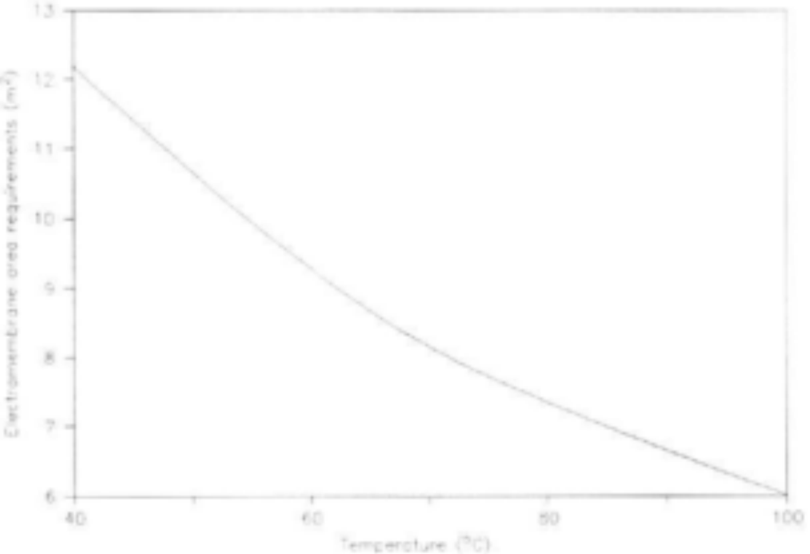


FIGURE 10.19 : DESIGN EXAMPLE: PROCESS CONFIGURATION 1: DEPENDENCE OF ELECTROCHEMICAL AREA REQUIREMENTS ON TEMPERATURE

10.11.2 Process Configuration 2 (5-stage with evaporation)

Process configuration 2 requires an additional evaporation stage. The sodium cloth mass loading after washing is 66 % lower than that for process configuration 1 and greater recovery of sodium, water and heat energy is effected. The design example has been presented for the case where an evaporation factor of four is applied and the anolyte is depleted to a sodium concentration of 3,7 g/ℓ. The depleted anolyte combined with the evaporator condensate and make-up water yields a recycled wash water with a concentration of 0,8 g/ℓ Na. A spreadsheet (Appendix 2) was used to compile an example worksheet (Table 10.18) for the extension of the calculations to include a range of wash-water concentrations from 0 to 1 g/ℓ.

TABLE 10.18

PROCESS DATA ON A DRY FABRIC MASS BASIS FOR PROCESS CONFIGURATION 2 (5-STAGE WITH EVAPORATION) - VARIABLE WASH-WATER CONCENTRATION

evaporation factor = 4;
temperature 60 °C

Note : where data is not shown values are equal to value in first column.

Determinand	Symbol	Unit	Value for C_q (g/*l* Na)					
			0	0,2	0,4	0,6	0,8	1,0
1. PROPOSED WASHING VARIABLES								
Moisture content of cloth into wash range	mi	*l*/kg cloth	0,5					
Na conc of moisture on cloth into wash range	ci	g/*l* Na	28,8					
Moisture content of cloth out of wash range	mo	*l*/kg cloth	0,5					
Na conc of moisture on cloth out of wash range	co	g/*l* Na	1,2	1,4	1,6	1,8	2,0	2,2
Average cloth mass	fm	kg/m	0,3					
Cloth speed	fs	m/h	3000					
Up-time of scouring wash range	tm	h/d	20,0					
Total wash-water flow	Q	*l*/kg cloth	1,5					
Na conc in total wash water	Cq	g/*l* Na	0,0					
effluent flow	L1	*l*/kg cloth	1,5					
Na conc in effluent	C1	g/*l* Na	9,2	9,3	9,4	9,6	9,7	9,9
2. TREATMENT PLANT VARIABLES								
Evaporator concentration factor	ECF	times	4,0					
Evaporator condensate concentration	Ce	g/*l* Na	0,0					
Sludge volume	SV	%	5,0					
Total Na in sludge	SN	%	5,0					
Cross-flow microfiltration water recovery	Rc	%	95,0					
Nanofiltration water recovery	Rn	%	95,0					
Nanofiltration point Na rejection	r	%	15,0					
Electrochemical cell current efficiency	E	%	75,0					
Electrochemical cell temperature	T	C	60,0					
Electrochemical cell water transport number	nw	g/g	1,6	1,5	1,5	1,4	1,4	1,3
Electrochemical cell electrolyte length	*l*	m	0,002					
Electrochemical cell average catholyte conductivity	CONDC	S/m	82,0					
Electrochemical cell decomposition, polarisation & membrane voltage	Vd	V	3,0					
Up-time of treatment plant	tp	h/d	20,0					

TABLE 10.18 (cont. i)

Determinand		Symbol	Unit	Value for C_w (g/l Na)					
				0	0,2	0,4	0,6	0,8	1,0
3. <u>MASS BALANCE CALCULATIONS</u>									
Wash range:	Mass Na in on cloth	Ni	g/kg cloth	14,4	14,4	14,4	14,4	14,4	14,4
	Mass Na out on cloth	No	g/kg cloth	0,6	0,7	0,8	0,9	1,0	1,1
	Mass Na in effluent	N1	g/kg cloth	13,8	14,0	14,2	14,4	14,6	14,8
Evaporator:	Concentrate and sludge flow	Ls	l/kg cloth	0,4	0,4	0,4	0,4	0,4	0,4
	Mass Na in concentrate and sludge	Ns	g/kg cloth	13,8	14,0	14,2	14,4	14,6	14,8
	Concentrate and sludge concentration	Cs	g/l cloth	36,7	37,2	37,8	38,3	38,8	39,4
	Concentrate flow	Lc	l/kg cloth	0,4	0,4	0,4	0,4	0,4	0,4
	Mass Na in concentrate	Ne	g/kg cloth	13,1	13,3	13,5	13,7	13,8	14,0
	Concentrate concentration	Ce	g/l cloth	36,7	37,2	37,8	38,3	38,8	39,4
	Condensate flow	Le	l/kg cloth	1,1	1,1	1,1	1,1	1,1	1,1
	Mass Na in condensate	Nc	g/kg cloth	0,0	0,0	0,0	0,0	0,0	0,0
Cross-flow microfiltration:	Concentrate flow	L2	l/kg cloth	0,0	0,0	0,0	0,0	0,0	0,0
	Na conc in concentrate	C2	g/l cloth	36,7	37,2	37,8	38,3	38,8	39,4
	Mass Na in concentrate	N2	g/kg cloth	0,7	0,7	0,7	0,7	0,7	0,7
	Permeate flow	L3	l/kg cloth	0,3	0,3	0,3	0,3	0,3	0,3
	Na conc in permeate	C3	g/l cloth	36,7	37,2	37,8	38,3	38,8	39,4
	Mass Na in permeate	N3	g/kg cloth	12,4	12,6	12,8	13,0	13,1	13,3
Nanofiltration:	Concentrate flow	L4	l/kg cloth	0,0	0,0	0,0	0,0	0,0	0,0
	Na conc in concentrate	C4	g/l cloth	57,5	58,3	59,2	60,1	60,9	61,8
	Mass Na in concentrate	N4	g/kg cloth	1,0	1,0	1,0	1,0	1,0	1,0
	Permeate flow	L5	l/kg cloth	0,32	0,32	0,32	0,32	0,32	0,32
	Na conc in permeate	C5	g/l cloth	35,6	36,1	36,6	37,2	37,7	38,2
	Mass Na in permeate	N5	g/kg cloth	11,4	11,6	11,8	12,0	12,1	12,3
Electrochemical cell:	Mass Na in recovered NaOH	N6	g/kg cloth	11,4	11,3	11,2	11,1	10,9	10,8
	Recovered NaOH flow	L6	l/kg cloth	0,0	0,0	0,0	0,0	0,0	0,0
	Na conc in recovered NaOH	C6	g/l cloth	642,3	663,0	686,0	709,9	732,8	758,2
	Depleted brine flow	L7	l/kg cloth	0,3	0,3	0,3	0,3	0,3	0,3
	Na conc in depleted brine	C7	g/l cloth	0,0	1,0	2,0	2,9	3,9	4,9
	Mass Na in depleted brine	N7	g/kg cloth	0,0	0,3	0,6	0,9	1,2	1,5
Make up Na as NaOH		N8	g/kg cloth	2,9	3,1	3,2	3,3	3,5	3,6
Make up water		L8	l/kg cloth	0,1	0,1	0,1	0,1	0,1	0,1

TABLE 10.18 (cont. ii)

Determinand	Symbol	Unit	Value for C_v (g/l Na)					
4. Na LOSSES								
Na loss in evaporator sludge	loss0	%	4,8	4,9	4,9	5,0	5,1	5,1
Na loss from drag-out	loss1	%	4,3	5,0	5,7	6,3	7,0	7,7
Na loss in cross-flow microfiltration concentrate	loss2	%	4,5	4,6	4,7	4,7	4,8	4,9
Na loss in nanofiltration concentrate	loss3	%	6,8	6,9	7,0	7,1	7,2	7,3
Na loss from system	S	%	20,4	21,3	22,2	23,2	24,0	24,9
Savings on existing Na make-up	N9	g/kg cloth	11,4	11,3	11,2	11,1	10,9	10,8
		%	79,6	78,7	77,7	76,8	75,9	75,0
			0	0,2	0,4	0,6	0,8	1,0
5. WATER LOSSES								
Water loss from system	W	%	3,7	3,7	3,6	3,6	3,5	3,5
Savings on existing water make-up	L9	l/kg	1,4	1,4	1,4	1,4	1,4	1,4
		%	95,3	96,3	96,3	96,3	96,3	96,3
6. ELECTROCHEMICAL UNIT OPERATING PARAMETERS								
Maximum anolyte conductivity	CONDA1	S/m	10,9	10,9	11,0	11,0	11,0	11,0
Minimum anolyte conductivity	CONDA2	S/m	0,0	0,5	1,0	1,5	2,0	2,5
Maximum limiting current density	CD1	A/m^2	2 835	2 842	2 848	2 853	2 857	2 860
Minimum limiting current density	CD2	A/m^2	-13	129	266	400	529	654
Average limiting current density	CD3	A/m^2	1 411	1 485	1 557	1 626	1 693	1 757
Minimum anolyte volt drop	VA1	V	0,5	0,5	0,5	0,5	0,5	0,5
Maximum anolyte volt drop	VA2	V	0,5	0,5	0,5	0,5	0,5	0,5
Average anolyte volt drop	VA3	V	0,5	0,5	0,5	0,5	0,5	0,5
Average catholyte volt drop	VC	V	0,0	0,0	0,0	0,0	0,0	0,0
Average cell potential	Vc	V	3,6	3,6	3,6	3,6	3,6	3,6
Electrical requirements	F	F/kg cloth	0,7	0,7	0,6	0,6	0,6	0,6
7. ELECTROCHEMICAL UNIT AREA AND POWER REQUIREMENTS								
Specific area requirements	As	m^2/kg cloth	0,001	0,001	0,001	0,001	0,001	0,000
Total area requirements	At	m^2	9,4	8,9	8,4	7,9	7,5	7,2
Power requirements for NaOH production	P	kWh/t NaOH	3 175	3 177	3 178	3 180	3 181	3 183

As with process configuration 1, there is an increase in the cloth and effluent loading, a decrease in the electrochemical membrane area requirements and an increase in the sodium hydroxide make-up requirements as the sodium concentration in the wash-water is increased.

The effect of changes in the evaporation factor on electromembrane area requirements and on sodium make-up requirements, as a function of the wash water concentration, is shown in Figures 10.20 and 10.21. Figure 10.20 indicates that after a concentration factor of four the additional saving on electromembrane area is small.

The data given above for process configuration 2 is for a fixed electrochemical operation temperature of 60 °C. The electromembrane area requirements can be expected to decrease by approximately 10 % for each additional 10 °C increase in temperature.

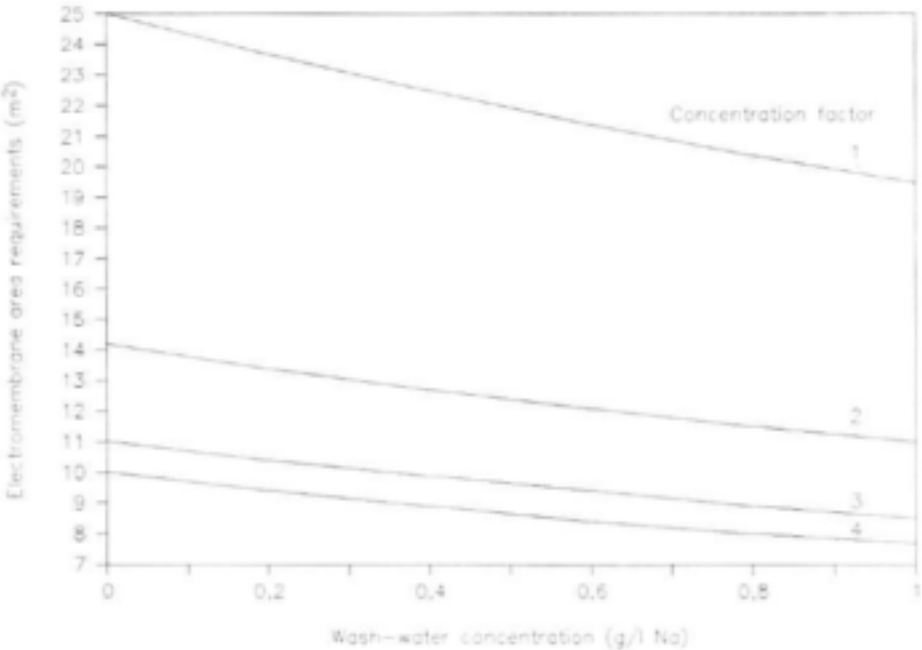


FIGURE 10.20 : DESIGN EXAMPLE: PROCESS CONFIGURATION 2: DEPENDENCE OF ELECTROMEMBRANE AREA REQUIREMENTS ON THE EVAPORATION FACTOR

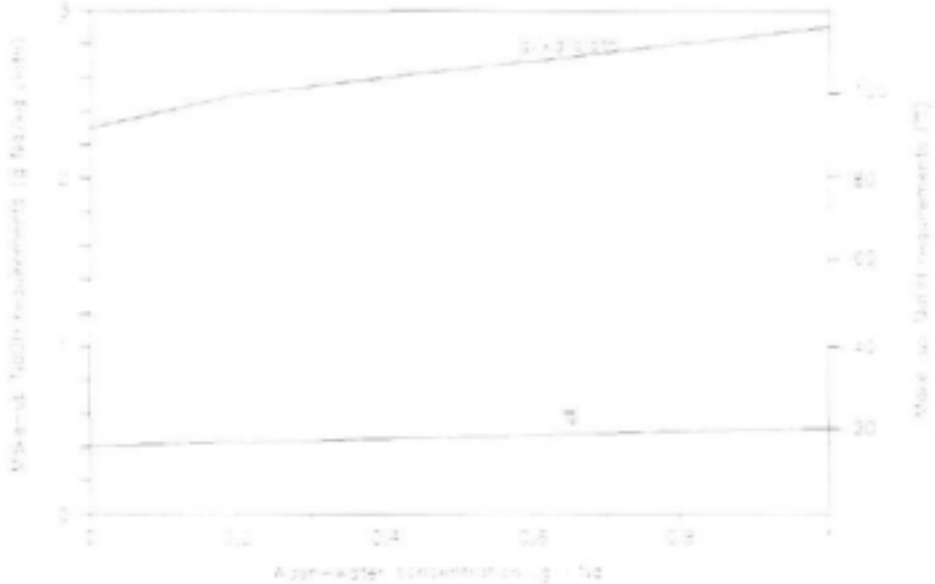


FIGURE 10.21 : DESIGN EXAMPLE: PROCESS CONFIGURATION 2: DEPENDENCE OF SODIUM LOSSES ON WATER CONCENTRATION

11 ECONOMIC EVALUATION

11.1 INTRODUCTION

Cost estimation of treatment plants for scouring effluents is difficult because of the variability of the scouring process, the effluent composition and the extent of treatment required. Additional variables include site development costs, exchange rates for imported equipment, inflation rates and different materials of construction.

This chapter estimates the cost of the implementation of an integrated plant for the electrolytic treatment and recovery of water, chemicals and heat energy from sodium hydroxide cotton scouring effluents as is described in chapters 9 and 10. All cost estimates in this chapter have been presented for guidance purposes only and must be used with caution and judgement.

The cost basis for chemicals and utilities is given in Table 11.1 (1987).

TABLE 11.1
TYPICAL COSTS OF UTILITIES AND CHEMICALS

Utility/Chemical	Cost (1987)
Electricity	R0,05/kWh
Water	R0,80/m^3
Effluent discharge	R0,50/m^3
Heat energy	R1,00/m^3 (20 to 100 °C)
Sodium hydroxide	R800/t 100 % NaOH
Limestone	R0,14/kg

The design parameters on which the economics are based are summarised in Table 11.2 and are the same as those specified for the design example in Chapter 10.

11.2 CAPITAL COST ESTIMATES (1987)

11.2.1 Scouring Equipment Modifications

The capital cost for the installation of additional high-expression nip rollers or vacuum extractors is R50 000 to R80 000 per unit. A minimum of two such devices is recommended :

(i) after the saturator to minimise chemical drag-out,

(ii) after the wash range to minimise impurity and moisture drag-out.

In addition, a third device, installed before the saturator would be advantageous in minimising dilution of the padding sodium hydroxide.

TABLE 11.2
DESIGN PARAMETERS FOR ECONOMIC EVALUATION OF ELECTROCHEMICAL TREATMENT OF STRONG SCOURING EFFLUENTS

Parameter		Value
Scouring padding solution		50 g/ℓ NaOH
Wash-water flow		1,5 ℓ/kg cloth
Moisture carry-over from saturator		0,5 ℓ/kg cloth
Moisture carry-over from wash range		0,5 ℓ/kg cloth
Cloth flow		780 kg/h
Effluent flow		1,2 m^3/h
Process Configuration 1 :	Background Na	5 g/ℓ
	Temperature of electrochemical cell operation	80 °C
Process Configuration 2 :	Evaporation factor	4
	Background Na	0,8 g/ℓ
	Temperature of electrochemical cell operation	80 °C
Operation		20 h/d, 300 d/a

11.2.2 Effluent Treatment Plant

The capital cost of the treatment plant is a function of :

(i) the chemical loading of the effluent,

(ii) the volume and concentration of the effluent. For a given chemical loading, a small volume, high-concentration effluent is desirable in terms of plant size requirements,

(iii) the degree of recovery of chemicals and water,

(iv) the means employed for maintaining an elevated sodium concentration in the anolyte of the electrochemical cell: i.e. either recycling a wash water which is only partially depleted or by using an evaporator to concentrate the raw effluent prior to recovery,

(v) the materials of construction.

Cost estimations of the equipment for the effluent treatment plant are given in Table 11.3. It is assumed that the effluent drainage facilities (sumps, pumps, pipework etc.) are already installed at the factory. The estimations in Table 11.3 may be adapted to predict rough costs of plants in cases where different levels of background sodium concentration in the wash water are used or where the evaporation factors are varied. Section 10.12 summarises the effect of these variables on the total plant size requirements.

TABLE 11.3
PLANT COMPONENT COST ESTIMATION

Component	Basis	Total cost (R)	
		Process configuration 1	Process configuration 2
Storage Tank			
8 hour storage of raw effluent	R1 000/m^3	9 600	9 600
2 hour storage after neutralisation	R1 000/m^3	2 400	1 000
after cross-flow microfiltration	R1 000/m^3	2 400	1 000
after nanofiltration	R1 000/m^3	2 400	1 000
8 hour depleted brine storage	R1 000/m^3	9 000	2 500
8 hour sodium hydroxide storage	R1 000/m^3	1 000	1 000
Evaporation Unit Pumps, heat exchangers, condensors, pipework, valves, coarse screening, centrifuge		-	120 000
Neutralisation Unit Pumps, pipework, valves, absorption column, heat exchanger		15 000	15 000
Cross-flow Microfiltration Unit Pumps, pipework, valves, controllers, manifolds and filter media	R2 000/m^2	52 000	28 000
Nanofiltration Unit Pumps, pipework, valves, controllers, membranes and membrane holders	R2 000/m^2	52 000	18 000
Electrochemical Unit d.c. power supply, pumps, pipework, valves, controllers, electrochemical membrane stack	R40 000/m^2	300 000	240 000
Scouring Machine Modifications High expression nip after saturator High expression nip after wash	R50 000	100 000	100 000
TOTAL		545 800	537 100

11.3 OPERATING COSTS

The finance costs and taxation have not been taken into account in this simplistic analysis.

The main operating costs are summarised in Table 11.4.

TABLE 11.4
OPERATING COST ESTIMATION FOR THE ELECTROCHEMICAL TREATMENT OF STRONG SCOURING EFFLUENTS

Type	Basis	Total annual cost (R)	
		Process configuration 1	Process configuration 2
Chemicals			
Limestone		80	50
Electricity			
Pumping, mixing etc.	0,24 kWh/m^3	430	520
Cross-flow microfiltration	2,2 kWh/m^3	800	200
Nanofiltration	2,5 kWh/m^3	830	200
Electrochemical	3 200 kWh/ton	11 700	14 200
Operation			
Plant	2 % of capital	11 000	11 000
Maintenance			
Absorption column	2 % of capital	300	300
Evaporator	2 % of capital	-	2 400
Cross-flow microfilter	2 % of capital	1 040	560
Nanofilter	2 % of capital	1 040	360
Electrochemical cell	2 % of capital	6 000	4 800
Membrane and Electrode Replacement			
Cross-flow microfilter (3 year)	R50/m^2.a	1 300	700
Nanofilter (3 year)	R150/m^2.a	3 900	1 275
Electromembrane (2 year)	R500/m^2.a	3 750	6 000
Anode (5 year)	R2 000/m^2.a	15 000	12 000
TOTAL		57 170	54 565

11.4 SAVINGS

The potential savings are given in Table 11.5. The calculations are based on the cost of utilities as given in Table 11.1.

The treatment process produces reusable water and chemicals and significant credits are available. The process also enables heat energy to be recovered.

The nett savings are calculated from the total savings minus the total operating costs and these are R84 870 and R101 200 for process configurations 1 and 2 respectively. The pay-back time in years, defined as the total capital cost divided by the nett savings is 6,4 and 5,3 years respectively (no tax or capital charge considerations are assumed).

TABLE 11.5
POTENTIAL SAVINGS

Type	Basis for saving	Total annual savings	
		Process configuration 1	Process configuration 2
Increasing nip expression from 0,8 to 0,5 ℓ/kg after saturator	8,5 g Na/kg cloth	70 960	70 960
Heat usage	R1/m^3	6 000	6 000
Water	R0,80/m^3	4 800	4 800
Effluent discharge	R0,50/m^3	3 000	3 000
Sodium hydroxide	R800/ton	57 200	70 960
	TOTAL	141 960	155 720

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INDEX

APPENDIX 1 : SPREADSHEET OF MASS BALANCE FORMULAE FOR PROCESS CONFIGURATION 1 (See Figure 10.7)

Determinand	Symbol	Unit	Equation
1. WASHING VARIABLES			
Moisture content of cloth into wash range	mi	*l*/kg cloth	Specified
Na conc of moisture on cloth into wash range	ci	g/*l* Na	Specified
Moisture content of cloth out of wash range	mo	*l*/kg cloth	Specified
Na conc of moisture on cloth out of wash range	co	g/*l* Na	Specified
Average cloth mass	fm	kg/m	Specified
Cloth speed	fs	m/h	Specified
Up time of scouring wash range	tm	h/d	Specified
2. TREATMENT PLANT VARIABLES			
Cross-flow microfiltration water recovery	Rc	%	Specified
Nanofiltration water recovery	Rn	%	Specified
Nanofiltration point Na rejection	r	%	Specified
Electrochemical cell current efficiency	E	%	Specified
Electrochemical cell temperature	T	C	Specified
Electrochemical cell water transport number	nw	g/g	$14.6.e^{-0.0629.cs}$
Electrochemical cell electrolyte length	l	m	Specified
Electrochemical cell average catholyte conductivity	CONDC	S/m	Specified
Electrochemical cell decomposition, polarisation and membrane voltage	Vd	V	Specified
Up time of treatment plant	tp	h/d	Specified
3. WASH-WATER AND EFFLUENT CHARACTERISTICS			
Na conc in total wash water	Cq	g/*l* Na	Specified
Total wash-water flow	Q	*l*/kg cloth	Specified
Effluent flow	L1	*l*/kg cloth	Specified
Na conc in effluent	C1	g/*l* Na	Specified

APPENDIX 1 (cont. i)

Determinand		Symbol	Unit	Equation
4. <u>MASS BALANCE CALCULATIONS</u>				
Wash Range :	Mass Na in on cloth	Ni	g/kg cloth	$mi.ci$
	Mass Na out on cloth	No	g/kg cloth	$mo.co$
	Mass Na in effluent	N1	g/kg cloth	$L1.C1$
Cross-flow microfiltration:	Concentrate flow	L2	*l*/kg cloth	$L1(1 - Rc/100)$
	Na conc in concentrate	C2	g/*l* Na	$C1$
	Mass Na in concentrate	N2	g/kg cloth	$L2.C2$
	Permeate flow	L3	*l*/kg cloth	$L1 - L2$
	Na conc in permeate	C3	g/*l* Na	$C1$
	Mass Na in permeate	N3	g/kg cloth	$L3.C3$
Nanofiltration:	Concentrate flow	L4	*l*/kg cloth	$L3(1 - Rn/100)$
	Na conc in concentrate	C4	g/*l* Na	$(N3 - N4)/L4$
	Mass Na in concentrate	N4	g/kg cloth	$L4.C4$
	Permeate flow	L5	*l*/kg cloth	$L3 - L4$
	Na conc in permeate	C5	g/*l* Na	$(C3.100/Rn)(1-(1-Rn/100)^{(1-r/100)})$
	Mass Na in permeate	N5	g/kg cloth	$L5.C5$
Electrochemical cell:	Mass Na in recovered NaOH	N6	g/kg cloth	$N5 - Cq.Q$
	Recovered NaOH	L6	*l*/kg cloth	$N6.nw/1000$
	Na conc in recovered NaOH	C6	g/*l* Na	$N6/L6$
	Depleted brine flow	L7	*l*/kg cloth	$L5 - L6$
	Na conc in depleted brine	C7	g/*l* Na	$(N5 - N6)/L7$
	Mass Na in depleted brine	N7	g/kg cloth	$C7.L7$
Make-up Na as NaOH		N8	g/kg cloth	$N0 + N2 + N4$
Make-up water		L8	*l*/kg cloth	$Q - L7$

APPENDIX 1 (cont. ii)

Determinand	Symbol	Unit	Equation
5. Na LOSSES			
Na loss from drag-out	loss 1	%	$N0.100/Nt$
Na loss in cross-flow microfiltration concentrate	loss 2	%	$N2.100/Nt$
Na loss in nanofiltration concentrate	loss 3	%	$N4.100/Nt$
Na loss from system	S	%	$N8.100/Nt$
Savings on existing Na make-up	N9	g/kg cloth	$N1 - N8$
		%	$N9.100/N1$
6. WATER LOSSES			
Water loss from system	W	%	$L8.100/Q$
Savings on existing water make-up	L9	*l*/kg cloth	$L1 - L8$
		%	$L9.100/L1$
7. ELECTROCHEMICAL UNIT OPERATING PARAMETERS			
Maximum anolyte conductivity	CONDA1	S/m	Equation 9.14/1000
Minimum anolyte conductivity	CONDA2	S/m	Equation 9.14/1000
Maximum limiting current density	CD1	A/m^2	$2.6.CONDA1.1000$
Minimum limiting current density	CD2	A/m^2	$2.6.CONDA2.1000$
Average limiting current density	CD3	A/m^2	$(CD1 + CD2)/2$
Minimum anolyte volt drop	VA1	V	$i.CD1/CONDA1$
Maximum anolyte volt drop	VA2	V	$i.CD2/CONDA2$
Average anolyte volt drop	VA3	V	$(VA1 + VA2)/2$
Average catholyte volt drop	VC	V	$i.CD3/CONDC$
Average cell potential	Vc	V	$VC + VA3 + Vd$
Electrical requirements	F	F/kg cloth	$N6/(23.E/100)$
8. ELECTROCHEMICAL UNIT AREA AND POWER REQUIREMENTS			
Specific area requirements	As	m^2/kg cloth	$26.8.F/(tp.CD3)$
Total area requirements	At	m^2	$As.fm.fs.tm$
Power requirements for NaOH production	P	kWh/t NaOH	$23000.CD3.At.Vc/N6.fm.fs.40$

APPENDIX 2 : SPREADSHEET OF MASS BALANCE FORMULAE FOR PROCESS CONFIGURATION 2

Determinand		Symbol	Unit	Equation
1.	WASHING VARIABLES			
	Moisture content of cloth into wash range	mi	*l*/kg cloth	Specified
	Na conc of moisture on cloth into wash range	ci	g/*l* Na	Specified
	Moisture content of cloth out of wash range	mo	*l*/kg cloth	Specified
	Na conc of moisture on cloth out of wash range	co	g/*l* Na	Specified
	Average cloth mass	fm	kg/m	Specified
	Cloth speed	fs	m/h	Specified
	Up time of scouring wash range	tm	h/d	Specified
	Total wash-water flow	Q	*l*/kg cloth	Specified
	Na conc in total wash water	Cq	g/*l* Na	Specified
	Effluent flow	L1	*l*/kg cloth	Specified
	Na conc in effluent	C1	g/*l* Na	Specified
2.	TREATMENT PLANT VARIABLES			
	Evaporator concentration factor	ECF	times	Specified
	Evaporator condensate concentration	Ce	g/*l* Na	Specified
	Evaporator sludge volume	SV	%	Specified
	Total Na in evaporator sludge	SN	%	Specified
	Cross-flow microfiltration water recovery	Rc	%	Specified
	Nanofiltration water recovery	Rn	%	Specified
	Nanofiltration point Na rejection	r	%	Specified
	Electrochemical cell current efficiency	E	%	Specified
	Electrochemical cell temperature	T	C	Specified
	Electrochemical cell water transport number	nw	g/g	$14,6.e^{-0.0679.t5}$
	Electrochemical cell electrolyte length	*l*	m	Specified
	Electrochemical cell average catholyte conductivity	CONDC	S/m	Specified
	Electrochemical cell decomposition, polarisation & membrane voltage	Vd	V	Specified
	Up time of treatment plant	tp	h/d	Specified

APPENDIX 2 (cont. i)

Determinand		Symbol	Unit	Equation
3. <u>MASS BALANCE CALCULATIONS</u>				
Wash range:	Mass Na in on cloth	Ni	g/kg cloth	$mi.ci$
	Mass Na out on cloth	No	g/kg cloth	$mo.co$
	Mass Na in effluent	Nl	g/kg cloth	$Ll.Cl$
Evaporator:	Concentrate and sludge flow	Ls	*l*/kg cloth	Ll/ECF
	Mass Na in concentrate and sludge	Ns	g/kg cloth	Nl
	Concentrate and sludge concentration	Cs	g/*l* Na	NS/LS
	Concentrate flow	Le	*l*/kg cloth	$LS(1-SN/100)$
	Mass Na in concentrate	Ne	g/kg cloth	$NS(1-SN/100)$
	Concentrate concentration	Ce	g/*l* Na	Ne/Le
	Condensate flow	Lc	*l*/kg cloth	$Ll-Le$
	Mass Na in condensate	Nc	g/kg cloth	$Cc.Lc$
Cross-flow microfiltration:	Concentrate flow	L2	*l*/kg cloth	$Le(1-Rc/100)$
	Na conc in concentrate	C2	g/*l* Na	Ce
	Mass Na in concentrate	N2	g/kg cloth	$L2.C2$
	Permeate flow	L3	*l*/kg cloth	$Le-L2$
	Na conc in permeate	C3	g/*l* Na	Ce
	Mass Na in permeate	N3	g/kg cloth	$L3.C3$
Nanofiltration:	Concentrate flow	L4	*l*/kg cloth	$L3(1-Rn/100)$
	Na conc in concentrate	C4	g/*l* Na	$(N3-N5)/L4$
	Mass Na in concentrate	N4	g/kg cloth	$L4.C4$
	Permeate flow	L5	*l*/kg cloth	$L3-L4$
	Na conc in permeate	C5	g/*l* Na	$(C3.100/Rn)(1-(1-Rn/100)^{(1-r/100)})$
	Mass Na in permeat	N5	g/kg cloth	$L5.C5$

APPENDIX 2 (cont. ii)

Determinand			Symbol	Unit	Equation
	Electrochemical cell:	Mass Na in recovered NaOH	N6	g/kg cloth	$N5 - Q.Cq - Ne$
		Recovered NaOH flow	L6	*l*/kg cloth	$N6.nw/1000$
		Na conc in recovered NaOH	C6	g/*l* cloth	$N6/L6$
		Depleted brine flow	L7	*l*/kg cloth	$L5 - L6$
		Na conc in depleted brine	C7	g/*l* cloth	$(N5 - N6)/L7$
		Mass Na in depleted brine	N7	g/kg cloth	$C7.L7$
	Make-up Na as NaOH		N8	g/kg cloth	$N0 + N2 + N4$
	Make-up water		L8	*l*/kg cloth	$Q - L7 - Lc$
4.	<u>Na LOSSES</u>				
	Na loss in evaporator sludge		loss0	%	$(N5 - Ne)/Nt$
	Na loss from drag-out		loss1	%	$N0.100/Nt$
	Na loss in cross-flow microfiltration concentrate		loss2	%	$N2.100/Nt$
	Na loss in nanofiltration concentrate		loss3	%	$N4.100/Nt$
	Na loss from system		S	%	$N8.100/Nt$
	Savings on existing Na make-up		N9	g/kg cloth %	$Ni - N8$ $N9.100/Nt$
5.	<u>WATER LOSSES</u>				
	Water loss from system		W	%	$L8.100/Q$
	Savings on existing water make-up		L9	*l*/kg %	$Q - L8$ $L9.100/Q$

APPENDIX 2 (cont. iii)

Determinand	Symbol	Unit	Equation
6. <u>ELECTROCHEMICAL UNIT OPERATING PARAMETERS</u>			
Maximum anolyte conductivity	CONDA1	S/m	Equation 9.14/1000
Minimum anolyte conductivity	CONDA2	S/m	Equation 9.14/1000
Maximum limiting current density	CD1	A/m^2	$2.6.CONDA1.1000$
Minimum limiting current density	CD2	A/m^2	$2.6.CONDA2.1000$
Average limiting current density	CD3	A/m^2	$(CD1+CD2)/2$
Minimum anolyte volt drop	VA1	V	$l.CD1/CONDA1$
Maximum anolyte volt drop	VA2	V	$l.CD2/CONDA2$
Average anolyte volt drop	VA3	V	$(VA1+VA2)/2$
Average catholyte volt drop	VC	V	$l.CD3/CONDC$
Average cell potential	Vc	V	$Vd+VC+VA3$
Electrical requirements	F	F/kg cloth	$N6/(23.E/100)$
7. <u>ELECTROCHEMICAL UNIT AREA AND POWER REQUIREMENTS</u>			
Specific area requirements	As	m^2/kg cloth	$26.8.F/(tp.CD3)$
Total area requirements	At	m^2	$As.fm.fs.tm$
Power requirements for NaOH production	P	kWh/t NaOH	$(23000.CD3.At.Vc)/(N6.fm.fs.40)$

APPENDIX 3 : COMPARISON OF SODIUM HYDROXIDE CONCENTRATION UNITS USED IN THE TEXTILE INDUSTRY

Conversion of Hydrometry Units

The following formulae can be used to convert specific gravity (SG) to degree Baume (°Bé) and vice versa, for liquids heavier than water :

$$^{\circ}Bé = \frac{144.38(SG-1)}{SG}$$

$$SG = \frac{144.38}{144.38 - {^{\circ}Bé}}$$

The formulae are only exact for comparison at 15 °C.

Example 1 : What is the specific gravity of a 32,6 °Bé sodium hydroxide at 15 °C?

Calculation :

$$SG = \frac{144.38}{144.38-32.6} = 1.29$$

The following formulae convert specific gravity and °Twaddell (°Tw)

$$^{\circ}Twaddell = (SG-1) \times 200$$

$$SG = 1 + \frac{(^{\circ}Tw \times 5)}{1\,000}$$

Example 2 : What is the specific gravity of 100°Tw sodium hydroxide?

Calculation :

$$SG = 1 + \frac{100 \times 5}{1\,000} = 1.5$$

Table to Convert SG to °Bé or °Tw

°Be	SG	°Tw	°Bé	SG	°Tw	°Be	SG	°Tw
0	1	0	24	1,20	40	41	1,40	80
3	1,02	4	26	1,22	44	43	1,42	84
6	1,04	8	28	1,24	48	44	1,44	88
8	1,06	12	30	1,26	52	46	1,46	92
11	1,08	16	32	1,28	56	47	1,48	96
13	1,10	20	33	1,30	60	48	1,50	100
15	1,12	24	35	1,32	64	49	1,52	104
18	1,14	28	37	1,34	68	51	1,54	108
20	1,16	32	38	1,36	72	52	1,56	112
22	1,18	36	40	1,38	76	53	1,58	116

Note : This table is valid only at 15 °C. °Bé values have been approximated to nearest whole number.

Specific Gravity and Concentration of Sodium Hydroxide Solutions (20 °C)

SG	°Bé	°Tw	Concentration of Sodium Hydroxide	
			% w/w	g/ℓ
1,000	0	0	1,05	10,6
1,050	6,7	10	4,66	48,9
1,100	13,0	20	9,19	101,1
1,150	18,8	30	13,73	157,9
1,160	19,8	32	14,64	169,8
1,170	20,9	34	15,54	181,8
1,180	22,0	36	16,44	194,0
1,190	23,0	38	17,35	206,4
1,200	24,0	40	18,26	219,0
1,210	25,0	42	19,61	231,8
1,220	26,0	44	20,07	244,9
1,230	26,9	46	20,98	258,0
1,240	27,9	48	21,90	271,5
1,250	28,8	50	22,82	285,2
1,260	29,7	52	23,28	299,0
1,270	30,6	54	24,65	312,9
1,280	31,5	56	25,56	327,1
1,290	32,4	58	26,48	341,6
1,300	33,3	60	27,41	256,2
1,310	34,2	62	28,33	371,1
1,320	35,0	64	29,26	386,2
1,330	35,8	66	30,20	401,6
1,340	36,6	68	31,14	417,2
1,350	37,4	70	32,10	433,2
1,360	38,2	72	33,06	449,6
1,370	39,0	74	34,03	466,0
1,380	39,8	76	35,01	483,2
1,390	40,5	78	36,00	500,4
1,400	41,2	80	36,99	518,0
1,410	42,0	82	37,99	535,6
1,420	42,7	84	38,99	553,6
1,430	43,4	86	40,00	572,0
1,440	44,1	88	41,03	590,8
1,450	44,8	90	42,07	610,0
1,460	45,4	92	43,12	629,6
1,470	46,1	94	44,17	646,2
1,480	46,8	96	45,22	669,2
1,490	47,4	98	46,27	698,2
1,500	48,1	100	47,33	710,0
1,510	48,7	102	48,30	730,4
1,520	49,4	104	49,44	751,2
1,530	50,0	106	50,50	772,4