A GUIDE FOR THE PLANNING, DESIGN AND IMPLEMENTATION OF WASTEWATER TREATMENT PLANTS IN THE TEXTILE INDUSTRY

PART ONE: Closed Loop Treatment/ Recycle System for Textile Sizing/Desizing Effluents

Prepared for the

WATER RESEARCH COMMISSION

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Foreword

That the Republic is a water-scarce country is evident from the country's water balance: the maximum available resources per annum amount to 34 000 million cubic metres, with present usage about 12 000 million cubic metres. It is estimated that the rapid growth in water demand will result in all available supplies being utilised by the year 2020 — 2030.

Simultaneous with the growth in demand the country is facing an increase in water pollution — the quality of the water returned to rivers and streams is deteriorating. Unless research is done on a national basis to combat pollution and to achieve maximum production per unit volume of water used, a serious breakdown in water supply will result.

Estimates are that industrial and domestic use will account for 35% of the available supplies by the turn of the century. Water economy in industry may become a determining factor in the allocation of additional fresh water supplies to industry.

Since its inception in 1971 the Water Research Commission (WRC) has given active attention to problems in the field of water supply, optimal water usage, effluent treatment and effluent reclamation, and the formulation of master plans and national priority research and development programmes to find solutions to these problems. In the textile industry this is of vital importance since the industry is a major one in the Republic with more than six hundred factories which support approximately a quarter of a million people in the textile and clothing manufacturing sectors. At the same time the textile industry is a large user of water (typically 200 to 400 litres are needed to produce 1 kg of fabric), and its concomitant effluent discharges create many problems in terms of water quality protection.

The main objectives with the research carried out on water and effluent problems in the textile industry were to optimise processes for increasing the efficient use of water, *i.e.* to effect maximum production per unit volume of water by ensuring maximum re-use of water, and the re-use and recovery of chemicals to reduce pollution. Technologies so developed will be made available to industry by way of guides for the planning, design and operation of treatment processes.

The research was carried out on behalf of the WRC by the Pollution Research Group of Natal University, Chemical Engineering Department, a centre of expertise recognised internationally as a major contributor to the research and application of advanced industrial effluent treatment and re-use processes.

This Guide contains the results of research relating specifically to the sizing/desizing process in the textile industry. It is the first in a series which will also cover wool washing, dyeing/printing and scouring/bleaching.

I trust the Guide will serve its intended purpose in providing decision makers, planners and engineers with the basic information needed to assist them in arriving at rational decisions when considering and implementing waste water treatment schemes in the textile industry.

MR HENZEN
CHAIRMAN: WATER RESEARCH COMMISSION

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The research and development investigations were guided by the Coordinating Research and Development Committee for the Textile Industry and the Management Committee for the Project.

Summary

This Technical Guide describes the application of closed loop recycle technology to the sizing/desizing effluent from cotton/synthetic fibre cloth production.

A pilot-plant project, sponsored by the Water Research Commission, was carried out at a textile factory during the period 1979-82. The pilot-plant consisted of a high temperature, spiral-wrap ultrafiltration system which processed about 20% of the desizing effluent from the factory. The permeate (product water) was recycled to desizing and the concentrate containing the recovered sizing agent was returned to sizing for reuse.

The project consisted of several task areas:

- (i) selection of a polymeric sizing agent which was reusable
- (ii) factory weaving trials on the virgin sizing agent and the recovered sizing agent to determine the weaving efficiency
- (iii) demonstration of a practical treatment/recycle system
- (iv) determination of the effect of the major variables of the treatment/recycle system
- (v) evaluation of the performance of the treatment/recycle system
- (vi) determination of the economics of the system
- (vii) development of a process design for full-scale treatment/recycle systems.

The traditional sizing agent, starch, was found to be unsuitable for recycle purposes because of the need for enzyme degradation prior to desizing. Polyacrylate sizes, although recoverable, were found to have poor weaving characteristics. Polyvinyl alcohol (PVA) size was recoverable and gave excellent sizing and weaving performance on reuse. Long term factory weaving trials showed that a very high percentage of cloth types found in the industry were suitable for sizing and weaving with both virgin PVA and recovered PVA size.

A survey of the treatment methods available for desizing effluent indicated that ultrafiltration was the most applicable method. High temperature, spiral-wrap membranes were chosen for the duty because of their cost effectiveness, power requirements and operability. The ultrafiltration pilot-plant was constructed and operated over a three year period at a textile factory site. The installed membrane area was 100 m^2 which allowed the processing of about 0,5 — 0,75 m^3/h of effluent. The membrane system was operated in both the series-taper mode and the batch concentration mode. No significant differences between the two configurations were found and it is recommended that the batch mode be used for smaller plants and the series-taper mode for larger plants.

Prefiltration of the effluent to remove lint was found to be the most difficult technical aspect of the project. A treatment sequence such as screening, backwashable candle filtration and cartridge filtration was found to be suitable and cost effective.

Investigations into the efficiency of desizing washing ranges showed that considerable variation exists in the industry. For fairly efficient countercurrent washers (washing efficiency parameter of about 0,25), PVA size removal from the cloth of over 95% is achievable at water usages of about 5 ℓ/kg of cloth. This loss is acceptable and together with a loss of about 10% during the dry processing stages between sizing and desizing, gives an overall loss of about 15% of that originally added in sizing. The PVA size left on the cloth after desizing has not caused any problems in down-stream processing.

The ultrafiltration membrane flux (volume of permeate produced per unit membrane area per unit time) is mainly dependent on the initial PVA concentration, the concentration factor needed for size reuse, temperature, degree of membrane fouling, pressure and reject flow rate.

For a given factory duty, the desizing water usage and the size add-on for the production types deter-

mine the initial PVA concentration of the effluent and the concentration factor needed. The pilot-plant results show that the membranes should be operated at their inlet pressure and temperature limits. Thus the degree of fouling and reject flow rate are the operating parameters that may be optimised.

A mathematical model was developed for this purpose and it was found that the membranes should be operated in the gel-polarised region. The relationship between flow velocity and pressure drop through the membrane was important in optimising the average membrane flux for the concentration duty required.

The efficient removal of lint is essential for successful operation of the ultrafiltration membranes and the degree of membrane fouling may be controlled by regular chemical cleaning. A membrane life-time of over three years may be expected.

A detailed economic analysis is presented for the range of textile mills found in South Africa. The effects of washer type, size add-on, production level and membrane optimisation are determined. The capital payback times are in the range 0,5 to 1,0 years.

The advantages of the incorporation of a desizing effluent ultrafiltration system into a cotton/synthetic fibre textile mill are:

(i) water usage in sizing/desizing is reduced to about 1-2 ℓ/kg of cloth processed. This is the moisture carry-over of cloth leaving desizing.

(ii) effluent production is minimal. Desizing COD and total solids loads are reduced by 84 g/kg of cloth and 90 g/kg respectively to a COD of 5 g/kg and a total solids of 5g/kg. This represents reductions in COD and total solids in the wet preparation section of about 65% and 31% respectively and for the total mill of about 20% and 11% respectively.

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

(iv) large chemical savings in terms of recycled size and significantly reduced enzyme consumption.

Thus, the treatment and recycle of desizing effluents by ultrafiltration has been shown to be both practical and economic. The use of this treatment technology by cotton/synthetic fibre textile mills will have a significant impact on effluent discharges and will result in major cost savings.

The Guide provides the necessary information for the planning, design and implementation of the ultrafiltration system for the treatment and recycle of textile sizing/desizing effluents. It is intended for use by the policy makers of the Textile Industry and to cater for the practical needs of design engineers, consultants and executive bodies.

Contents

Textile Terminology

Beam	A roller on which warp yarn is wound, back beams after sizing become weaver's beams
Carding	An operation during which raw fibres are cleaned and aligned
Cropping	The shearing of the surface of the fabric
Drill	A type of weave
Easy care	A finish applied to cloth to resist staining, creasing etc
Greige	Woven cloth which has not had any further processing
Handle	The feel of the cloth
Mercerising	The treatment of cotton fabric with cold concentrated sodium hydroxide to impart sheen and to improve the water absorbtion
Opening	The breaking open of raw cotton bales
Palladin	A type of weave
Sateen	A type of weave
Scouring	The removal of waxes and pectins from cotton by treatment with hot sodium hydroxide
Singe	The burning of the surface hairs from fabric
Size	A coating applied to warp yarn to improve its weaving efficiency
Sizing (Slashing)	The application of size to the warp yarn
Tex	A measure of the thickness of yarn; the mass per 10 000 m of yarn
Twill	A type of weave
Warp	The longitudinal threads in a length of fabric
Weft	The threads inserted into the warp by a loom

Abbreviations

ADMI	American Dyestuff Manufacturers Institute
BOD_5	Biological Oxygen Demand (5 day test)
C-C	Counter Current wash range
Co	Cotton yarn or fabric
COD	Chemical Oxygen Demand
CMC	Carboxymethyl Cellulose based sizes
OA	Oxygen Absorbed
PAA	Polyacrylic Acid based sizes
PE	Polyester yarn or fabric
PVA	Polyvinyl Alcohol based sizes
TC	Total Carbon
TCE	Tetrachloroethylene
TS	Total Solids
TSS	Total Suspended Solids
UF	Ultrafiltration
WRC	Water Research Commission

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Chapter 1

PLANNING FOR INDUSTRIAL WASTEWATER REUSE AND RECLAMATION

South Africa is a relatively arid country with an average rainfall of under 500 mm compared to a world average of 860 mm. The distribution of rainfall is uneven and about one third of the country receives an annual rainfall of less than 300 mm.

It is estimated that South Africa's total water credit is 34 000 million m^3/a. Present usage is 12 000 million m^3 but demand is rising rapidly and projections indicate that supply and demand will be equal by the year 2020 (1).

The effective use of fresh water supplies is being impaired through quality deterioration brough about by the discharge of partially treated wastewaters and pollution from non-point sources. Industry, in general, discharges many substances which are resistant to degradation by conventional biological treatment and the self-purification processes of the water environment. Wastewaters containing intractable, toxic or carcinogenic substances should not be permitted to enter clean water supplies or water reclamation systems.

The Commission of Enquiry (2) into Water Matters estimated that 8 700 million m^3/a could be saved by improved utilisation of irrigation water (17%) and by water reclamation and reuse schemes (83%). The ratio of industrial to domestic water usage is about 60:40. For these reasons, it is evident that, in the future, industry has a major role to play in the South African water economy.

Water reclamation and reuse can be achieved in three main ways:

(i) water recycling
(ii) reclamation of industrial wastewaters
(iii) reclamation of sewage for use in
  (a) irrigation
  (b) cooling systems
  (c) industrial use
  (d) potable supply systems

1.1 THE SUPPLY OF WATER TO INDUSTRY

Water Act No. 54 of 1956 makes provision for the intake quantities of public water for municipal, urban and industrial purposes, and the siting of industries using water, to be strictly controlled. The Act is administered by the Department of Environment Affairs and Fisheries, in consultation with the Department of Health and the South African Bureau of Standards.

1.1.1 Section 12 Provisions

Any industrialist wishing to start a new industry must apply for a permit if he intends using more than an average of 250 m^3 per day (recently reduced to 150 m^3/d) or a maximum quantity of more than 300 m^3 on any one day of public water for industrial purposes. All industrialists must advise the Department as to how they propose to purify their effluent.

Water abstracted for industrial (including municipal) use must be returned as far as it is practically feasible, undiminished in quantity, to the stream of its origin after it has been purified to prescribed standards.

Embodied in the Water Act is the philosophy that:

(i) purification of effluent is considered to be part of the industrial process, and
(ii) the industrial activities of the upstream user should not be to the detriment of the downstream user.

In this way it is endeavoured to obtain maximum use from the country's limited water resources.

1.2 EFFLUENT DISCHARGE BY INDUSTRY

The disposal of industrial effluents may be managed by three main methods.

(i) discharge to public streams
(ii) discharge to municipal sewers
(iii) industry based treatment and recycle

1.2.1 Discharge to Public Streams (Section 21 of the Water Act)

The purification of wastewater resulting from the use of water for industrial purposes is considered to be part of the industrial process.

The standards that must be achieved are prescribed by the Department of Environment Affairs and Fisheries and comprise

(i) a general standard
(ii) special standards for specified streams, specified areas and for specified industrial processes.

Table 1.1 summarises these discharge regulations.

1.2.1.1 EXEMPTION FROM COMPLIANCE

Section 21(5) of the Water Act covers the case where it would be impractical for an industry to purify its effluent to the prescribed standard.

After careful consideration, the Minister of Environment Affairs and Fisheries may grant permits of exemption from the standards and from the stipulation that water abstracted be returned to the stream of origin. The degree of exemption must be specified and the point of discharge must be such that no other person will be prejudically affected.

An exemption permit is subject to revision, modification or cancellation by a Water Court to whom any interested person may apply. The Minister may withdraw or amend the permit at any time by notice in writing to the permit holder.

1.2.1.2 SEA DISCHARGES

Sea discharges are also covered by the provisions of the Sea Shore Act.

1.2.2 Discharge to Municipal Sewers

The municipalities may accept industrial effluents into their sewerage systems and sewage works. The responsibility for effluent purification and disposal then rests with the municipality. The municipal use of water is, under the terms of the Water Act, classed as an industrial use and hence all municipal discharges must comply with the relevant standards.

The municipalities promulgate their own discharge regulations with which industry must comply and charge tariffs for accepting industrial effluent. Examples of municipal discharge regulations are given in Table 1.2.

The discharge regulations endeavour to ensure that the municipal sewage works are not overtaxed or put out of order. They are indicative of the amount of pretreatment required by industry to ensure treatability at the sewage works and allow compliance with the discharge standards.

TABLE 1.1 GENERAL AND SPECIAL STANDARDS FOR DISCHARGE IN TERMS OF THE SOUTH AFRICAN WATER ACT, ACT NO. 54 OF 1956

Parameter	General Standard	Special Standard
Colour, odour, taste	nil	nil
pH	5,5 – 9,5	5,5 – 7,5
Dissolved Oxygen (%)	>75	>75
Temperature (°C)	≯35	≯25
Typical Faecal Coliforms (per 100 mℓ)	nil	nil
Chemical Oxygen Demand (mg/ℓ)	≯75	≯30
Oxygen Absorbed (mg/ℓ)	≯10	≯ 5
Total Dissolved Solids	≯500 mg/ℓ above intake	≯15% above intake
Suspended Solids (mg/ℓ)	≯25	≯10
Sodium (mg/ℓ)	≯90 above intake	≯50 above intake
Soap, oil and grease (mg/ℓ)	≯2,5	nil
Residual Chlorine – as Cl (mg/ℓ)	≯0,1	nil
Free and Saline ammonia – as N (mg/ℓ)	≯10	≯ 1
Nitrate – as N (mg/ℓ)	not specified	≯1,5
Arsenic (mg/ℓ)	≯0,5	≯0,1
Boron (mg/ℓ)	≯1,0	≯0,5
Chromium – total (mg/ℓ)	≯0,5	≯0,05
Copper (mg/ℓ)	≯1,0	≯0,02
Phenol (mg/ℓ)	≯0,1	≯0,01
Lead (mg/ℓ)	≯1,0	≯0,1
Copper (mg/ℓ)	≯0,5	≯0,02
Sulphides – as S (mg/ℓ)	≯1,0	≯0,05
Fluorine (mg/ℓ)	≯1,0	≯1,0
Zinc (mg/ℓ)	≯5,0	≯0,3
Phosphate – total as P (mg/ℓ)	not specified*	2,0**
Iron (mg/ℓ)	not specified	≯0,3
Manganese (mg/ℓ)	not specified	≯0,1
Cyanide – as CN (mg/ℓ)	not specified	≯0,5

*In terms of Government Notice No. 7159 of 1 August 1980, effluents draining to certain sensitive areas must have soluble orthophosphate (as P) concentrations of less than 1,0 mg/ℓ.

**In terms of Government Notice No. 7159 of August 1980 this figure has been amended to not greater than 1 mg/ℓ of soluble orthophosphate (as P).

TABLE 1.2 COMPARISON OF MUNICIPAL DRAINAGE REGULATIONS WITH WATER ACT 'GENERAL STANDARD'

	Water Act No. 54, 1956	City drainage by-laws			
	General Standards	Johannesburg	Pretoria	Durban	Cape Town
pH	5,5 – 9,5	>6,0	6–10	>6,0	5,5 – 12,0
Faecal coli	Nil	N.S.	N.S.	N.S.	N.S.
Dissolved O_2	>75%	N.S.	N.S.	N.S.	N.S.
Temperature	≯35°C	N.S.	N.S.	43°C	43°C
Chemical oxygen demand (COD)	75	N.S.	5 000	N.S.	N.S.
4 h OA	10	1 400	200	N.S.	N.S.
TDS	] Not increasing to] more than 500] above intake	N.S.	2 000	N.S.	1 000 – 2 000
Electrical conductivity (mS/m)	N.S.	500	N.S.	N.S.	300 – 500
Suspended solids	max. 25	N.S.	600	2 000	1 000
Sodium (as Na)	] Not more than] 90 above intake	N.S.	N.S.	N.S.	N.S.
Soap, oil and grease	max. 2,5	N.S.	400	50	400
Substances not in solution (incl. fat, oil, grease, waxes, etc.)	N.S.	2 000	N.S.	N.S.	N.S.
Substances soluble in petroleum ether	N.S.	500	N.S.	N.S.	N.S.
Chlorides	N.S.	N.S.	N.S.	1 000	N.S.
Free Cl	max. 0,1	100	N.S.	N.S.	N.S.
Free and saline NH_3	10	N.S.	N.S.	N.S.	N.S.
Silver (as Ag)	N.S.	N.S.	Nil	N.S.	N.S.
Iron (as Fe)	N.S.	]	N.S.	N.S.	N.S.
Chromium (as Cr)	0,5	] total concen-	20	50]	
Copper (as (Cu)	1,0	] tration of all	20	50]	
Nickel (as Ni)	N.S.	] metals 50;	20	50]	
Zinc (as Zn)	5,0	] individual	20	50]	total not
Cadmium (as Cd)	N.S.	] metal 20	20	50]	to exceed
Arsenic (as As)	0,5	]	N.S.	N.S.]	50
Boron (as B)	1,0	] total of all	N.S.	N.S.]	
Lead (as Pb)	1,0	] metals 20;	N.S.	N.S.]	
Selenium (as Se)	N.S.	] individual	N.S.	N.S.]	
Mercury (as Hg)	.N.S.	] metal 5	N.S.	N.S.]	
Sulphides (as S)	1,0	50	25	50	50
Fluorides (as F)	1,0	5	N.S.	N.S.	N.S.
Phenols	0,1	N.S.	N.S.	N.S.	N.S.
Formaldehyde	N.S.	50	N.S.	N.S.	N.S.
Cyanides (as CN)	0,5	20	10	20	20
Total sugars and starch	N.S.	1 500	N.S.	1 500	1 500
Tar and tar oils not soluble in water	N.S.	N.S.	60	60	60
Calcium carbide	N.S.	Nil	Nil	Nil	Nil
Total sulphates	N.S.	1 800	300	200*	500

N.S. = Not specified
Units = mg/ℓ

*Sulphate in solution

1.2.3 Industry Based Recycling and Reclamation

Industry based reclamation and reuse of their wastewaters has the advantage that undesirable pollutants are not discharged into the water environment as they are removed at source. The wastewaters in a factory are fairly well-defined and being relatively concentrated, a wide range of separation techniques and treatment methods may be applied. In addition the recovery of process chemicals, by-products and heat energy is achievable in many instances.

Examples of industry based recycling and reclamation are:

(i) direct reuse of non-contaminated process water; for example, cooling water to general factory use.

(ii) cascading of process water used on a high quality process to another process requiring only low quality water; for example, final rinses to first rinse operation.

(iii) treatment of a wastewater from one source for reuse in another process; for example, removal of suspended solids.

(iv) closed loop treatment and recycle of wastewater from a particular source for direct reuse in the process. This is often accompanied by recovery of process chemicals, by-products and heat energy.

(v) end-of-line mixed factory effluent treatment and reuse.

1.2.4 Future Trends

Municipalities planning sewage reclamation schemes will have to assess critically their industrial effluents in order to preclude those pollutants that are undesirable. In general it can be expected that municipal discharge regulations will be tightened especially with respect to colour, dissolved salts, heavy metals and intractable organic compounds.

The Water Act is in the process of revision and it can be expected that:

(i) discharge conditions will become more strict

(ii) exemption permits will be examined critically in the light of new technology

(iii) new dams, water works, reticulation systems and sewage works will have to become self-financing resulting in higher charges for fresh water and effluent discharge.

In longer term, the introduction of a Water Levy Act is being considered (3). This proposes that dischargers pay a levy based on the number of "harmfulness units" present in their annual discharge. The progressively increasing levy is aimed at providing an economic incentive to improve effluents and to facilitate long term economic planning.

Chapter 2

TEXTILE INDUSTRY POLLUTION MANAGEMENT

2.1 INTRODUCTION

With the future need to safeguard the quality of fresh water supplies and reduce fresh water usage by the introduction of reclamation schemes, the control of industrial discharges will become of great importance. In many instances the wastes that industry discharges to the sewers are detrimental to the production of a high quality reclaimed water.

2.1.1 Industrial Use of Water

Industry requires water for:

Process water	Steam generation
Product washing	Air conditioning
Plant and equipment washing	Transport of materials
	Personnel consumption
Cooling systems	and sanitation.

Steam generation, air conditioning, human consumption and certain stages in the production of textiles and other industries require water of potable or higher quality as given in Table 2.1 (4), while a water of lower quality may be employed for other uses.

Typical water usage figures (5) for various industries are given in Table 2.2.

2.1.2 Industrial Waste Discharges

Table 2.3 illustrates the range of wastewater contaminants produced from industry (4). The type, number and concentration of undesirable compounds depends on the industrial process. Many of these pollutants resist degradation by the self-purification processes of the water environment as well as the controlled environment of the conventional biological treatment works and eventually find their way into potable water supplies.

2.1.3 The Need for Pollution Control in the Textile Industry

Textile processing plants utilise a wide variety of dyes and other chemicals such as acids, bases salts, detergents, wetting agents, sizes, stripping agents and finishes. Many of these are not retained in the final product and are discharged in the effluent. Typical textile processing water usage is 150 - 1 400 litres per kilogram of product (6,7) and hence large volumes of textile effluents have to be disposed of in South Africa.

TABLE 2.1 MAXIMUM PERMISSIBLE CONCENTRATIONS IN HIGH-QUALITY WATER FOR SPECIFIC INDUSTRIAL USES (All values in mg/ℓ except colour)

	Textiles	Viscose Pulp	Fine Paper Pulp	Plastics
Colour (platinum)	0 – 20	5	5	2
Hardness as $CaCO_3$	0 – 20	8	100	N.S.
Alkalinity	N.S.	50	75	N.S.
Total solids	N.S.	100	250	200
Turbidity (SiO_2)	3 – 27	5	10	2
Fe	0,1 – 1,0	0,0005 – 0,05	0,01	0,02
Mn	0,05 – 1,0	nil – 0,03	0,05	0,02
Fe + Mn	0,05 – 1,0	–	0,05	0,02

N.S. = Not Specified

TABLE 2.2 INTAKE WATER USE PER UNIT PRODUCED

Process		Water intake per unit
Kraft pulp, unbleached grade		12 to 15 m^3/t
NSSC pulp, unbleached grade		10 to 12 m^3/t
Linerboard, fluting paper	on paper machine	13 to 17 m^3/t
Newsprint, fine paper	on paper machine	17 to 30 m^3/t
Cardboard	on paper machine	1,5 to 22 m^3/t
Steel		4 to 200 m^3/t
Breweries		8 to 13ℓ/ℓ of product
Milk powder		Nil to 18 m^3/t
Cotton, wet processing		80 to 600 m^3/t
Wool washing		7 to 40 m^3/t
Wool, dyeing and finishing		100 to 600 m^3/t
Abattoirs		0,2 to 9 m^3/cattle unit
Abattoirs with meat canneries		0,8 to 20 m^3/cattle unit
Thermal power stations		2,5 to 8,7 ℓ/kWh

TABLE 2.3 EFFECTS AND SPECIFIC TYPES OF POLLUTION IN INDUSTRIAL WASTE DISCHARGES

Water pollutants	Industries and industrial activities responsible	Adverse effects
Colour	Pulp and paper, textiles, abattoirs, steel, dairy	Visually objectionable
Solids	Pulp and paper mills, textile factories, tanning, canning, breweries, steel mills, boiler-house operations, mining (drainage from mine dumps), abattoirs	Blockage of sewer lines and equipment, damage to rivers by deposit of solids and depletion of oxygen
Oil and grease	Abattoirs, wool-washeries, tanneries, metal finishing, dairy plants, steel mills, oil refineries, railway workshops, locomotive, truck and aircraft washing, engineering works	Blockage of sewer lines and equipment, floating scum on water which prevents transfer of oxygen, anaerobic conditions, unpleasant smell and attraction of flies
Organic wastes	Pulp and paper, textiles, abattoirs, tanneries, canning, brewery, starch and yeast factories	Overloading of conventional sewage treatment plants, depletion of oxygen in rivers
Insecticides, pesticides	Chemical, food and textile factories	Toxic to bacterial and aquatic life, puts sewage treatment works out of action
Heavy metals	Pickling, plating	
Cyanide	Metal finishing, plating, coking, refineries	
Chemical wastes	Coking, synthetic dyes, chemicals, plastics, solvents, textile finishing, Kraft and sulphite pulp	Unpleasant taste and odour, toxic to aquatic life
Acids (mineral and organic)	Steel pickling, chemicals, food processing, acid mine drainage	Corrosion of concrete structures
Alkalis, sodium	Metal finishing, plating, textile and pulp mills, tanneries, water softening, ion-exchange installations	Toxic to fish, rendering water unsuitable for irrigation by causing brack conditions due to imbalance of ions
Nitrogen, phosphorus	Fertilizer plants, synthetic detergents	Rapid growth of aquatic organisms, algae, *Sphaerotilus natans*
Carbohydrates	Fruit and vegetable canning, sugar milling	
Heat	Cooling, all processes	Stimulates organic growth and reduces oxygen in water
Detergents	Textiles, metal finishing	Foaming
Pathogens, viruses, worm eggs	Hospitals, abattoirs	Spreading of disease

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

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

(ii) many organic substances in textile effluents, such as dyes, synthetic sizes and detergents, are relatively non-biodegradable and hence cause problems in municipal sewage works.

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

(iv) the presence of inorganic salts, acids or alkalis in high concentrations may make the receiving water unsuitable at a later stage for most industrial and municipal purposes.

2.2 TEXTILE PROCESSING

2.2.1 South African Textile Industry

The SA Textile Industry 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 (8). The textile industry uses 5% of the energy requirements of the manufacturing sector (9) and consumes over 30 × 10^6 m^3/annum of water (8).

2.2.2 Textile Manufacturing

The textile industry is a group of related industries which use natural and/or synthetic fibres to produce fabric as shown in Figure 2.1. Sizing is only carried out in the woven sector of the industry. The main fibres used are cotton and polyester. Two types of mills undertake sizing and desizing; these are the dry processing type (Figure 2.2) and the woven fabric finishing mill (Figure 2.3). In South Africa, the two types are mostly integrated on the same site.

2.2.3 Cotton/Polyester Cloth Manufacturing

2.2.3.1 OPENING AND PICKING

The bales of raw fibres (cotton and polyester staple) are opened and blended together with the removal of trash, seed and short fibre.

2.2.3.2 CARDING AND SPINNING

During carding the long axes of the fibres are aligned and further removal of short fibre and blending takes place. In spinning, fibres are drawn out into yarn and a twist is introduced. The yarn is used either as warp (longitudinal threads) or weft (inserted into the warp threads) to produce cloth by the weaving process.

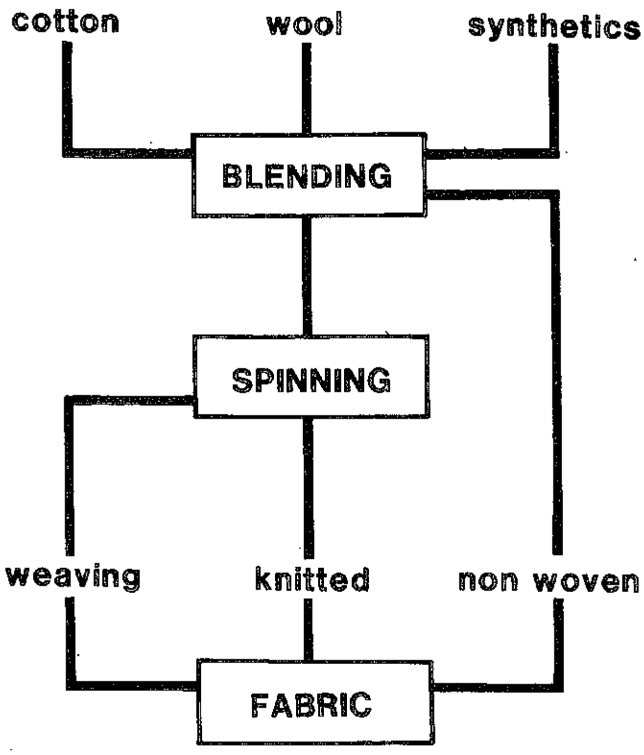


Figure 2.1: Production of fabric

2.2.3.3 WARPING

During warping about 500 parallel yarns are wound onto a back beam. Up to 12 of these are combined during sizing to form a weaver's beam which consists of about 4 000 threads and is approximately 1 000 m long. In the case of coloured woven fabrics, the yarn is dyed prior to warping.

2.2.3.4 SIZING (SLASHING)

The sizing operation coats the individual yarns with a protective film of size in order to resist the abrasive effects of the filling yarns as these are positioned by the shuttle action of the weaving loom. The size strengthens the yarn and reduces the hairyness of the threads. Typical sizing agents are starch, starch ether, polyacrylate, polyvinyl alcohol and carboxymethyl cellulose.

2.2.3.5 WEAVING

Weaving is a dry operation but is normally carried out under high humidity conditions. This helps to minimize yarn breaks on the loom as the size film is flexible under these conditions. After inspection for faults the greige cloth is cropped and singed to remove any surface hairyness.

2.2.3.6 DESIZING

The size is solubilized by enzymes in the case of starch and the cloth is then washed in hot water, usually with an open width, countercurrent washing machine.

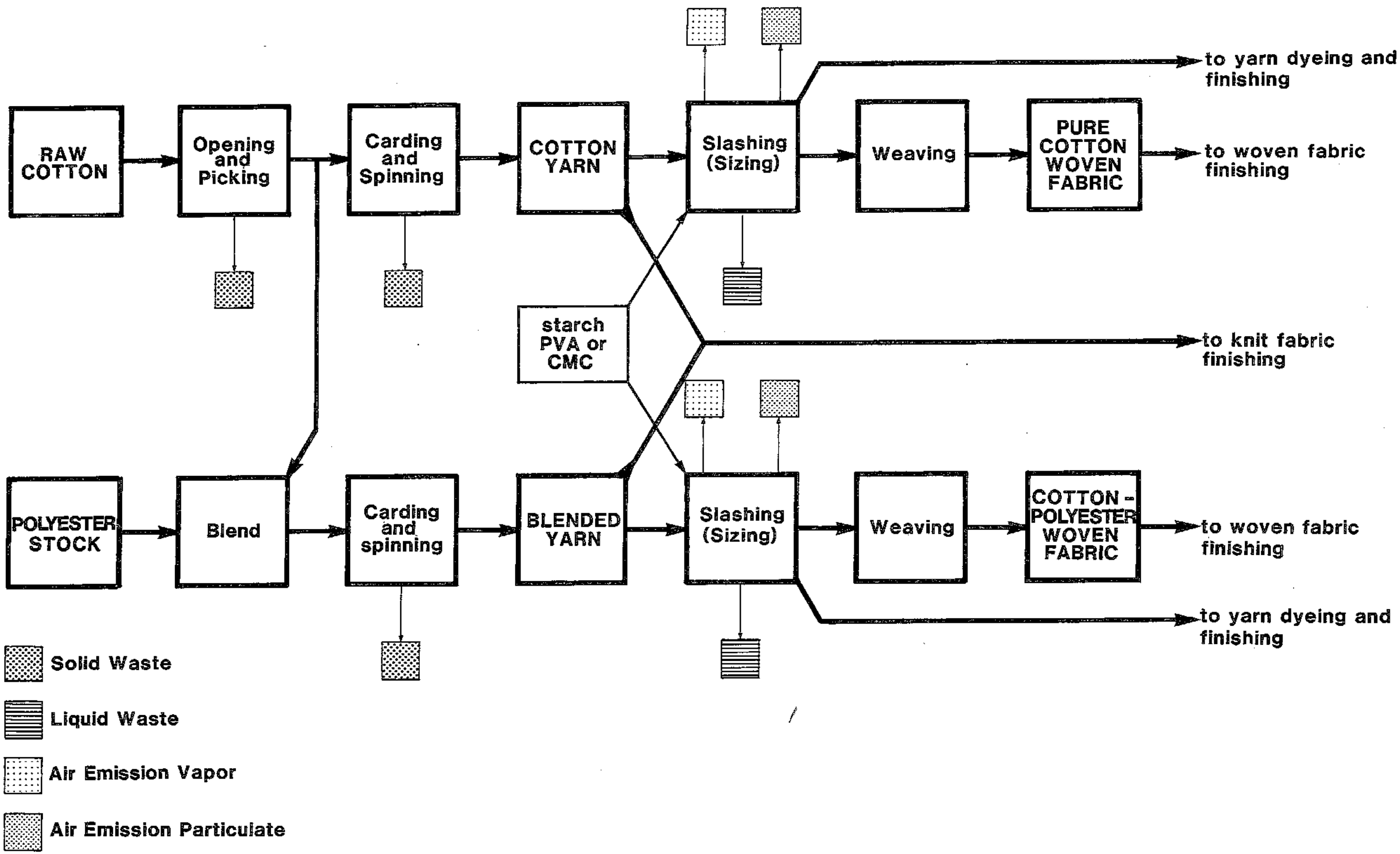


Figure 2.2: Dry processing mill

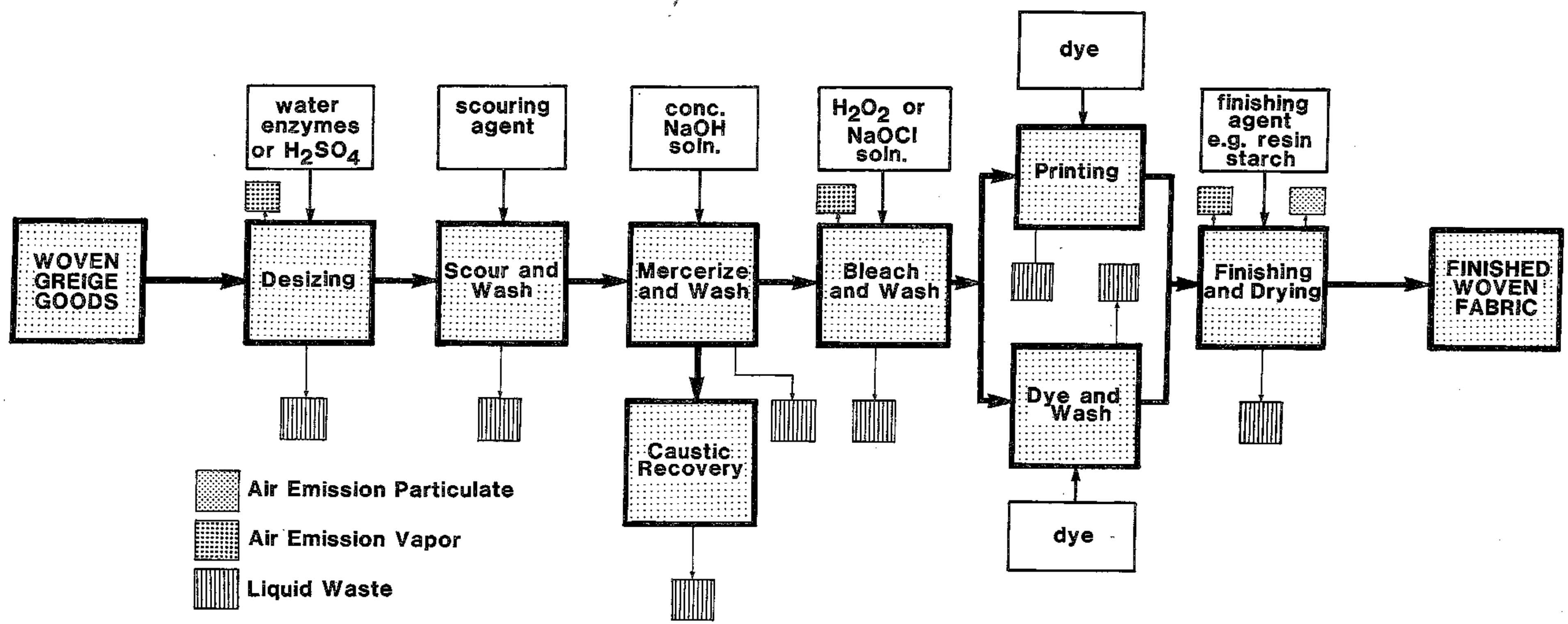


Figure 2.3: Woven fabric finishing mill

2.2.3.7 SCOURING, BLEACHING AND MERCERISING

Scouring with hot alkali removes the natural waxes and pectins from the cotton together with spinning oils. Bleaching with hydrogen peroxide or hypochlorite is used to whiten the fabric. Mercerising is used to increase the water absorbancy of cotton and to impart a sheen.

2.2.3.8 DYEING AND PRINTING

Cloth is coloured to customers requirements by either dyeing or printing. Final finishing in the form of easy care or handle finish is often carried out prior to the sale of the cloth.

2.2.4 Water Usage and Effluent Production

The overall wastewater characteristic of the two types of textile mills of interest to this report are given in Table 2.4 for dry processing mills and Table 2.5 for woven fabric finishing mills. The presented data was obtained from an ATMI (American Textile Manufacturers Institute) survey (10) and from a study (11) carried out for the National Commission on Water Quality (NCWQ).

The contribution of the various wet processing operations to the overall pollution load for a 50/50 cotton/polyester blend fabric are given in Table 2.6.

TABLE 2.4 EFFLUENT PRODUCED FROM DRY PROCESSING MILLS

	ATMI		NCWQ
	Avg. mg/ℓ	Std. Dev. mg/ℓ	Arith. Mean mg/ℓ
BOD	274	123	300
TSS	87	163	150
COD	871	230	950
Oil & Grease	–	–	–
Sulphide	8,00	–	–
Colour (ADMI)	–	–	–
pH (Units)	11,53	5,78	6 – 11
Faecal Coliform	–	–	–
Temp. °C	–	–	24
Water Use (ℓ/kg)	12,6	12,7	12,5

TABLE 2.5 EFFLUENT PRODUCED FROM WOVEN FABRIC FINISHING MILLS

	ATMI		NCWQ
	Avg. mg/ℓ	Std. Dev. mg/ℓ	Arith. Mean mg/ℓ
BOD	592	392	550
TSS	313	533	185
COD	1 093	513	1 850
Oil & Grease	14	–	–
Sulphide	2,72	4,57	2,72
Colour (ADMI)	–	–	325
Faecal Coliform	–	–	–
pH (Units)	11,62	2,89	6 – 11
Temp. °C	–	–	42
Water Use (ℓ/kg)	151	83	112

2.3 SIZING AND DESIZING TECHNOLOGY

2.3.1 Sizing Agents

The traditional sizing agent is starch; however, in recent years the trend has been towards synthetic sizes because of increased demand for synthetic fibres, the need for upgraded size performance arising from the elaboration of textile fabrics and environmental pollution considerations.

Table 2.7 gives the application characteristics of typical sizes (12). With natural polymer based sizes, e.g. starch, the solution viscosity is unstable and the films have poor adhesion and flexibility. Acrylate sizes exhibit high adhesion to hydrophobic fibres but their excessive softness gives a sticky quality and a lower strength. They also have low viscosities. The viscosity of polyvinyl alcohol is unaffected by cooking temperature or time.

To overcome the deficiencies of single component sizes, size blends are commonly used. Many factors affect the performance of the size film during weaving and these include the type of fibre, yarn surface and wettability, fineness, twist factor, film thickness, adhesive properties of the size mix and auxillaries used (13, 14).

2.3.1.1 STARCH

Starches (flours with the gluten removed) are the traditional sizing agents. They are obtained from maize, corn, potato, tapioca and rice.

Starch granules consists of alpha- and beta-amylose; the former is insoluble in water whereas the latter is soluble. The beta-amylose is contained within a membrane of the alpha-amylose. On heating the water permeates through the outer membrane causing the beta-amylose to dissolve and swell. The granules become expanded and the viscosity increases. Excessive temperature or agitation causes the alpha-amylose membrane to be ruptured leading to a decrease in viscosity. Many starches form an irreversible gel on cooling. Reheating the gel with strong agitation causes redispersion, however small pieces of gelled particles tend to remain.

By substituting acetyl or hydroxy-ethyl groups for hydrogen or hydroxide groups on the starch molecule, modified starches are formed. These have lower and more stable viscosity characteristics. Starch ethers adhere more strongly to synthetic fibres than does native starch.

Even the modified starch films are not very water soluble and in order to remove the size from the fabric, enzymes are used to degrade the starch into soluble sugars.

TABLE 2.6 POLLUTION LOADS FOR VARIOUS WET PREPARATION OPERATIONS (50/50 POLYESTER/COTTON)

PROCESS	pH	BOD kg/ 1 000 kg/ product (mg/ℓ)	Total suspended solids kg/ 1 000 kg product (mg/ℓ)	Total dissolved solids kg/ 1 000 kg product (mg/ℓ)	Oil & grease kg/ 1 000 kg product (mg/ℓ)	Colour kg/ 1 000 kg product (mg/ℓ)	Water use ℓ/kg product 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 (PVA)	6 – 8	2,5 (200)	5,0 (400)	50,4 (4 029)	3,6 (192)		12,5
Carboxymethyl Cellulose (CMC)	6 – 8	3,93 (314)	5,0 (400)	54,5 (4 349)	9,4 (751)		12,5
SCOURING:							
Unmercerized, Greige Fabric	12,0	10,8 (432)	5,0 (200)	9,8 (392)	20 (799)		25
Mercerized, Greige Fabric	12,0	8,34 (333)	5,0 (200)	9,7 (387)	15 (100)		25
MERCERIZING:							
Greige Fabric	12,0	5,72 (343)	5,0 (300)	77 (4 616)	5 (300)		16,7
Scoured Fabric	12,0	3,2 (192)	5,0 (300)	77 (4 616)			16,7
Bleached Fabric	12,0	1,3 (76)	5,0 (300)	72 (4 317)			16,7
BLEACHING:							
Hydrogen Peroxide (Woven Goods)	10,0	1,3 (78)	4,0 (240)	20 (1 199)			16,7
Hydrogen Peroxide (Knit Goods)	12,0	15,3 (183)					83
Hydrogen Peroxide (Yarn Goods)	10,0	13,8 (138)		50 (500)	1,0 (10)		100
DYEING:							
Direct & Disperse Dyeing (Woven Goods)	6 – 8	10,7 (257)		114 (2 734)		0,5 (12)	42
Vat & Disperse Dyeing (Woven Goods)	12,0	22,8 (547)		122 (2 926)		1,38 (33)	42
Sulfur & Disperse Dyeing (Woven Goods)	11,0	22,8 (547)		69,7 (1 671)		2,1 (50)	42
Napthol & Disperse Dyeing (Woven Goods)	11,0	13,8 (331)		57,2 (1 372)		0,55 (13)	42
Fibre Reactive & Disperse Dyeing (Woven Goods)	12,0	13,5 (324)		192 (4 604)		0,68 (16)	42
PRINTING:							
Pigment (Woven Goods)	6 – 8	1,26 (101)	0,13 (10)	2,5 (200)		0,05 (4)	12,5
Pigment (Knit Goods)	6 – 8	1,26 (101)	0,13 (10)	2,5 (200)		0,05 (4)	12,5
Vat Dye (Woven Goods)	10,0	21,5 (644)	25 (750)	34 (1 019)		0,05 (15)	33,3
Vat Dye (Knit Goods)	10,0	21,5 (644)	25 (750)	35 (1 049)		0,5 (15)	33,3
FINISHING:							
Resin Finishing (Woven Goods)	6 – 8	(96)		22 (1 759)			
Resin Finishing	6 – 8	6,32 (505)	12 (959)	17,3 (1 383)			12,5
Flat curing (Woven Goods)							12,5

2.3.1.2 CARBOXYMETHYL CELLULOSE

Carboxymethyl cellulose (CMC) is formed by treating cellulose with sodium hydroxide and mono-chloroacetic acid. The two properties which can be varied are degree of substitution and molecular weight. Solutions of CMC maintain their viscosity for up to 24 hours. Sodium and potassium salts do not effect the viscosity but calcium, iron and aluminium salts form a gel-like precipitate. Warps sized with CMC can be woven at lower humidities than starches. The CMC film readily dissolves in water and desizing can be accomplished by a hot water wash.

TABLE 2.7 PHYSICAL CHARACTERISTICS OF SIZES

Size	Viscosity of aqueous solutions	Moisture content at various relative humidities (%) 60% r.h.	70% r.h.	80% r.h.	Folding fre-quency	Tensile strength (kgf/mm2)	Elasticity (%)	Young's modulus (kgf/mm2)	Adhesion to film (g/mm2) Acetate	Nylon-6	Acrylic	Polyester
Wheat starch	Dissolves in hot water and gels on cooling	11,0	12,8	16,5	188	3,7	2,0					
Corn starch	Viscosity varies with heating temperature and time. It is also highly dependent on time elapsed	12,0	14,8	19,0	345	4,9	3,0	380				
Hydroxyethyl-cellulose-corn starch	Lower sizing temperature than raw starch; viscosity more stable	12,3	16,2	24,7		4,4	2,9	96				
Sodium alginate	Viscosity varies considerably with heating and depends on pH	15,7	26,0	35,8	508	2,8	3,7		0,5	1,0	2,5	1,0
Carboxymethyl cellulose	Dissolves in both warm and cool water High viscosity; on heating, viscosity changes with lapse of time	15,9	25,0	30,5	1 151	4,3	7,5	52	0,5	2,0	1,5	0,5
Partly hydrolysed polyvinyl alcohol d.p. = 500	Dissolves in both cold and warm water	10,7	14,1	17,0	Over 10 000	2,4	147	24	9,0	9,0	8,5	5,0
Partly hydrolysed polyvinyl alcohol d.p. = 2 000	Viscosity is stable, unaffected by time	10,3	13,4	16,8	Over 10 000	4,0	259	32	10,0	11,0	9,0	7,0
Fully hydrolysed polyvinyl alcohol d.p. = 1 700	Dissolves in warm water Viscosity is stable, unaffected by time when heated	10,6	13,9	16,4	Over 10 000	4,6	225	62	2,0	6,0	4,0	1,0
Fully hydrolysed polyvinyl alcohol d.p. = 2 600	May cause time-dependent viscosity change and gel at higher concentrations and low temperatures	10,7	13,6	16,6	Over 10 000	5,2	244	67				
Acrylic resin A	Dissolves in cold and warm water. Viscosity is extremely low but unaffected by time	10,9	14,1	17,5		0,33	315	9,34				
Acrylic resin B	Ammonium-salt type resins cause time-dependent viscosity change when heated	12,3	16,5	21,1		0,16	635	0,25				

Values of mechanical properties and adhesion are given at 65 per cent. relative humidity and 20°C

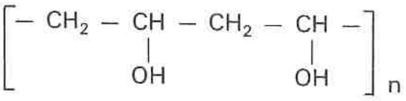
2.3.1.3 POLYACRYLATES

Polyacrylate sizes (PAA) are based on salts of polyacrylic acid. The two most common salts are sodium and ammonium. The former can be supplied as a dry powder whereas the latter can only be supplied as a solution.

The films produced from these polymers are thermoplastic, clear and colourless, and have good strength and flexibility. Acrylate sizes have higher adhesion than starch, CMC or polyvinyl alcohol. They are suitable particularly for nylon and polyester. The humidity in the weaving shed must be carefully controlled as they become sticky and lose film strength at high humidities. They are very soluble in water and can be removed from the fabric with ease.

2.3.1.4 POLYVINYL ALCOHOL

Polyvinyl alcohol (PVA) has the chemical structure:



and is produced by acid or alkaline hydrolysis of polyvinyl acetate. The two chemical properties that can be manipulated during the manufacturing process are:

(i) the degree of polymerisation (n) or molecular weight

(ii) the degree of hydrolysis or the fraction of sites that have OH groups attached to them.

2.3.2 Reusable Sizing Agents

For a size to be reusable, no significant differences between the virgin and reclaimed size should exist, otherwise control of the slashing operation becomes extremely difficult.

2.3.2.1 STARCHES

Starch and starch derivatives are enzyme degraded to facilitate their removal from the fabric. During the degradation process the primary structure is destroyed. In addition, virgin starches lose viscosity on agitation, prolonged heating or storage. Low viscosity, modified starches could be reusable if they were made sufficiently water soluble to be desized without the need for enzyme degradation.

Starches on their own are not suitable for sizing synthetic fibres. Thus, the reuse potential of starch or starch derivative sizes is not favourable.

2.3.2.2 CARBOXYMETHYL CELLULOSE

Carboxymethyl cellulose is suitable for sizing cotton and viscose yarns, and with admixture of PVA, for polyester yarn. On storage and mechanical agitation, CMC loses viscosity which makes the control of the size add-on during sizing very difficult. Contact of this size with calcium, iron and aluminium salts must be avoided to prevent the irreversible formation of a gel. The limited range of yarns for which CMC can be used together with difficulties in controlling the size add-on preclude CMC from being recycled on a large scale.

2.3.2.3 POLYACRYLATES

Polyacrylates are easily removed from the fabric by hot water. The viscosity of PAA solutions is stable and unaffected by temperature, storage or agitation. The ammonium polyacrylates, however, decompose on the drying cans with the loss of ammonia. This has to be replaced prior to reuse. A second and more serious problem is that the polymer forms very strong complexes with divalent and trivalent cations. The film forming properties of the complexed polymer are inferior to those of the monovalent cations and the complexed polymers are unsuitable for sizing. The divalent cations are natural impurities in raw cotton and are leached from the fibres during desizing. The size manufacturers are attempting to develop suitable non-ionic polyacrylate sizes but at present there are no products available. Under the high temperature and humidity conditions of the South African textile mills, 100% polyacrylate sizes are sticky and poor weaving efficiencies are experienced.

2.3.2.4 POLYVINYL ALCOHOL

Polyvinyl alcohol has been successfully used on its own to size a large range of cotton and polyester/cotton warps. It is removed from the fabric by a hot water wash. There is no polymer degradation due to agitation and the solution maintains its viscosity upon prolonged heating and pumping.

2.3.3 Desizing

The complete removal of size is a necessary prerequisite for successful finishing. The chemicals and methods used for desizing depend on the type of size that has been used. Starch and modified starches must be padded with an enzyme and detergent and allowed a dwell time of up to 8 hours. The action of the detergent is to allow the enzyme solution to penetrate into the fabric so as to degrade the starch into its constituent sugar units. Complete degradation is seldom achieved and the removal of the starch is by reducing the viscosity and solubilising the fragment portions. Acrylic sizes when used on their own are very water soluble and a high removal rate can be achieved by the use of cold water. Heating the rinse water allows a more complete removal to be achieved at a lower water consumption. Polyvinyl alcohol size, if used on its own, can be removed from the fabric by washing at the boil. When either PAA or PVA sizes are used on their own, padding and batching are not necessary, although it will promote gelling of the size and assist removal.

2.4 DESIZING EFFLUENT CHARACTERISTICS AND TREATMENT METHODS

2.4.1 Desizing Effluent Loads

The relative contribution of the desizing effluent to the pollution load of a South African mill is given in Table 2.8 (15). In this case, the desizing effluent contributed over 55% of the COD and over 40% of the total solids of the wet preparation section. On a mill basis, the COD was 20% and the total solids 11% of the total. In general, it is expected that the desizing effluent will contribute 15-40% of the mill pollution load depending on the type of sizing agents in use and the relative contributions of other textile processes (e.g. dyeing, printing).

TABLE 2.8 PERCENTAGE EFFLUENT PARAMETER LOADS

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
Merceriser Wash 1	0,8	0,1	0,4	0,1	0,1
Merceriser Wash 2	18,8	3,2	5,9	5,9	2,0
Total Load kg/month	4 797 (m^3/month)	49 912	68 519	7 820	21 148
Concentration	mg/ℓ	10 400	14 280	1 630	4 410

TABLE 2.9 WATER USAGE AND EFFLUENT PARAMETER LOADINGS AT THREE SOUTH AFRICAN TEXTILE MILLS

Parameter	Mill A		Mill B		Mill C	
	Singe	Desize	Singe	Desize	Singe	Desize
Water Usage (ℓ/kg)	1,22	4,23	–	14	–	10,3
COD (g/kg)	8,9	74,0	–	–	–	45,7
TS (g/kg)	8,5	78,3	–	98,0	–	44,5
OA (g/kg)	1,2	9,7	–	–	–	–
TC (g/kg)	2,9	33,8	–	50,75	–	44,5

The water usage and pollution parameters of the desizing effluent at three SA mills are summarised in Table 2.9. The pollution loadings of various sizing agents are compared in Table 2.10.

Desizing effluent is discharged at 90-95°C and contains high concentrations of organic matter and total solids. Starches are easily biodegradable as shown by their high BOD/COD ratios, but the synthetic sizes are relatively unbiodegradable. Recently it has been reported that over 90% removal of PVA is possible in activated sludge waste treatment systems that contain acclimatised micro-organisms (16).

2.4.2 Treatment Methods

The various methods that have been proposed for the reduction of the pollution load or treatment of desizing effluent are:

(i) solvent sizing
(ii) hot melt sizing
(iii) substitution of sizing agents
(iv) precipitation of the size in the desizing effluent
(v) biological treatment of desizing effluent
(vi) plasma discharge desizing
(vii) high expression washing
(viii) size recovery and reuse by ultrafiltration or hyperfiltration.

TABLE 2.10 POLLUTION LOADINGS AND PRICES OF VARIOUS SIZING AGENTS

Size	BOD_5 g/kg	COD g/kg	Price R/kg
Starch	640	1 200	–
Starch Ether	530	1 100	0,76
Polyvinyl Alcohol	10	1 700	2,51
Polyacrylates	–	1 300	0,81
Carboxymethyl Cellulose	40	900	–

Price at Sept. 1982 (R1 = $0,92)

2.4.2.1 SOLVENT SIZING

In solvent sizing or desizing, water is replaced by an organic solvent such as tetrachloroethylene (TCE). The desizing effluent is concentrated by distillation and the size is reused. The advantage of using an organic solvent in preference to an aqueous system is in the lower boiling point and latent heat of vaporisation of the solvent. Conventional sizing agents cannot be used and modified cellulosic sizes are applied either as an aqueous or TCE solution and subsequently desized with TCE. The desizing effluent is evaporated and reused. The cost of the system is reduced if aqueous sizing is undertaken as a sophisticated vapor recovery system need not be installed around the slasher drying cans. A major cost of this system is the solvent losses in both evaporation and retention in the polyester fibre. In a recent study (17), the weaving efficiency using the modified cellulosic size on cotton was found to be lower than that obtained when PVA was used (0,6 to 4 warp breaks per hour compared to 0,3 for PVA warps); for 50/50 polyester/cotton, the warp breaks per hour were 1,5 to 3 for the solvent system and 0,0 for the PVA system.

The Duplosolve Process (18) is a variant of high expression washing in that an organic solvent is used to displace the aqueous phase from the fabric after an aqueous padding and dwell stage. The two phases are allowed to separate and the recovered aqueous phase containing the size is reused. Only 80% of the moisture is displaced from the fabric and the concentration of the displaced size solution is about half of that used in slashing. The disadvantages of the system are similar to those of high expression washing (see 2.4.2.7).

2.4.2.2 HOT MELTING SIZE

Fabrics woven from warps which have been hot melt sized have to be desized using either water or solvents and the effluent produced would have to be treated in a similar manner to conventional desizing effluent.

2.4.2.3 SUBSTITUTION OF SIZING AGENTS

Sizing chemicals can be selected on the basis of their environmental impact. Table 2.10 indicates the pollution potential and price of some commonly used sizing agents. The contribution of BOD_5 and OA by the size to the desizing effluent can be substantially decreased by substituting PVA, PAA or CMC for starch based sizes. In South Africa, the COD parameter is being preferred as the main organic pollution parameter, and in this case starch based sizes compare favourably with the synthetic polymer sizes. Size substitution becomes important if size reuse is considered because the recovered size must not be degraded between the initial sizing and subsequent reuse.

2.4.2.4 PRECIPITATION OF SIZING AGENTS

Precipitation has been proposed (19) as a method for recovering CMC. Trials indicated that nearly quantitative precipitation of the CMC occurred if aluminium sulphate (alum) was added to the desizing effluent. The precipitate was dewatered to a 10 to 15% slurry and treated with sodium hydroxide to dissolve the CMC which was then recycled to sizing. A large proportion of the COD (70 to 80%) was found to remain in the supernatant after precipitation. The recovered size had to be stored hot to prevent biodegradation of the CMC, and prolonged heating resulted in a decrease in solution viscosity which caused problems in obtaining reproducible sizing conditions.

2.4.2.5 BIOLOGICAL DEGRADATION OF DESIZING EFFLUENTS

Starches, CMC and PVA sizes are biodegradable. In order to obtain an acceptable reduction in organic pollution load (greater than 90%), large bioreactor sizes are needed. For example, 1 000 m/d of starch sized fabric required 22,5 m^3 of reactor volume for an 80 to 90% COD reduction in an anaerobic reactor (20). The COD of the treated effluent was 1 040 mg/ℓ. Aerobic treatment of a mixed textile effluent from PVA sized warps reduced the COD by 80% after a 5 day aeration period (conventional sewage works aeration period is 8 to 10 hours) (16). The resultant COD was 60 mg/ℓ. Aerobic or anaerobic biological treatment is thus expensive in terms of reactor size and energy consumption. In addition the resultant effluent is not of a sufficient quality to allow reuse and the running expenses are relatively high.

2.4.2.6 PLASMA TREATMENT

The treatment of cloth containing PVA size with a low temperature plasma has been suggested as a pretreatment to desizing (21). The PVA was degraded by the oxygen in the air to carbon dioxide and water during plasma exposure. Adverse effects on fabric properties were not observed. Up to 95% of the PVA can be oxidised in this manner. Costs of the process are not available and no useful products can be recovered.

2.4.2.7 HIGH EXPRESSION WASHING

The installation of high efficiency multi-unit desizing washing range reduces the volume of the effluent produced. Both the Duplosolve and the BASF Benninger (22) process utilise this principle. The concentration of size in the product stream and the fraction of size removed from the cloth are related and depend on the amount of water used, the moisture content of the cloth after the nip rollers and the number of squeeze stages. Typical results on PAA size are a 50-80% size removal at 98-50%, respectively, of the required concentration required for reuse. The disadvantage of this system is that as the size recovery is increased the volume of the recovered size increases exponentially and as the volume of size recovered cannot exceed that required in sizing, a concentration stage will be needed (23).

The example in Tables 2.11 and 2.12 indicates that, for a 2-stage 80% impregnation and 40% expression system, 75% of the size is recovered. After adding virgin size to bring the concentration up to the desired level for slashing there is a 5,5% excess volume of size. In the case of a moisture content of 100% after impregnation and 50% after expression, the size removal is again 75% and the size volume excess would be 33,9%. An acrylate size (BASF CA) is the main size used with this system.

These examples show that although high expression washing will give a limited amount of reusable size, a desizing effluent containing significant amounts of size is still produced.

2.4.2.8 ULTRAFILTRATION OF DESIZING EFFLUENTS

Textile sizes are high molecular weight polymers. If these polymers can be removed from the fabric in the same form as they were applied to the warp then the recovery of the size from the effluent by means of ultrafiltration becomes feasible. Ultrafiltration is a low pressure membrane filtration process used for separating macro-molecules (Figure 2.4) and suspended solids from water (24). A semi-permeable microporous membrane performs the separation. Water and low molecular weight solutes pass through the membrane and are removed as permeate. The feed stream flows parallel to the membrane surface. This cross-flow characteristic differs from the perpendicular flow of ordinary filtration. For ordinary filtration, a filter cake builds up on the filter surface, resulting in frequent filter replacement or cleaning. In ultrafiltration, the cross flow conditions prevent filter cake build up and high filtration rates or fluxes can be maintained continuously. The membranes for desizing effluent have to be able to handle high temperatures (80°C) and a wide pH range (to allow cleaning). The two types of modules suitable for this application are tubular and spiral-wrap. For desizing effluents the spiral-wrap modules offer the best compromise between operability, surface-to-volume ratio, power requirements and replacement costs.

Ultrafiltration has successfully recovered PVA, CMC and PAA sizes. PVA is the preferred size for reuse as CMC suffers a slow degradation in viscosity leading to pick-up problems on the slasher and PAA complex with the calcium and magnesium ions present in the desizing effluent resulting in undesirable film-forming properties. Starch blends are normally not recoverable because of the need for degradation prior to removal in desizing.

2.4.2.9 COMPARISON OF SIZE RECOVERY PROCESSES

The two most practicable size recovery processes are ultrafiltration and high-expression washing. Because starch and starch derivatives are not reusable, the size formation should be changed from starch/PAA/PVA blends to a single component size.

At the moment, the available PAA sizes in South Africa are chemically modified during drying and desizing and hence their reuse is limited. Newer types of PAA size may have enhanced reuse potential. Polyvinyl alcohol size is recoverable by both treatment processes.

The use of enzymes for desizing is unnecessary for synthetic polymeric sizing agents.

The rate of removal of polymeric sizing agents during desizing is an important consideration. Polyacrylates are removed easier and quicker than PVA; this is especially important in the high-expression washing process where very low water usages are necessary for the process to be viable.

The basic concept of the high-expression washing recovery process is that by using a low volume of water, the size removed from the cloth produces an effluent with a high enough concentration of size to allow reuse either as is or by admixture with virgin size solids or solution. However, the low water usage only allows the removal of a percentage of the size on the cloth and the remainder has to be removed by a conventional washing range.

The amount of size removed depends on type, water usage and dwell time. Typical values are 50-80% for PAA sizes and 40-60% for PVA sizes (22,23). The process has been used in Germany with some success using a special acrylate size.

The high-expression washing recovery process has three main disadvantages when compared to the ultrafiltration technique. These are:

(i) polyacrylate sizes are very sensitive to weaving temperature and humidities.

(ii) if a large percentage of production is processed by a high-expression washer, then the volume of reclaimed size solution is in excess of requirements at high removal efficiencies. This may be overcome either by accepting a lower removal efficiency or by processing only a percentage of production.

(iii) as the high-expression washing process removes only a percentage of the size, further washing is necessary on a conventional washing range. The total amount of water needed for desizing (high-expression washer plus conventional washer) is not significantly reduced because of the diffusion properties of the size from the inner parts of the cloth threads. If it is necessary to reduce the pollution load of the factory, then an ultrafiltration size recovery plant would be needed to treat the effluent from the conventional washer.

TABLE 2.11 SIZING AND WEAVING SPECIFICATIONS

Width	1 260 mm
Density	199,7 g/m²
Weave Rate	14,9 h/100 m
Reed (ends)	29,52 ends/cm
Reed (dents)	9,84 dents/cm
Reed (width)	1 304,5 mm
Ends/dent	3
Picks/cm	15,5
Total ends	3 814
Selvage	56
Weave	2/1 twill
Warp	cotton 42 tex
Weft	cotton 36 tex
Picks/min	184
Cloth density	0,27 kg/m
Weaving efficiency	90-95%
Fraction warp in cloth	0,71
Size concentration	10% Acrylate 2,5% as Total Solids
Wet pick-up	110%
Size loading	11% as Acrylate 2,75% as Total Solids
Volume of size for 100 kg cloth	78,1ℓ

TABLE 2.12 SIZE RECOVERY BY EXPRESSION

	Example A	Example B
First impregnation moisture content	80%	100%
First expression moisture content	40%	50%
Second impregnation moisture content	80%	100%
Second expression moisture content	40%	50%
Mass of warp	71 kg	71 kg
Mass of size (Total Solids)	1,953 kg	1,953 kg
Volume of first expression	40 ℓ	50 ℓ
Mass of size expressed (Total Solids)	0,976 kg	0,976 kg
Volume of 2nd expression	40 ℓ	50 ℓ
Mass of size expressed (Total Solids)	0,488 kg	0,488 kg
Total mass size removed (Total Solids)	1,464 kg	1,464 kg
Total volume size removed	80 ℓ	100 ℓ
Concentration of size removed	18,30 g/ℓ	14,64 g/ℓ
Volume 25% Total Solids Acrylate to bring concentration to 25,0 g/ℓ (Total Solids)	2,382 ℓ	4,604 ℓ
Total volume reclaimed size at 25 g/ℓ (Total Solids)	82,38 ℓ	104,60 ℓ
Percentage of size recovered	75%	75%
Percentage excess size	5,5%	33,9%

Basis 100 kg of Cloth

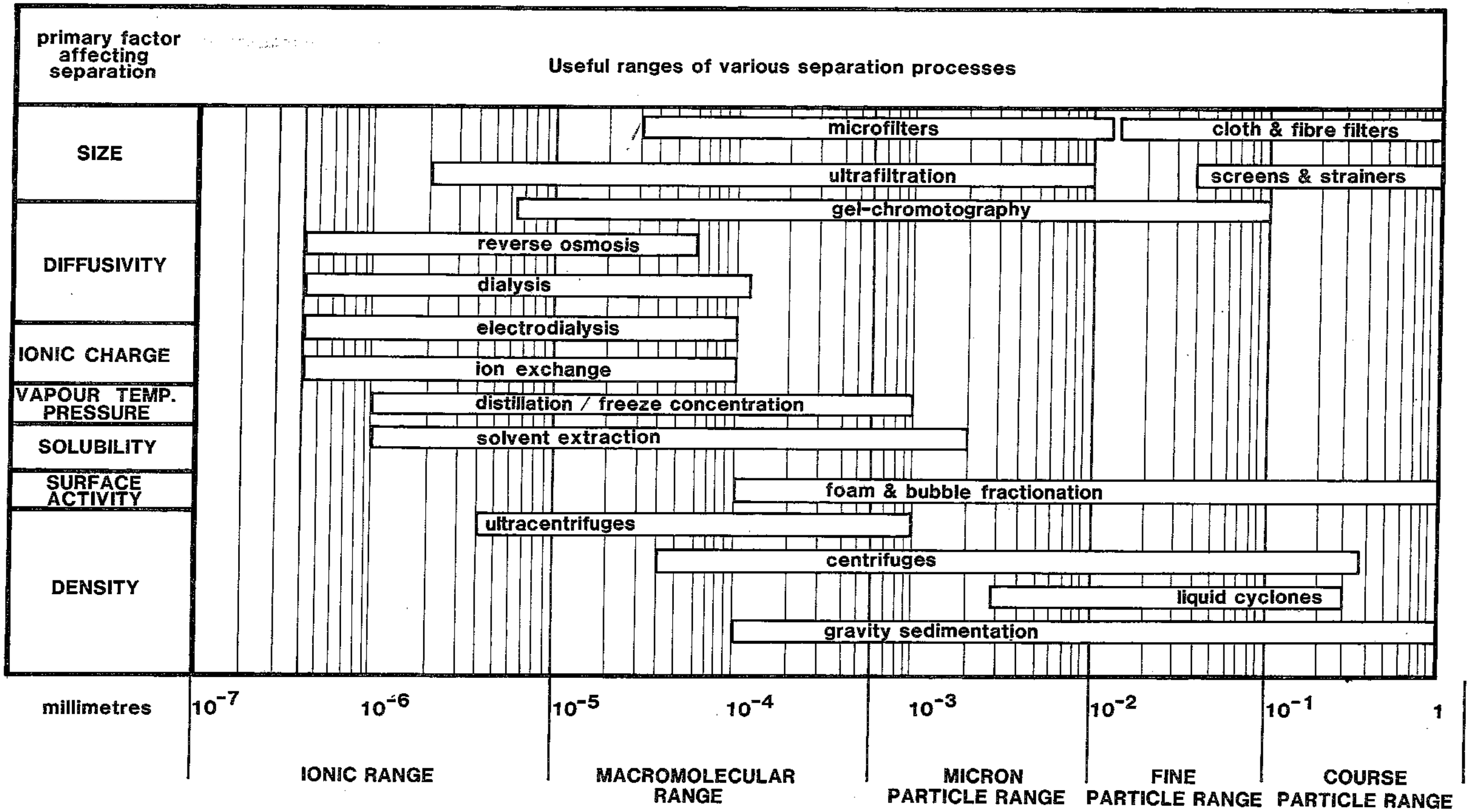


Figure 2.4: Useful ranges of separation processes

Chapter 3

CLOSED LOOP RECYCLE TREATMENT SYSTEM FOR TEXTILE SIZING/DESIZING EFFLUENTS

3.1 INTRODUCTION

Desizing effluents from cotton/synthetic fibre textile mills are largely composed of sizing agents and hence are organic in nature. They are a major contributor to the total mill effluent load.

The closed loop recycle system using UF separates the polymer sizing agents into a concentrate for reuse in sizing and the effluent is purified for reuse in desizing. This is illustrated in Figure 3.1.

Sizing agents are applied to warp threads at 3-15% by weight of warp prior to weaving. The synthetic sizing agents (PAA and PVA) do not require enzymatic desizing and are removed at 95-100°C by hot water washing. Two important factors, in determining the economic feasibility of a size recovery process, are the fraction of size that is removable and the concentration of size in the desizing effluent. Losses of sizing agent are about 10% in the dry processing stages prior to desizing, up to 5% during sizing due to wastage (25) and up to 5% during desizing due to incomplete washing (26). Recovery of size during UF is close to 100%. Hence, the overall recovery is in the range 80-85% of that initially formulated in sizing.

Water usage in desizing is typically 4-20 ℓ/kg of cloth. For an average size add-on of 6% on a cloth basis, the effluent size concentrations will be 3-15 g/ℓ. For reuse in sizing the concentration needed is about 90 g/ℓ. Hence the range of concentration factors for the two extremes are 6-30:1. Thus the importance of a low water usage during desizing is evident as the higher the concentration factor needed, the larger the required membrane area of the ultrafiltration plant.

An additional factor for consideration is that a proportion (approximately 1 ℓ/kg) of the incoming water to desizing is carried over as moisture in the cloth and this provides a natural bleed-off for the recovery process.

Using the basis of:

Size add-on	60 g/kg on weight of cloth
Size concentration	9%
Desizing water usage	6 ℓ/kg
Moisture carry over	1 ℓ/kg
Size losses	15%

then the mass balances for size and water are shown in Figure 3.2.

3.2 PROCESS CONSIDERATIONS

Several factors are important in the implementation of a closed loop recycle-treatment system for textile sizing/desizing effluents. These are:

(i) the range and type of fabrics that may be sized with a one-component, reusable sizing agent.

(ii) the weaving efficiencies of cloth sized with virgin and reclaimed size.

(iii) the desizing efficiency of reusable sizing agents.

(iv) the technical and economic feasibility of ultrafiltration of desizing effluents.

(v) the reusability of the product water (permeate) from ultrafiltration.

A series of projects sponsored by the Water Research Commission (25 — 31) were carried out to investigate these factors.

It was found that a wide range of fabrics could be sized and woven successfully by both PAA and PVA sizing agents. Both of these sizes were removable from the cloth using, for example, a 3 bowl, counter-current washer at about 4 ℓ/kg of hot water with a removal efficiency in the range 93-97%.

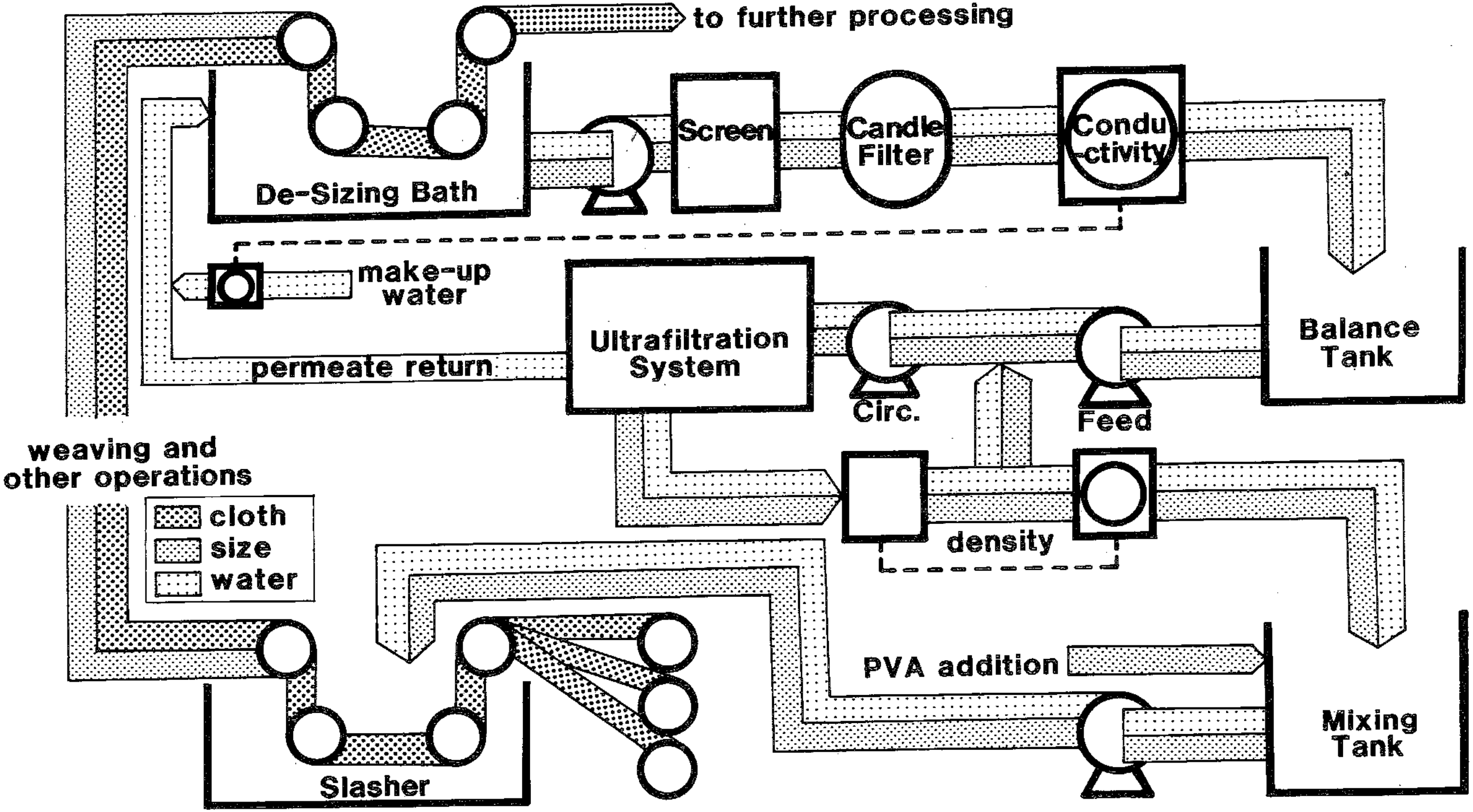


Figure 3.1: Flow Schematic for Textile Sizing Recovery by Ultrafiltration

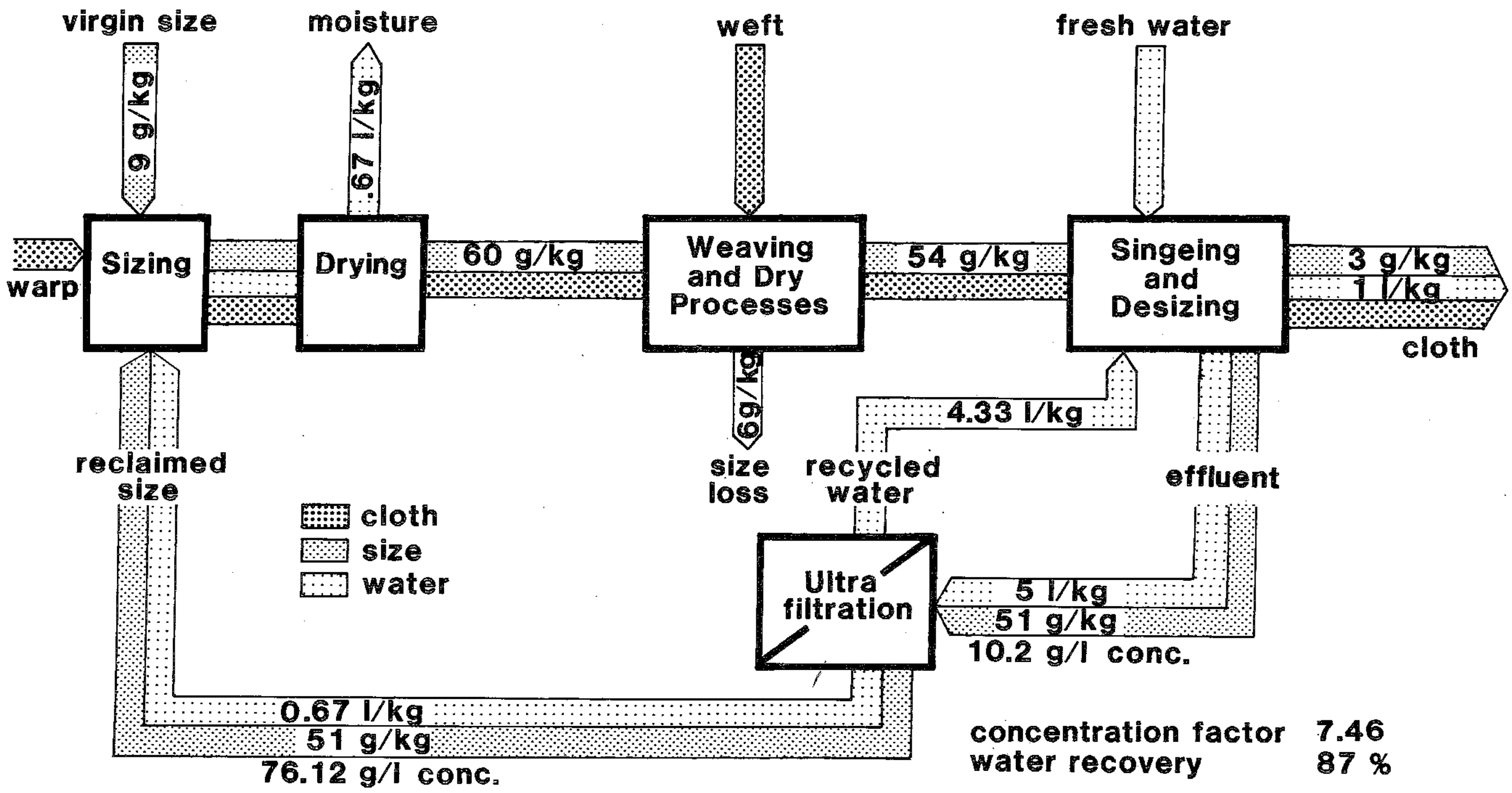


Figure 3.2: Closed Loop Recycle — Mass Balance

Both types of sizing agent were recoverable by UF, but the PAA type had poor weaving performance. This was determined to be caused by the replacement of the ammonium base of the polymer with divalent cations resulting in different film forming characteristics. The reclaimed PVA size was found to have excellent sizing and weaving performance.

These investigations demonstrated that UF was a suitable effluent treatment process for desizing effluents and the closed loop recycle system provided significant savings in terms of chemical reuse, heat energy reuse, water reuse and reduced effluent discharge from the textile factory.

3.3 ULTRAFILTRATION FOR TEXTILE SIZE RECOVERY

A pilot-plant investigation was undertaken for the Water Research Commission to develop design and operating criteria for full-scale treatment/recycle plants to handle sizing/desizing effluents from cotton/synthetic fibre textile mills (29). The results of this project are summarised in chapter 4 and provide the guidelines for the planning, design and implementation of the closed loop treatment-recycle system.

3.3.1 Ultrafiltration

3.3.1.1 ULTRAFILTRATION MEMBRANES

The major ultrafiltration membrane manufacturers are listed in Table 3.1. Each manufacturer has a range of molecular weight cut-off membranes such as given in Table 3.2, although not as extensive.

In general, UF membranes are fairly robust with pH and temperature ranges of 2-12 and 10-90°C respectively. Cellulosic membranes have lower operating ranges.

Various polymeric materials are used for membrane preparation: cellulose acetate, polyamide, polysulphone and zirconium oxide (24).

3.3.1.2 ULTRAFILTRATION MODULE TYPES

The membranes are assembled into several different module types:

- tubular
- plate and frame
- spiral
- hollow fibre.

These are illustrated in Figures 3.3. – 3.6.

TABLE 3.1: COMMERCIAL ULTRAFILTRATION MEMBRANES

Manufacturer	Membrane Type	Module Configurations	pH Range	Temperature Range (°C)
Abcor	Cellulosic	Tubular/	3- 9	60
	Non-cellulosic	Spiral	2-13	90
Carre	Dynamic	Tubular	3-10	100
Dorr-Oliver	Non-cellulosic	Plate & Frame	3-11	60
DDS	Cellulosic	Plate & Frame	3- 8	50
	Non-cellulosic		3-12	70
PCI	Cellulosic	Tubular	2- 8	30
	Non-cellulosic		3-12	70
Romicon	Non-cellulosic	Linear Thin Channel	3-11	60
		Hollow Fibre	2-13	75

TABLE 3.2: RANGE OF ULTRAFILTRATION MEMBRANES

Nominal Molecular Weight Cut-Off	Apparent Pore Diameter (Å)	Water Flux* (ℓ/m²h)	Temperature Range °C	pH Range
500	21	9	60	3,0-11,0
2 000	24	15	45	1,5- 9,0
5 000	30	68	75	1,5-13,0
10 000	38	60	75	1,5-13,0
30 000	47	920	75	1,5-13,0
50 000	–	–	75	1,5-13,0
50 000	66	305	50	1,5-13,0
80 000	–	–	50	1,5-13,0
100 000	110	1 000	60	3,0-11,0
300 000	480	600	60	3,0-11,0

(* Flux at 367 kPa)

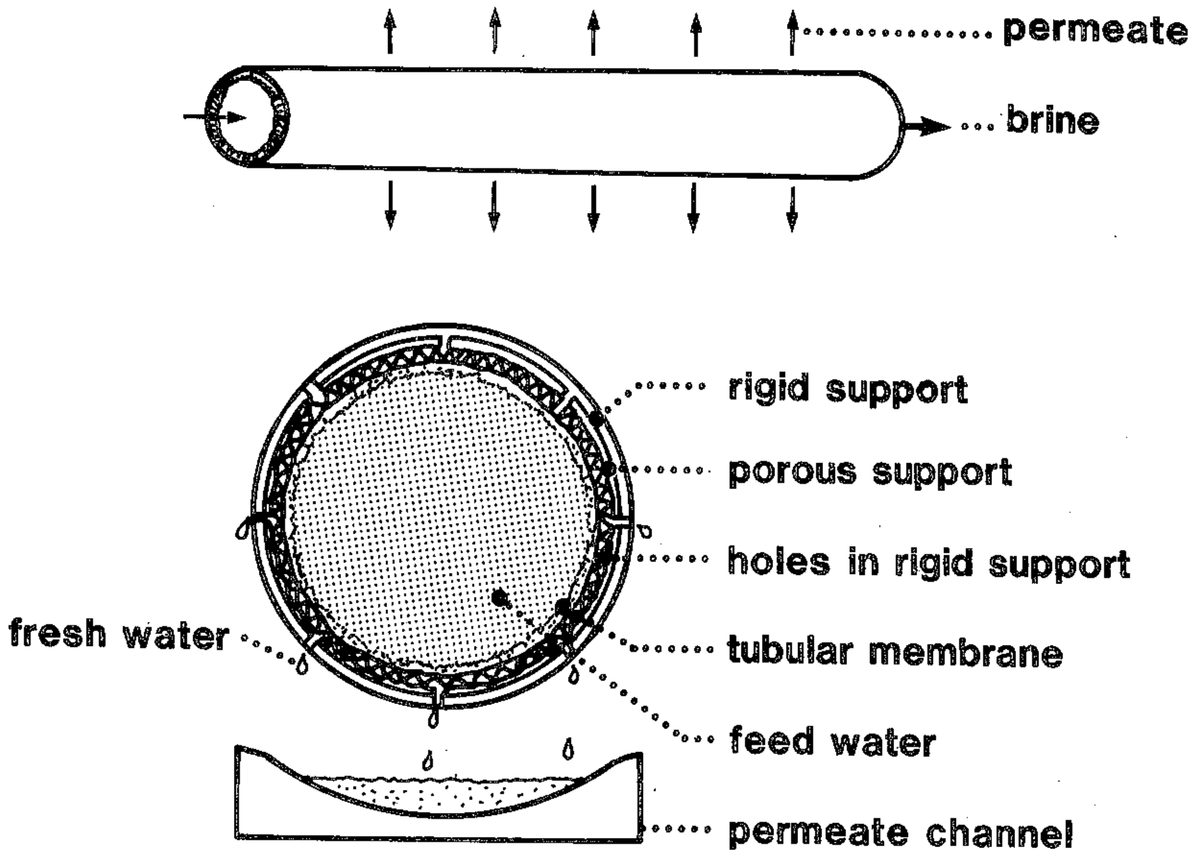


Figure 3.3: Construction of a Tubular Membrane

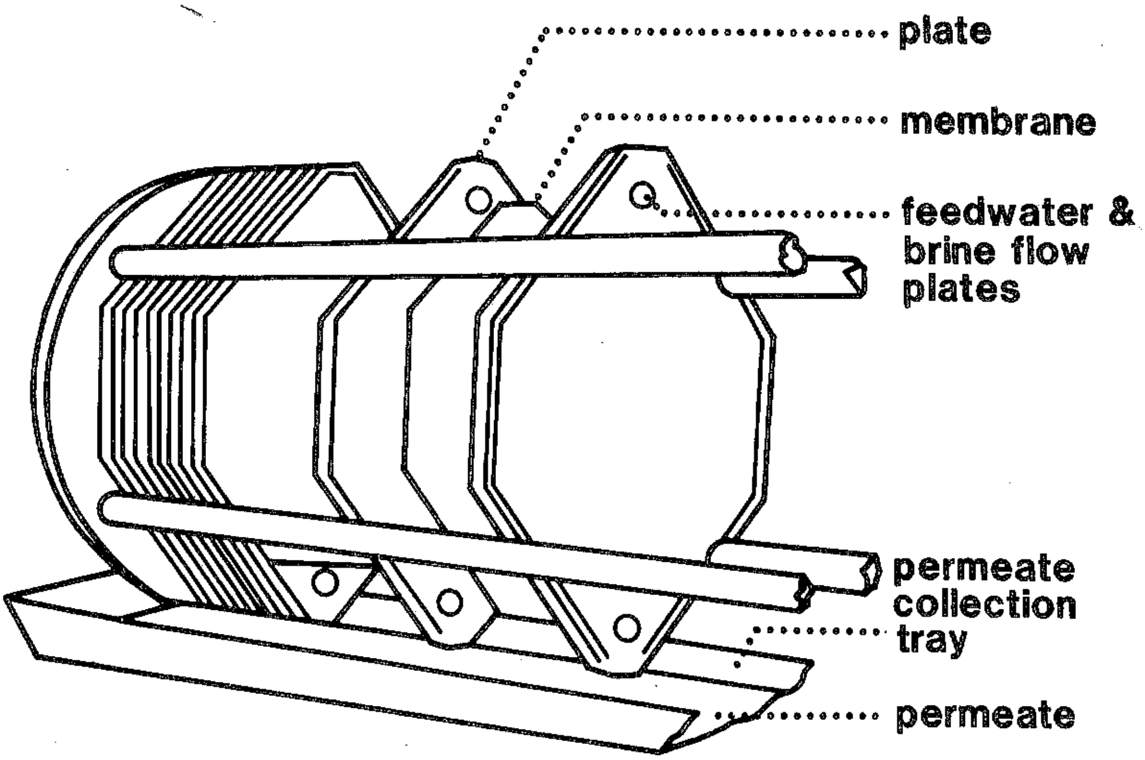
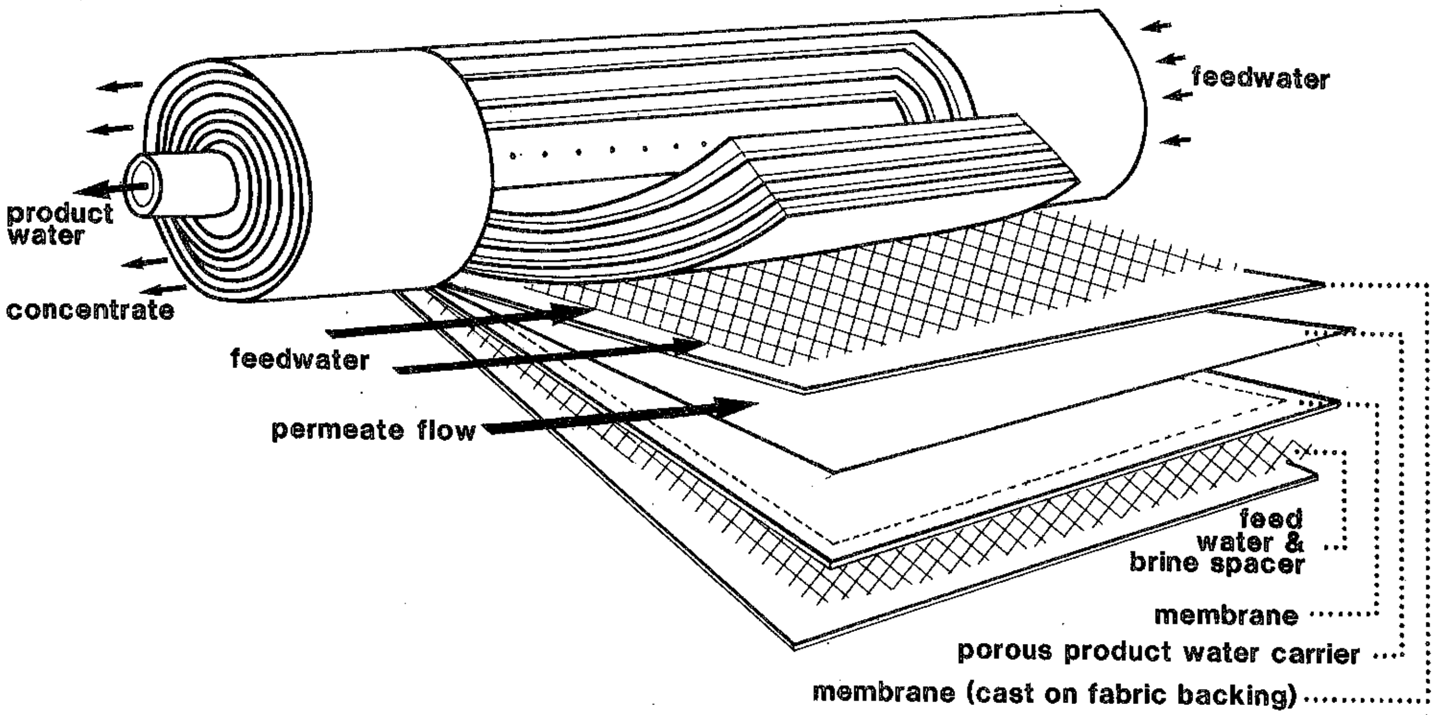
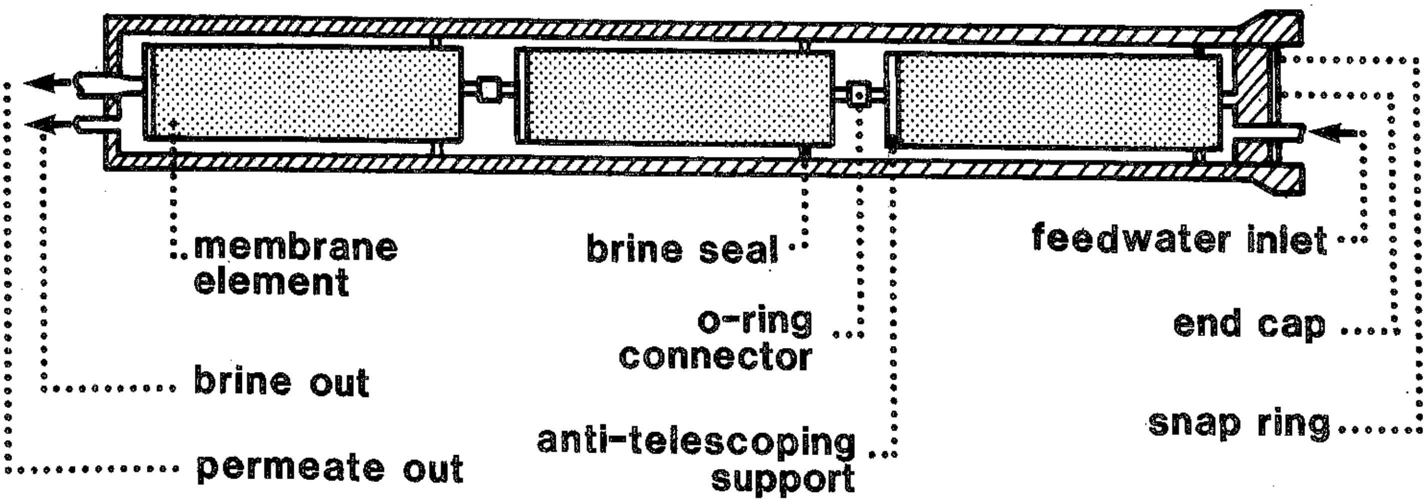


Figure 3.4: Construction of a Plate and Frame Membrane



Cutaway view of a spiral membrane element



Cross - section of pressure vessel with 3-membrane element

Figure 3.5: Spiral Membrane Cutaway View with Elements in a Pressure Vessel

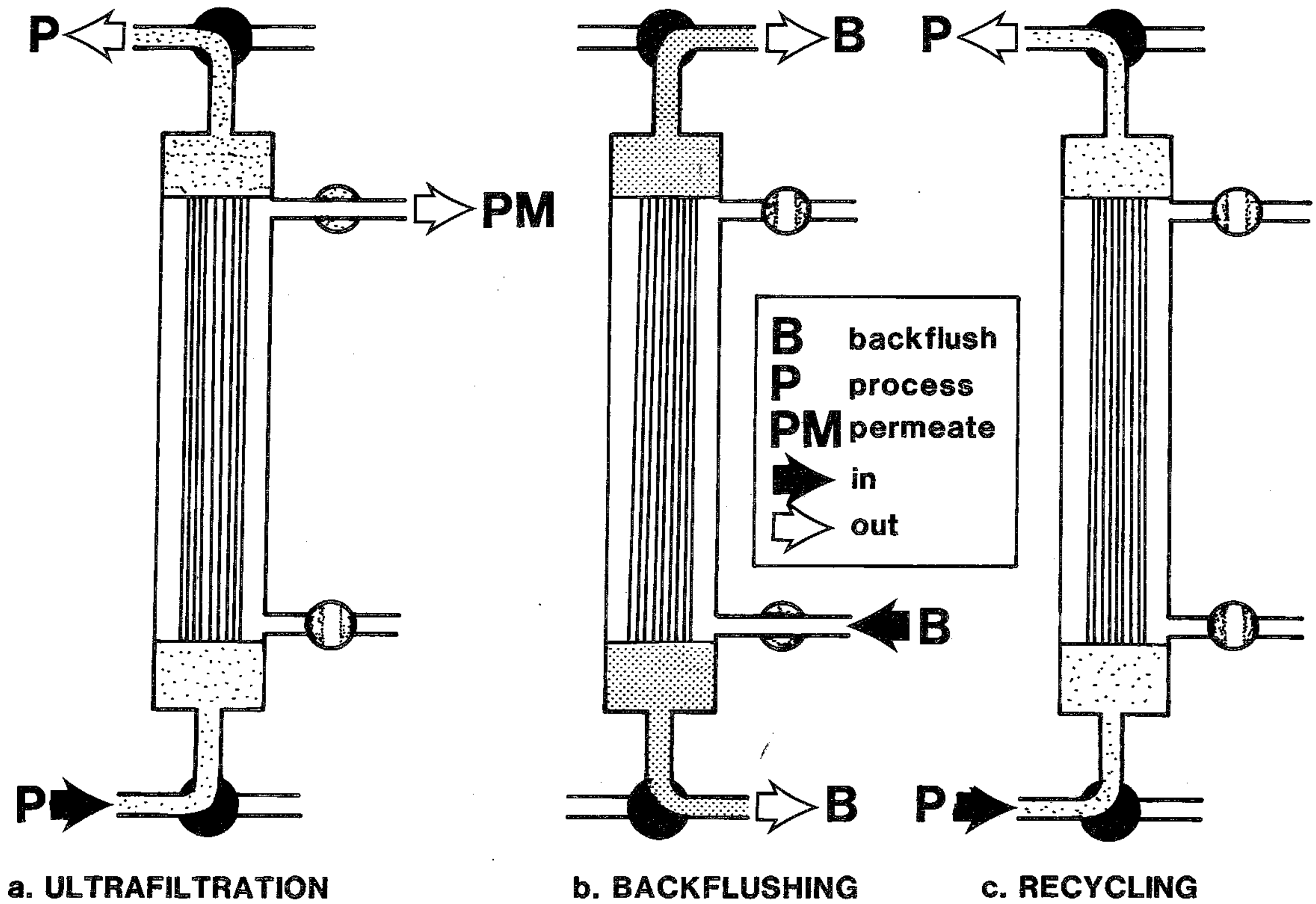


Figure 3.6: Schematic of Hollow Fibre Cartridge showing the Three Modes of Operation Used in Systems Design

Each module type has its own processing characteristics and limitations. Often membrane types are specific to certain modules.

Typical ultrafiltration flux rates are in the range 10 – 200 litres of product per m² of membrane area per hour (ℓ/m²h) and this is about 1/200th of that in normal barrier filtration. Thus membranes must be packed into a small volume leaving little space for a flow channel and no room for a filter cake. Hence UF modules are operated in the cross-flow mode with two outlet streams: the product (permeate) and the concentrate (reject). This is illustrated in Figure 3.7.

3.3.1.3 ULTRAFILTRATION PLANT CONFIGURATIONS

The three common UF system designs are batch concentration, continuous feed and bleed and continuous multi-stage feed and bleed. These are illustrated in Figures 3.8 to 3.10.

3.3.2 Ultrafiltration for Textile Size Recovery

The major membrane and module specifications for the ultrafiltration treatment of polymeric sizing solutions are:

(i) temperature capability above 75°C as the effluent is at 90-100°C. High temperature operation minimises microbial degradation of the effluent and allows heat recovery.

(ii) high turbulence device to minimise gel-polarisation at reasonable pumping rates.

(iii) membrane resistance to cleaning solutions.

(iv) nominal molecular weight cut-off in range 20 000-50 000.

(v) high flux performance per unit pressure.

3.3.3 Ultrafiltration Pilot-Plant

The desizing effluent pilot-plant is shown schematically in Figure 3.11. It was constructed at a factory site and processed 15-25% of the cloth production of the factory.

The design of the pilot-plant is covered in detail in Report UF7 (30) and the operating instructions in Report UF8 (31). The membrane structure is shown in Figure 3.12 and the detailed fabrication of the spiral-wrap module in Figure 3.13. A photograph of the pilot-plant is shown in Figure 3.14.

Initially the pilot-plant was designed as a three stage, series taper with 27 spiral-wrap membranes. The specification of the membranes is given in Table 3.3. During the project the configuration of the plant was altered to batch concentration mode to allow comparison of the two processing modes.

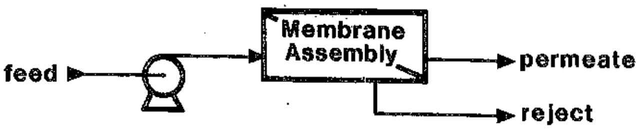


Figure 3.7: Single Stage with a Single Element

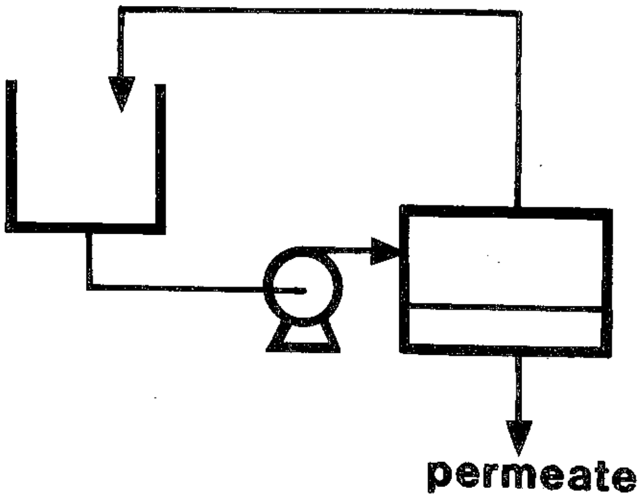


Figure 3.8: Batch System

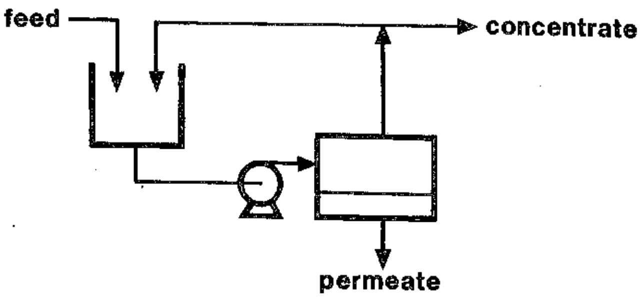


Figure 3.9: Continuous Feed and Bleed

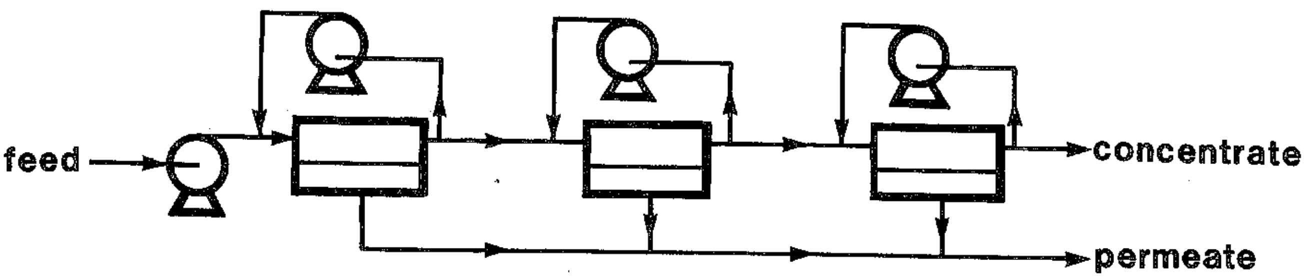


Figure 3.10: Continuous Multistage Feed and Bleed

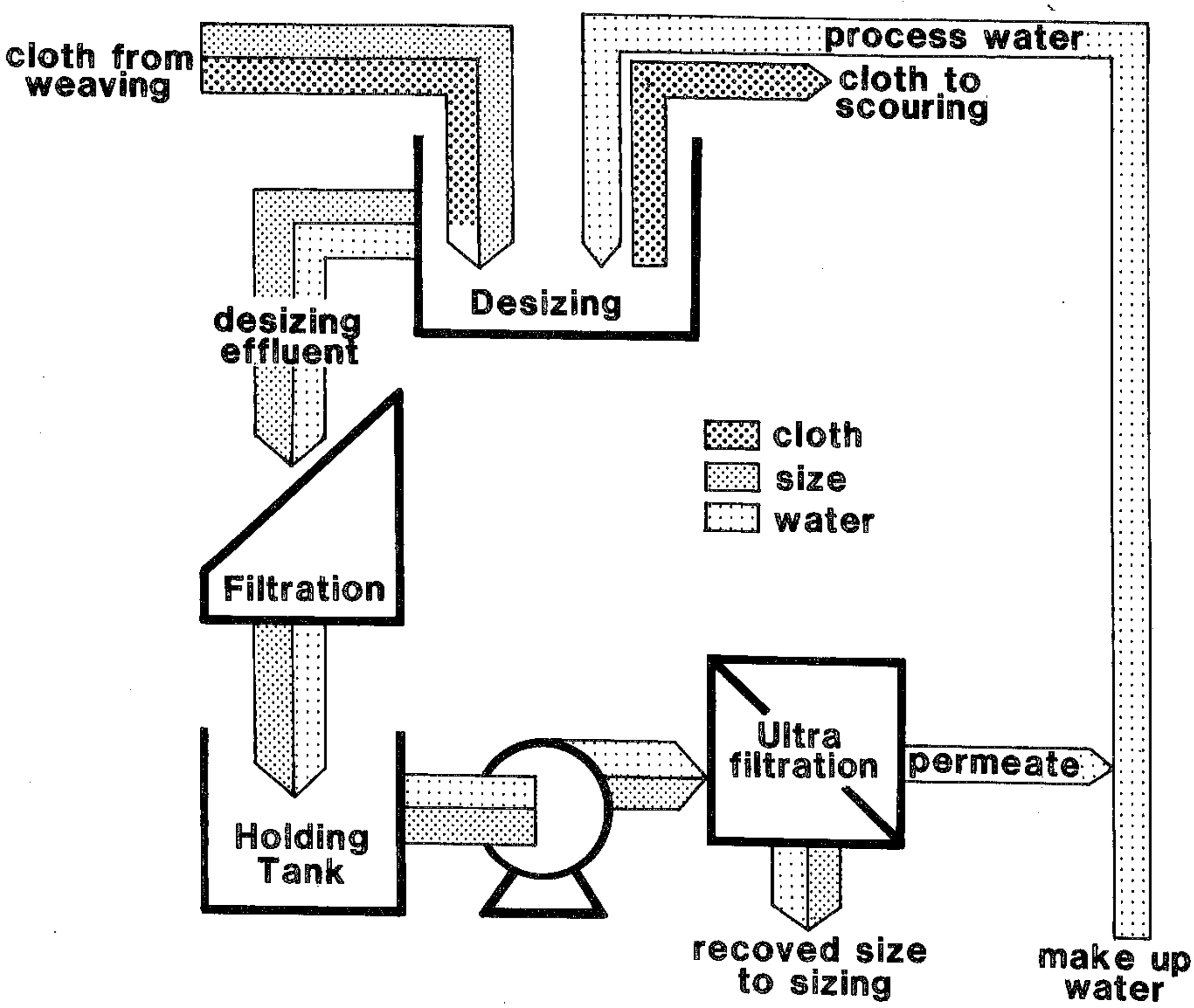


Figure 3.11: Desizing Effluent Pilot Plant

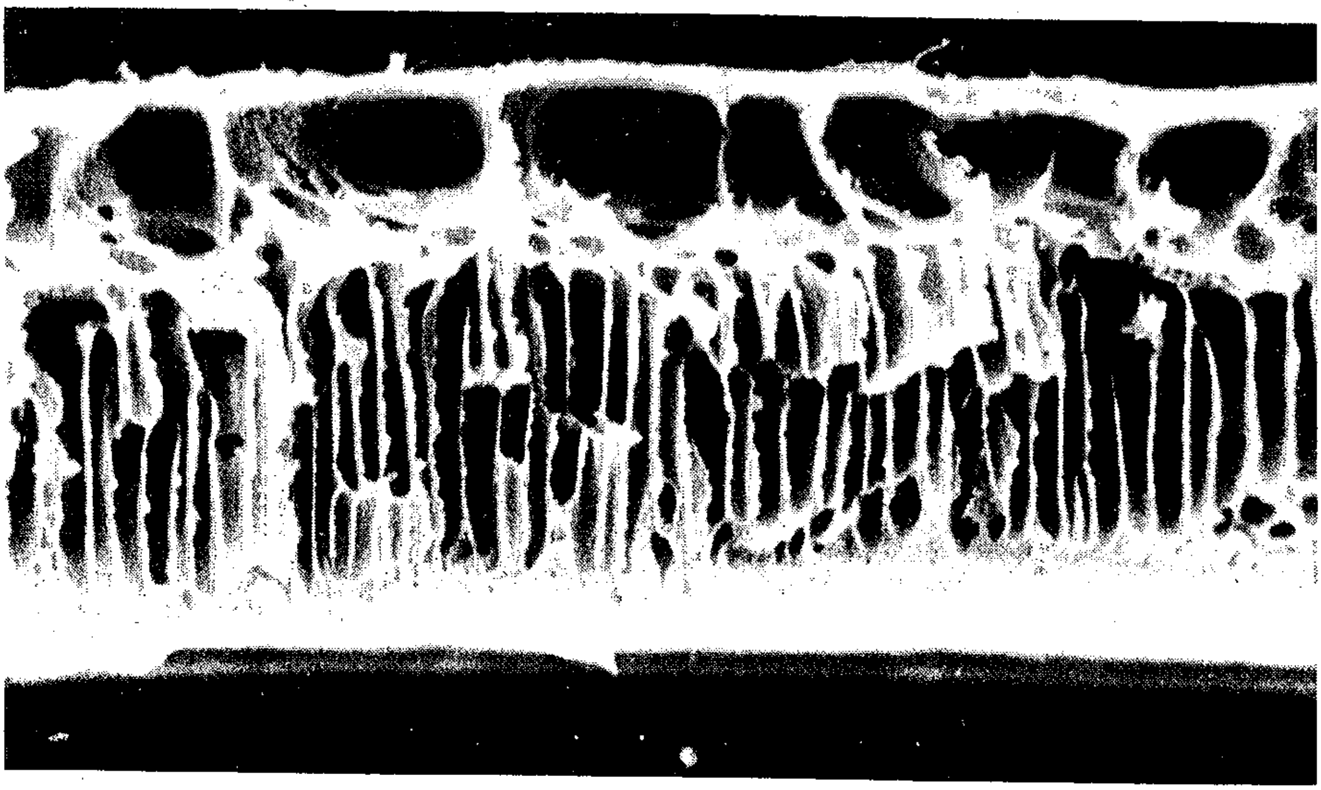


Figure 3.12: Electron Micrograph of an Ultrafiltration membrane

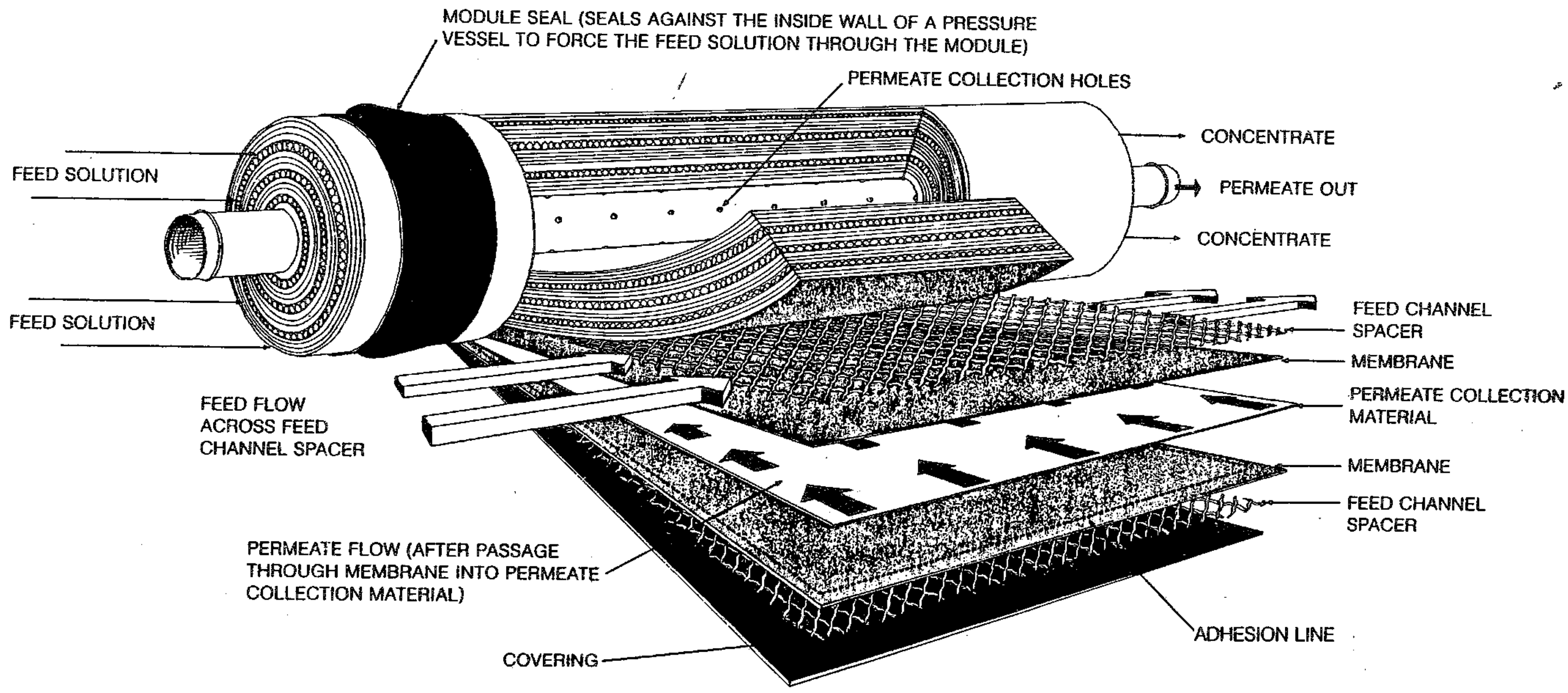


Figure 3.13: ABCOR Spiral Wound Membrane Element

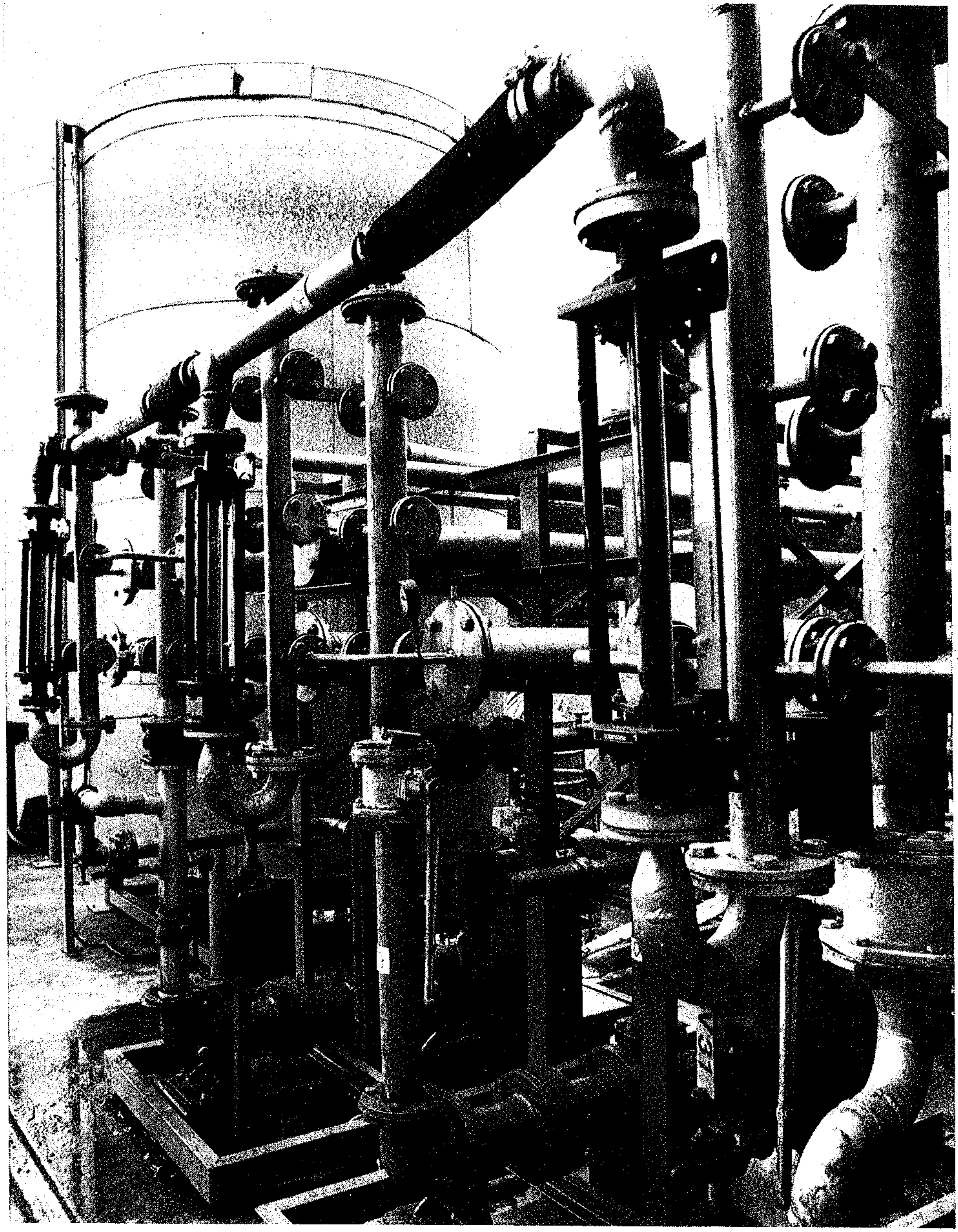


Figure 3.14: A View of the Ultrafiltration Pilot-Plant

TABLE 3.3 SPECIFICATIONS OF ABCOR HFM 180 MEMBRANES (4 INCH DIAMETER)

Membrane configuration	spiral-wrap			
Membrane material	polysulphone			
Molecular weight rejection	18 000			
Temperature limit (°C)	25	50	70	90
pH	0.5-13	1-12	1-10	2-9
Maximum pressure (kPa)	600	530	500	460
Membrane area	3,3 m^2			
Water flux (340 kPa and 25°C)	255 ℓ/m^2 h			
Chlorine exposure: continuous	10 ppm			
peak	500 ppm			
Chemical compatability:				
hydrogen peroxide	0,5%			
sodium hypochlorite	nil			
polar solvents	nil			

Chapter 4

DESIGN BASIS

4.1 EFFLUENT CHARACTERISTICS

The singeing and desizing effluent analysis and pollution parameter loadings are given in Table 4.1 and 4.2 respectively.

If singeing is carried out prior to desizing, then both effluent streams are collected for treatment by ultrafiltration. The effluent parameter loadings of the singeing effluent are about 10% of those from desizing.

4.2 FACTORY SIZING AND WEAVING TRIALS

4.2.1 Sizing

The impurity content of virgin and reclaimed PVA size is given in Table 4.3.

Infra-red spectra of the virgin and reclaimed PVA size show no significant differences (29).

4.2.2 Weaving

4.2.2.1 RECLAIMED PVA SIZE

The reclaimed PVA from the pilot-plant was reused by the factory either on its own or in admixture with virgin PVA. The overall ratio of reclaimed PVA to virgin PVA in these trials was 5:1.

The mill management consider that reclaimed PVA sizes and weaves as well as, if not better than, virgin PVA.

4.2.2.2 CONTROLLED WEAVING TESTS

Controlled weaving tests were carried out by the South African Wool and Textile Research Institute (29). The analysis of the stop time due to sizing faults indicated that the performance improved in the order:

starch/PAA,
virgin PVA,
once reclaimed PVA and
twice reclaimed PVA.

The starch/PAA blend was, at that time, the sizing agent in general use in most South African textile mills.

4.2.2.3 FACTORY WEAVING TRIALS

Systematic PVA weaving trials have been carried out by the factory to determine the percentage of production and the quality types that may be sized and woven with PVA size. Detailed trials on over 8 000 km of PVA sized cloth

TABLE 4.1: SINGEING AND DESIZING EFFLUENT ANALYSIS

		SINGEING		DESIZING	
		Mean	Range	Mean	Range
Total Solids	g/ℓ	38,8	1,5 – 66,3	18,5	7,6 – 42,9
COD	g/ℓ	40,3	1,5 – 82,5	17,5	1,5 – 66,8
OA	g/ℓ	5,4	0,25 – 10,8	2,3	0,3 – 7,2
Total Carbon	g/ℓ	13,4	1,3 – 27,5	8,0	1,4 – 18,0
Conductivity	mS/cm	12,3	3,6 – 32	5,1	1,6 – 10,8

were carried out and the conclusions were that the following types of warps may be woven successfully without loss of weaving efficiency:

cotton	above 15 tex
cotton/polyester	above 15 tex
cotton/viscose	36 tex and above
polyester	15 tex and above (high endages)
polyester/nylon	36 tex and above

The factory has woven 8 000 km of cloth using a mixture of reclaimed and virgin PVA. The range of qualities produced were cotton and polyester/cotton (65:35) of 20 to 78 tex for drill, twill, palladin and sateen weaves. The results of some typical trials are given in Table 4.4.

It has been found that the recycled PVA is softer than the virgin material resulting in fewer breaks at the split rods and fewer twisted or lost ends on the loom.

Warps of 15 tex and below can be woven, however, the efficiency is decreased. It is expected that as more experience is gained in sizing with PVA the weaving efficiencies of the lighter fabrics should improve.

This is an important consideration as a change in weaving efficiency of 1% represents about R0,003/metre of cloth (fixed costs and overheads).

TABLE 4.2 SINGEING AND DESIZING EFFLUENT PARAMETER LOADINGS

		Singeing	Desizing
Total Solids	g/kg	8,5	78,3
COD	g/kg	8,9	74,0
OA	g/kg	1,2	9,7
Total Carbon	g/kg	2,9	33,8
Water Usage	ℓ/kg	1,22	4,23

TABLE 4.3 IMPURITY CONTENT OF VIRGIN AND RECYCLED SIZE (mg/g PVA)

		Times Recycled		
	Virgin	1	2	3
Total Carbon	550	486	500	553
Total Solids	1 000	1 070	1 037	1 105
Calcium	0,28	0,54	1,16	0,25
Magnesium	0	1,08	2,03	0,75
Potassium	0	2,70	3,20	1,23
Sodium	0,6	13,5	24,1	19,7

4.3 DESIZING

4.3.1 Desizing Washer Efficiency

Figure 4.1 shows the percentage size removal at different water usages for the following three cases (26):

(i) A: three stage counter-current unit with a washing efficiency factor of 0,24

(ii) B: four stage full counter-current unit with a washing efficiency factor of 0,4

(iii) C: four stage split cross-flow, counter-current unit with a washing efficiency factor of 0,4.

If a 95% size removal is acceptable, then for cases A, B and C the water usage required is 4,9; 7,4 and 9,5 ℓ/kg respectively and the concentration factors needed for size reuse are 6,2; 9,5 and 12,2 respectively.

Hence it is clearly shown that counter-current operation of multi-stage washers is essential and that washers with good washing efficiency factors are advantageous.

4.3.2 Desizing Pollution Loads

The relative contribution of the desizing effluent to the pollution load of a South African mill is given in Table 4.5. In this case, the desizing effluent contributed 20% of the total mill COD load. In general, it is expected that the desizing effluent will contribute 15-40% of the mill pollution load, depending on the textile processes in use at the mill.

TABLE 4.4 LOOM EFFICIENCY OF WEAVING TRIALS

Type	Tex	Warp Ends/cm	Conventional Efficiency (%)	PVA Weaving Efficiency (%)	Comments
Co	25	33	80,8	83,3	Major Product
PE/Co	42	30	91,6	91,6	Minor Product
PE/Co	36	36	63,3	70,0	Difficult Product
PE/Co	15	40	92,0	89,0	2 Trials
Co	42	30	88,5	90,6	Major Product
Co	36	35	87,0	90,0	Major Product

Co Cotton PE/Co Polyester/Cotton

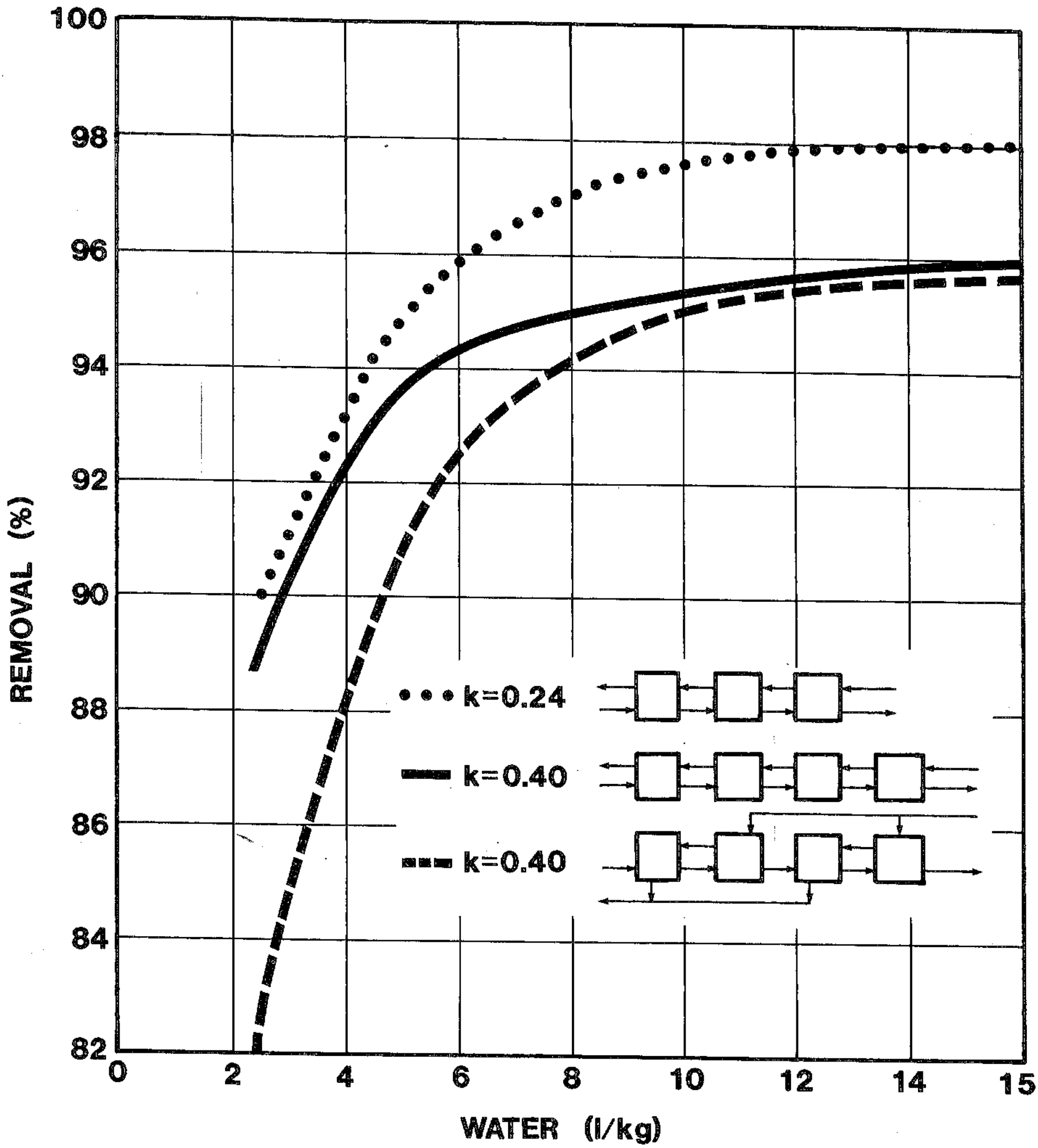


Figure 4.1: The Effect of Water Usage on Washing Efficiency for Three Washing Ranges.

TABLE 4.5: REDUCTION IN POLLUTION LOADS FOLLOWING THE IMPLEMENTATION OF A SIZE RECOVERY SYSTEM

Stage	Normal Pollution Load*		Pollution Load with Size Recovery		% Reduction	
	COD g/kg	TS g/kg	COD g/kg	TS g/kg	COD %	TS %
Desizing	89	95	5	5	94	95
Wet preparation	130	186	46	129	65	31
Total Mill	424	511	340	454	20	11

*Conventional sizing agents

4.4 SIZE LOSSES

A detailed cloth tracking exercise was carried out in order to determine the losses of size that occur during the processes from sizing through weaving, desizing and recovery (32). The specifications of the cloth are given in Table 4.6.

The results indicate that the PVA loss (expressed as a percentage of the total size applied at sizing) due to:

(a) weaving is small (1%)
(b) singeing is limited to the contents of the quench bowl of 4,2 kg of PVA per dump. This loss may be eliminated by recovering the quench bowl contents
(c) desizing varies from 2 to 12% of the size initially applied depending on the water consumption during desizing (Section 4.3.1)
(d) dumping of the bowls in the desizing wash range may be eliminated by recovering the contents of the washer compartments
(e) ultrafiltration is 3% of the size initially applied after all losses due to cleaning and membrane rejection are taken into account.

The total size loss that may be expected in different mill situations ranges from 6 to 19% of the size initially applied. Desizing efficiency is the major variable. Increasing the water usage to improve size removal results in a lower PVA concentration in the feed to the ultrafiltration plant. The optimum water usage would be an economic balance between the capital cost of the recovery plant and the incremental savings achieved by higher PVA recoveries.

TABLE 4.6 SPECIFICATIONS OF TRACKED CLOTH

Warp	36 tex cotton
Weft	42 tex cotton
Warp mass	17,02 kg/100 m
Weft mass	8,41 kg/100 m
Weave	Satin 4/1
Size Mix	90 g/ℓ PVA
Size add-on	1,68 kg/100 m

4.5 ULTRAFILTRATION SYSTEM

4.5.1 Prefiltration

4.5.1.1 PREFILTRATION REQUIREMENT

The presence of lint in the feed to spiral-wrap membranes, which have a spacing of 1,5 mm, causes mechanical blockage of the feed spacer mesh. This results in decreased membrane flux because of the reduction in available area and an increase in pressure drop.

In order to minimise the membrane area of the ultrafiltration plant, low desizing wash-water flow rates are advantageous, but this results in a significant fraction of PVA being in the gel form in the desizing effluent. This causes blinding of screens and cartridge filters.

4.5.1.2 LINT LOADS

Typical lint loads in the desizing effluent of 42 tex cotton fabric that had been cropped and singed were 69 mg/kg fabric. At a cloth speed of 70 m/min and a water flow of 2 m^3/h the lint concentration was 37 mg/ℓ.

4.5.1.3 RECOMMENDATIONS

Part of the PVA in the effluent is present as a gel. This should be dissolved either before filtration or recovered from the lint.

The lint loads are high and the volume of lint removed from the effluent is considerable, hence self-cleaning filtration systems should be employed. The high length to diameter ratio of lint requires tangential flow across filtration surfaces.

Suitable equipment for prefiltration is:

(i) mixing, centrifugation, cartridge filtration
(ii) mixing, wedge wire screen, radial flow vibrating screen, candle filtration with recycle of back-flush liquor, cartridge filtration
(iii) mixing, cartridge filtration.

The first case has the highest capital cost and the lowest operating cost and the third case has the lowest capital but the highest operating costs. The second case is a compromise between the two.

4.5.2 Ultrafiltration Membrane System

4.5.2.1 SYNTHETIC PVA SOLUTIONS

The ultrafiltration of synthetic PVA solutions is reported in Figure 4.2. Membrane fluxes are relatively low compared to other applications and this is mainly caused by the high viscosity of PVA solutions.

Figure 4.3 shows the effect of PVA concentration on viscosity as a function of temperature.

Figure 4.4 gives the flow resistance (pressure drop/flow rate) of PVA solutions on 4 inch Abcor spiral modules.

These two aspects and their relationship to membrane flux performance are covered in more detail in section 4.5.2.2.

4.5.2.2 MEMBRANE PERFORMANCE ON DESIZING EFFLUENTS

4.5.2.2.1 Factors Affecting Permeate Flux

The permeate flux from a spiral-wrap UF module is a complex function of inlet pressure, reject flow rate, polymer concentration, temperature and membrane fouling.

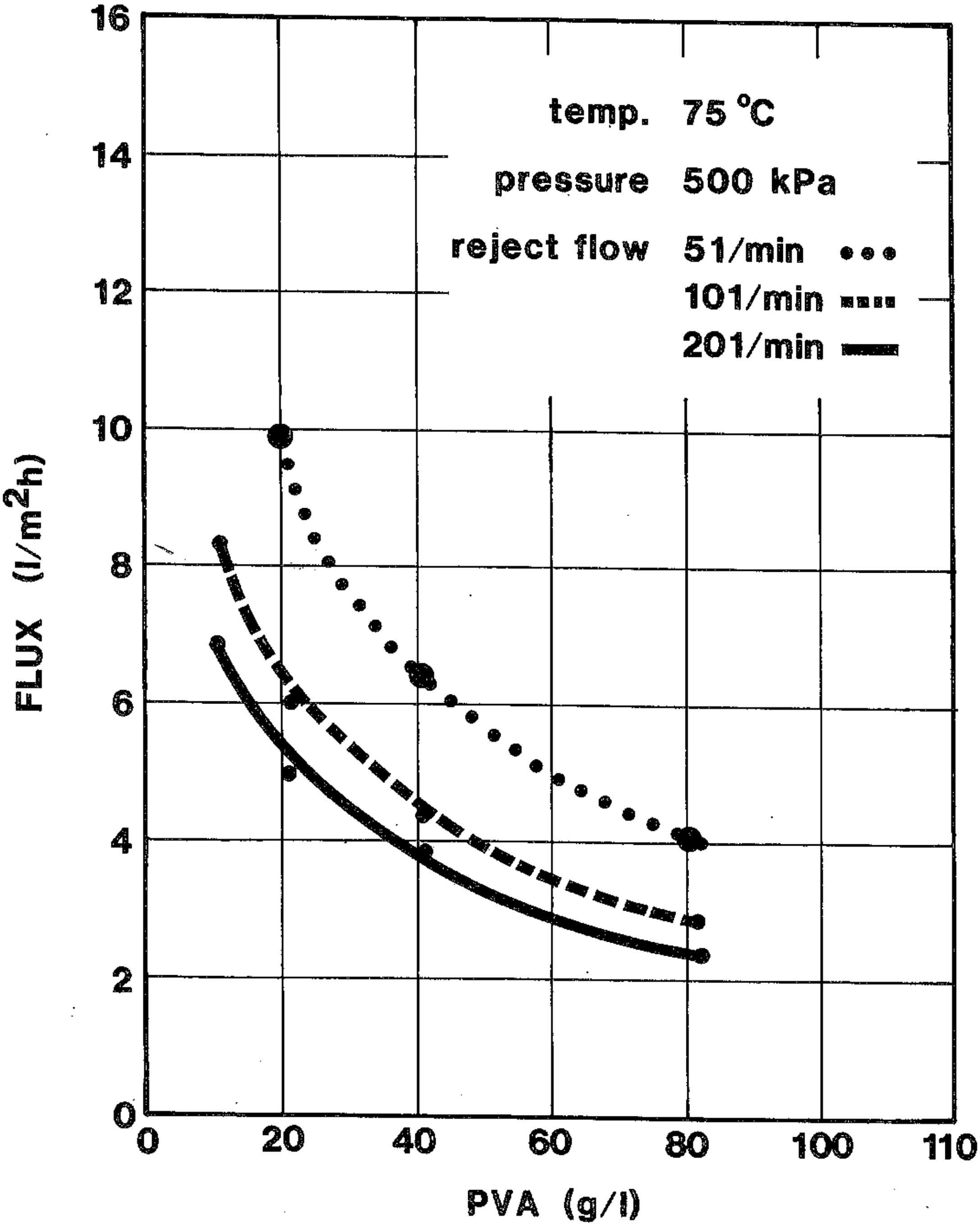


Figure 4.2: Synthetic Effluent Permeate Flux

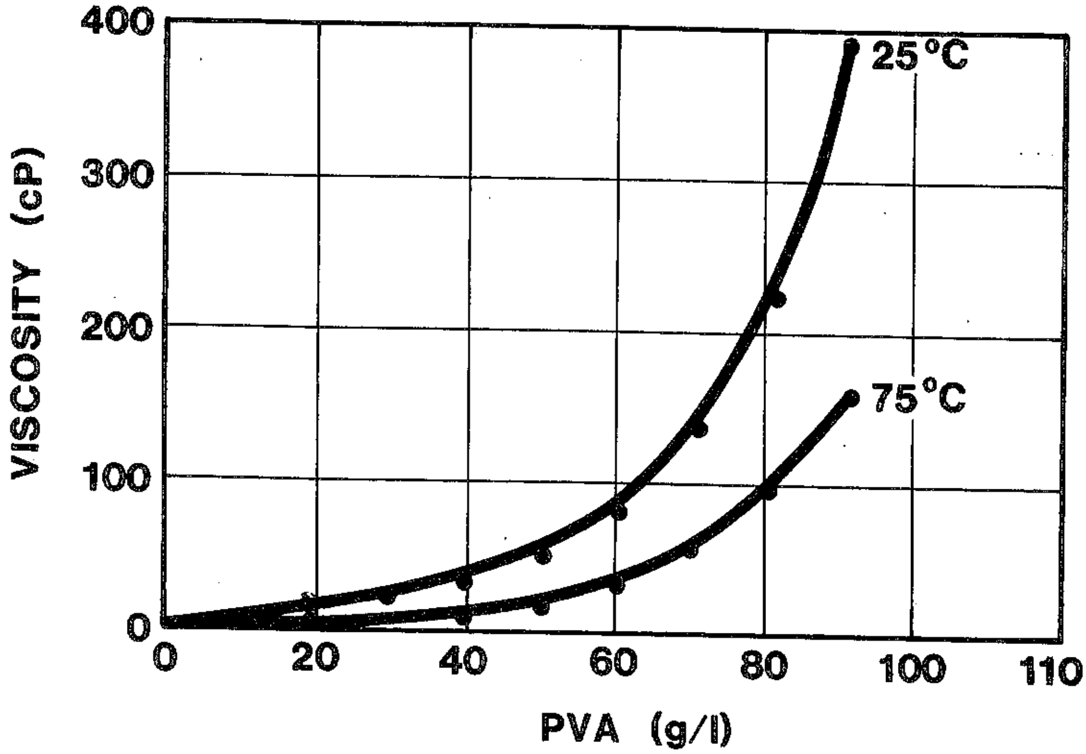


Figure 4.3: Viscosity of PVA Solutions

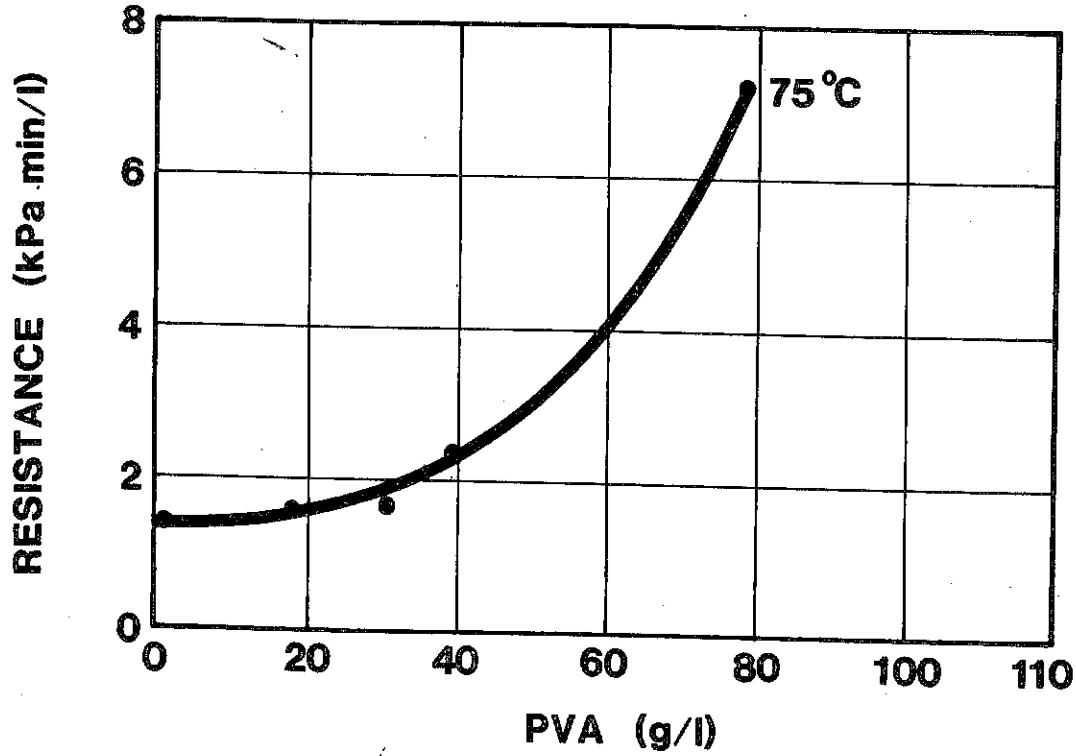


Figure 4.4: Resistance of ABCOR module

The following set of design equations can be used to assess the relative and interactive effects of the above variables (33, 34).

The permeate flux is given by:

$$J = \propto C_B^{\beta} Q^{\gamma} \ln \left[\frac{C_G}{C_B}\right] F + \delta \left[\tfrac{1}{2}(P_c + P_o) - \xi C_B \right] . (1 - F) \qquad 4.1$$

Where J is the membrane flux
C_b and C_g are the bulk and gel concentrations
Q is the reject flow rate
Po is the outlet pressure

The critical local pressure Pc, above which any point in the module is gel-polarised and the fraction of membrane area (F) which is gel-polarised are defined as:

$$Pc = \left[\propto C_B^{\beta} Q^{\gamma} \ln \left[\frac{C_G}{C_B}\right] . \frac{1}{\delta} \right] + \xi C_B \qquad 4.2$$

$$F = \frac{P_I - P_c}{P_I - P_o} \qquad 4.3$$

Where Pi is the inlet pressure and F is constrained to lie between O and 1.

The pressure drop along a single membrane element is given by:

$$\Delta P = aQ^b \left[1 + cC_B + dC_B^2 \right] \qquad 4.4$$

The regressed values for the above constants at 73°C are given in Table 4.7. A plot of actual and predicted permeate fluxes is given in Figure 4.5.

TABLE 4.7: REGRESSED VALUES OF THE PARAMETERS USED IN THE ULTRAFILTRATION MODEL

a	=	$1,0319 \times 10^9$	α	=	$1,8536 \times 10^{-6}$
b	=	1,366	β	=	−0,3032
c	=	−8,128	γ	=	0,327
d	=	183,1	δ	=	$1,27 \times 10^{-11}$
C_G	=	0,335	ξ	=	$7,5607 \times 10^5$

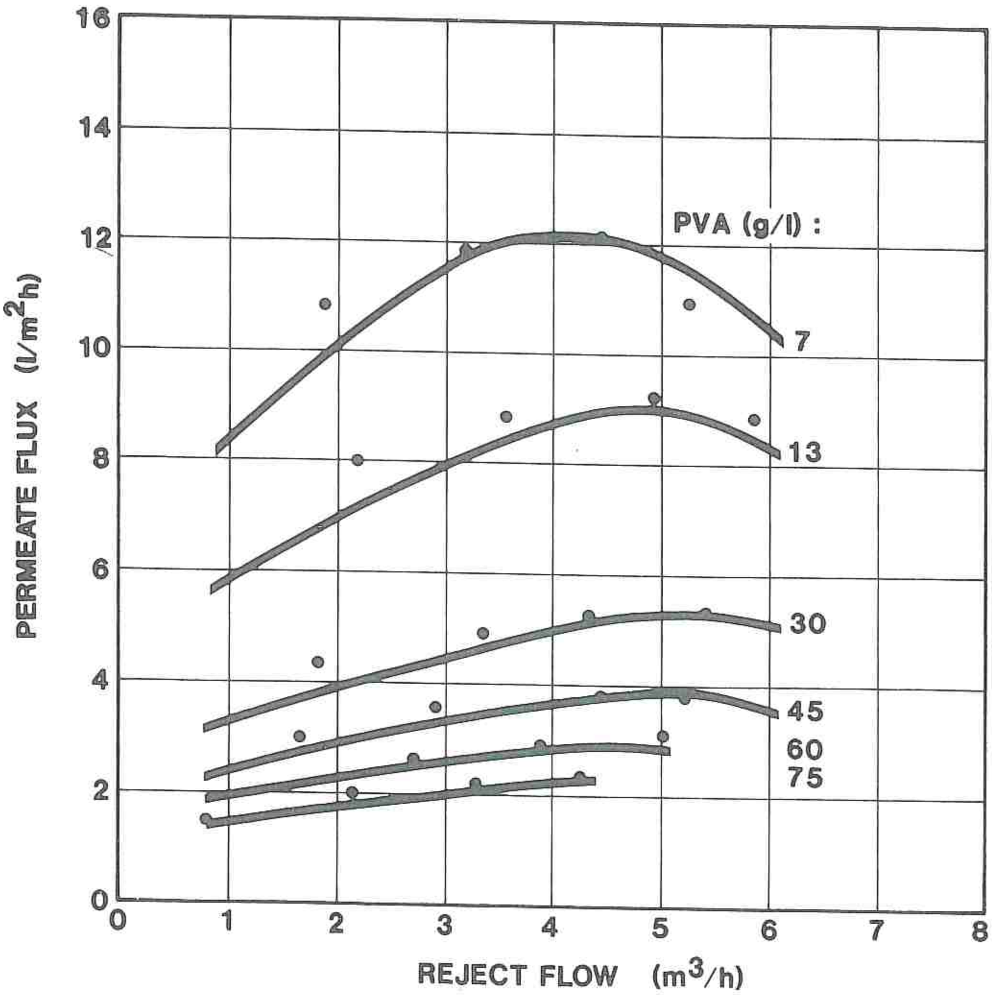


Figure 4.5: The effect of reject flow rate and PVA concentration on permeate flux. (The solid lines are the model predictions)

The two main effects which determine the permeate flux of a clean membrane are the transmembrane driving force and the formation of a polymer gel-layer adjacent to the membrane. For very dilute solutions the permeate flux increases with the average transmembrane pressure, which is at a maximum when the reject valve is closed, and decreases as the reject flow rate increases. For solutions which form gel-layers the permeate flux becomes limited because the formation of a gel-layer implies that the process becomes diffusion controlled. An increase in the reject flow rate decreases the thickness of the gel-layer resulting in an increase in flux. The model assumes that for any particular position along the membrane element, conditions will either be those of gel-polarisation or such that the eddies in the reject flow will be adequate to scour the surface.

The conclusions that can be drawn from the above analysis are:

(i) the inlet pressure to the membranes should be at the maximum allowed by the manufacturer.

(ii) higher permeate fluxes are achieved when the membrane is gel-polarised than when it is not gel-polarised.

(iii) when all the membrane is gel-polarised the permeate flux is independent of the pressure but is proportional to the reject flow rate to the power α.

(iv) equations 4.1 to 4.4 can be used for selecting the operating conditions for maximising the permeate flux.

(v) membrane fouling does not normally affect the permeate flux if the membrane is fully polarised because the flux is diffusion limited. However, fouling increases the critical pressure, Pc, and hence the fraction of the membrane area which is gel-polarised may be reduced resulting in a decreased permeate flux.

4.5.2.2.2 The Effect of Temperature on Permeate Flux

The effect of temperature on permeate flux has not been considered in the above analysis. The effect of temperature on the viscosity of PVA solutions is shown in Figure 4.3.

The desizing effluent is produced at 95-100°C and in order to conserve heat energy in the recycled permeate and concentrate, it is advantageous to operate the ultrafiltration plant at as high a temperature as possible. The recommended operating conditions for the membrane are given in Table 3.3. Figure 4.6 gives the effect of feed temperature on the permeate flux for a range of PVA concentrations in the effluent.

Operation at high temperature significantly increases the permeate flux and results in lower pumping cost due to the reduced viscosity of the effluent. Hence it is recommended that ultrafiltration be undertaken at the highest temperature possible.

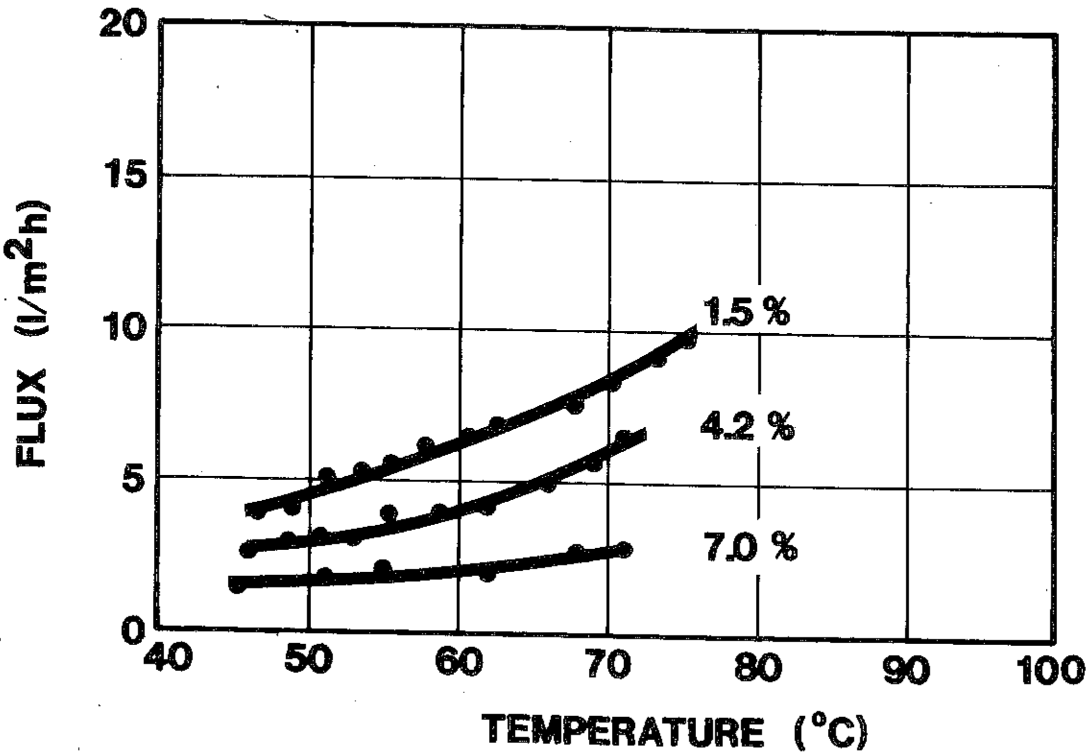


Figure 4.6: Variation of permeate flux with temperature

4.5.2.2.3 The Effect of Reject Flow Rate and Gel-Layer Formation

A series of experiments were carried out to determine the effect of reject flow rate on gel-layer formation. The feed pressure to the three elements in series was maintained at 500 kPa and the reject flow rate was varied by adjusting the back pressure valve. The experiments were carried out using desizing effluent at 75°C and membranes which had been used in the pilot plant for 15 months. The results are shown in Figure 4.7 and Table 4.8.

The two main effects which determine the permeate flux are transmembrane driving force and the formation of a polymer gel-layer adjacent to the membrane.

At 0% PVA, no gel-layer formation takes place and the average transmembrane pressure dominates, thus increasing the reject flow rate decreases the flux. The effect of gel-layer formation was dominant at 8% PVA and increasing the reject flow rate increased the permeate flux. At 1% PVA, the permeate flux remained constant for reject flow rates between 1,8 and 3,5 m^3/h. Intermediate PVA concentrations produced a maximum in the flux/reject flow rate curve indicating a gradual shift in dominance of the two effects.

The information given in Figure 4.8 provides the basis for determining the hydraulic flow regime that is needed for design purposes. For a multi-stage plant, the permeate flux may be maximised by operating each stage at the required reject flow rate and hence pressure drop relevant to the interstage concentration. This would result in the stage reject flow rates being different and hence would infer a series taper design with increasing velocities in succeeding stages. For a batch system the reject flow rate should be programmed to increase as the concentration increases.

TABLE 4.8 THE EFFECT OF REJECT FLOW RATE ON PERMEATE FLUX

Conc %	P_{in} kPa	P_{out} kPa	Reject Flow m^3/h	Flux ℓ/m^2h
0	500	160	4,60	16,83
		275	4,02	20,20
		325	3,38	21,64
		35	5,58	13,98
1,0	500	240	3,69	8,76
		45	5,54	7,74
		100	4,96	8,08
		160	4,80	8,26
		210	4,23	8,46
		270	3,51	8,76
		320	2,88	8,76
		385	2,15	8,76
		390	1,82	8,76
2,0	500	110	4,08	7,48
		190	3,64	7,51
		250	2,71	7,04
		330	2,23	6,47
		50	4,75	7,42
5,2	500	0	5,37	6,37
		50	5,29	6,26
		120	4,61	6,73
		200	3,79	6,20
		300	3,07	5,61
		400	2,05	4,72
8,0	500	40	4,99	3,46
		90	3,98	3,10
		192	3,37	5,19
		290	2,59	2,74
		0	5,50	3,58

Feed Temperature = 75°C

4.5.2.2.4 Flux — Pressure — Concentration Data

The permeate flux for three elements in series as a function of exit pressure and PVA concentration is summarised in Figure 4.9. Flow rate and pressure drop are interrelated as shown in Figure 4.8. These two design graphs provide the necessary information for the design of ultrafiltration plants for sizing/desizing effluent duty.

4.5.3 Membrane Cleaning

The degree of fouling of the membranes can be evaluated by measuring the water flux of the membranes and determining the membrane permeability constant, δ, from equation 4.5:

$$\delta = \frac{2J}{P_i + P_o} \qquad 4.5$$

A decrease in water flux can be caused by:

(i) membrane compaction
(ii) chemical fouling of the membrane surface
(iii) mechanical fouling of the feed spacer mesh.

The water flux of a new membrane is in the region of 200 $\ell/m^2/h$ but after about two months operation the flux drops to 80-120 $\ell/m^2/h$ (clean membrane). This membrane compaction is irreversable.

Chemical fouling is due to the build-up of PVA, waxes, starches and metal hydroxides on the membrane surface. The water fluxes can be restored by water rinses or by chemical cleaning with sodium peroxide or ammonium citrate rinses.

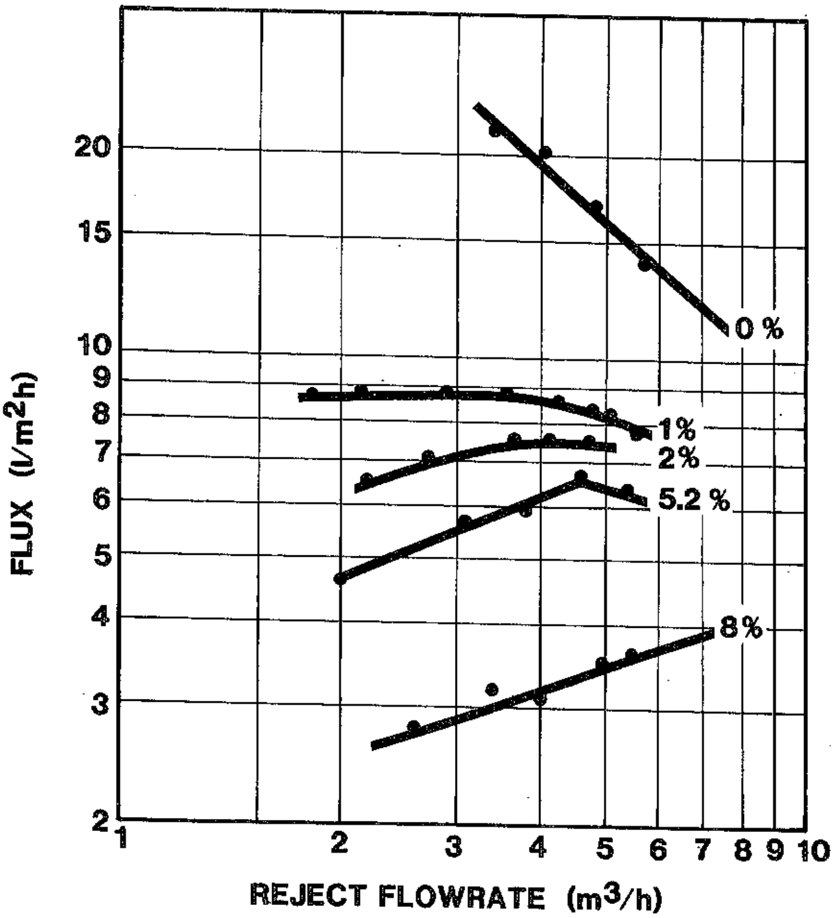


Figure 4.7: The Effect of reject flow rate on permeate flux

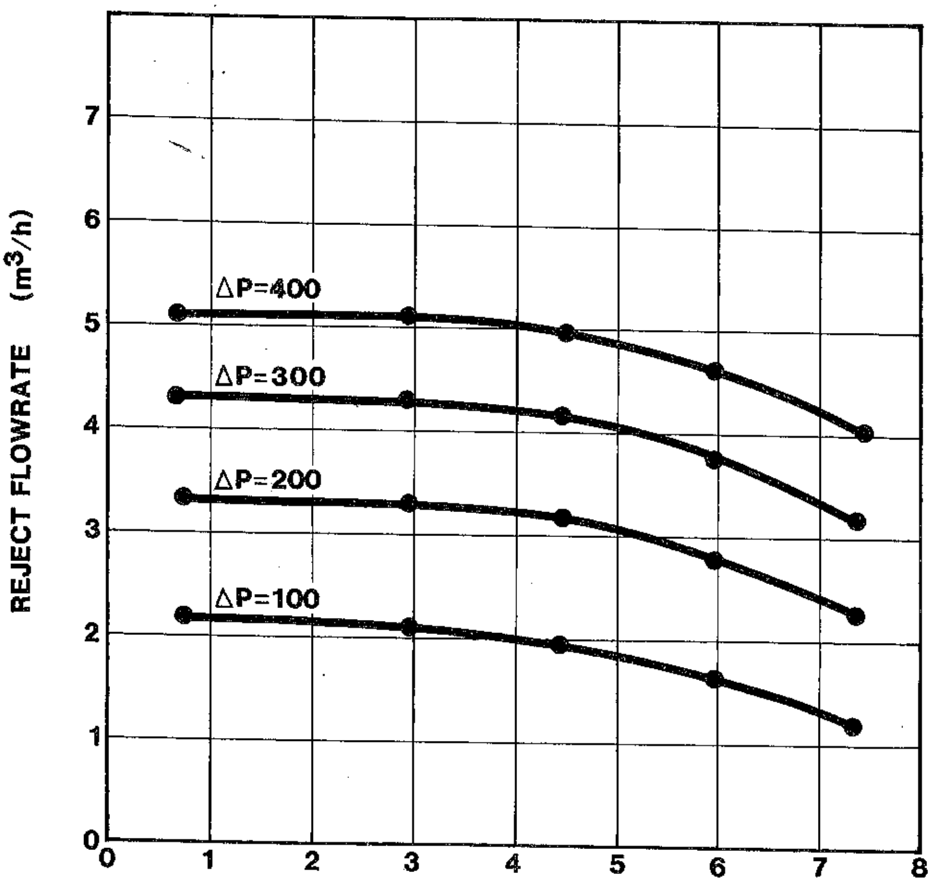


Figure 4.8: Pressure drop through three elements

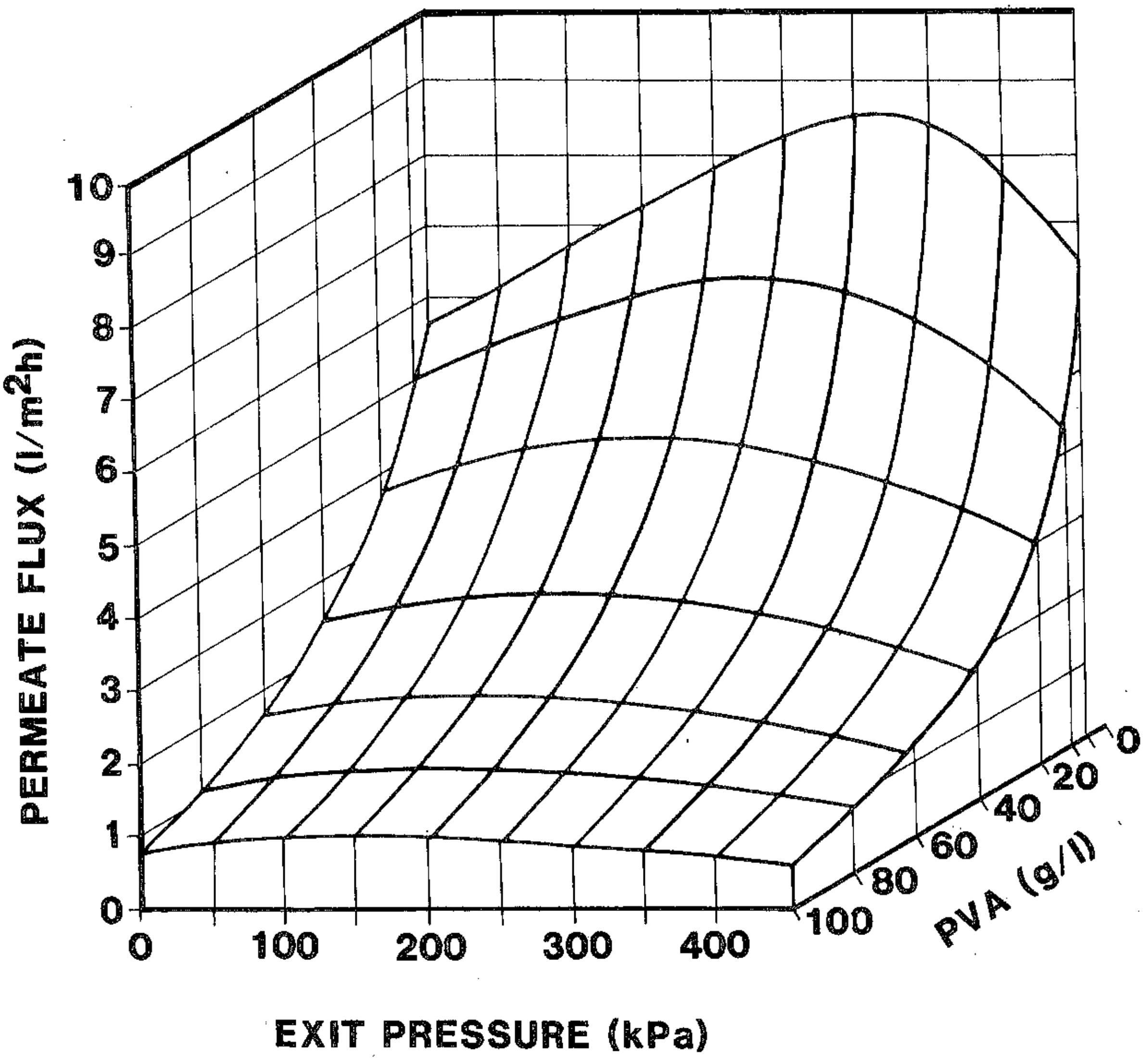


Figure 4.9: The Effect of PVA Concentration and Outlet Pressure on the Permeate Flux

Mechanical fouling is caused by the blockage of the feed spacer mesh by particulates leading to an increased pressure drop through the module. In addition the effective membrane area is decreased.

Results have been published showing the effect of membrane fouling on the average flux during the batch concentration of effluent for a range of operating conditions (35). The conclusions indicated that for membranes operating in the gel-polarised region the degree of fouling experienced in the pilot-plant studies has no effect on permeate flux. However fouling is of consideration where non-polarised conditions predominate, namely high reject flow rates, low inlet pressures and low concentrations of PVA.

Short (2 h) rinses with cold water are as effective as hot sodium peroxide rinses in restoring performance. These rinses should take place daily. In the longer term, 3 or 4 monthly rinses with sodium peroxide are required to maintain the membrane permeability after long term fouling.

4.5.3.1 CLEANING SOLUTIONS

(i) Cold Water Rinse
Recirculate cold water or permeate for 2 hours

(ii) Sodium Peroxide
10 mℓ/ℓ sodium peroxide (80%)
6,6 mℓ/ℓ sodium hydroxide (400 g/ℓ)
Recirculate at 50-60°C for 2 hours and then flush out with permeate

(iii) Ammonium Citrate
20 g/ℓ citric acid
Adjust pH to 2,5 with ammonia solution
Circulate for 2 hours and then flush out with permeate.

4.6 COMMERCIAL PLANT EXPERIENCE

The early publications by Abcor refer to results obtained with desizing effluent containing Du Pont Elvanol T25G PVA while the more recent results reflect the trend in the USA towards lower viscosity sizes (for energy conservation) and refer to Elvanol T66. The lower viscosity of Elvanol T66 results in a higher permeate flux and low pumping costs.

Results from the 50 m^3/day 3 stage system at Springs Mills factory in the USA using Elvanol T25G indicate permeate fluxes of

12 ℓ/m^2h at 10 g/ℓ
7 ℓ/m^2h at 50 g/ℓ
5 ℓ/m^2h at 60 g/ℓ

after 5 600 hours of operation (36).

The relationship between flow rate, PVA concentration and permeate flux is given in Figure 4.10 for a single 4 inch element operating on effluent at 82°C and an inlet pressure of 480 kPa (37).

The flux/pressure dependence of Elvanol T66 is given in Figure 4.11, the flux/temperature dependence in Figure 4.12, the flux/flow rate dependence in Figure 4.13 and the flux/concentration dependence in Figure 4.14 (38).

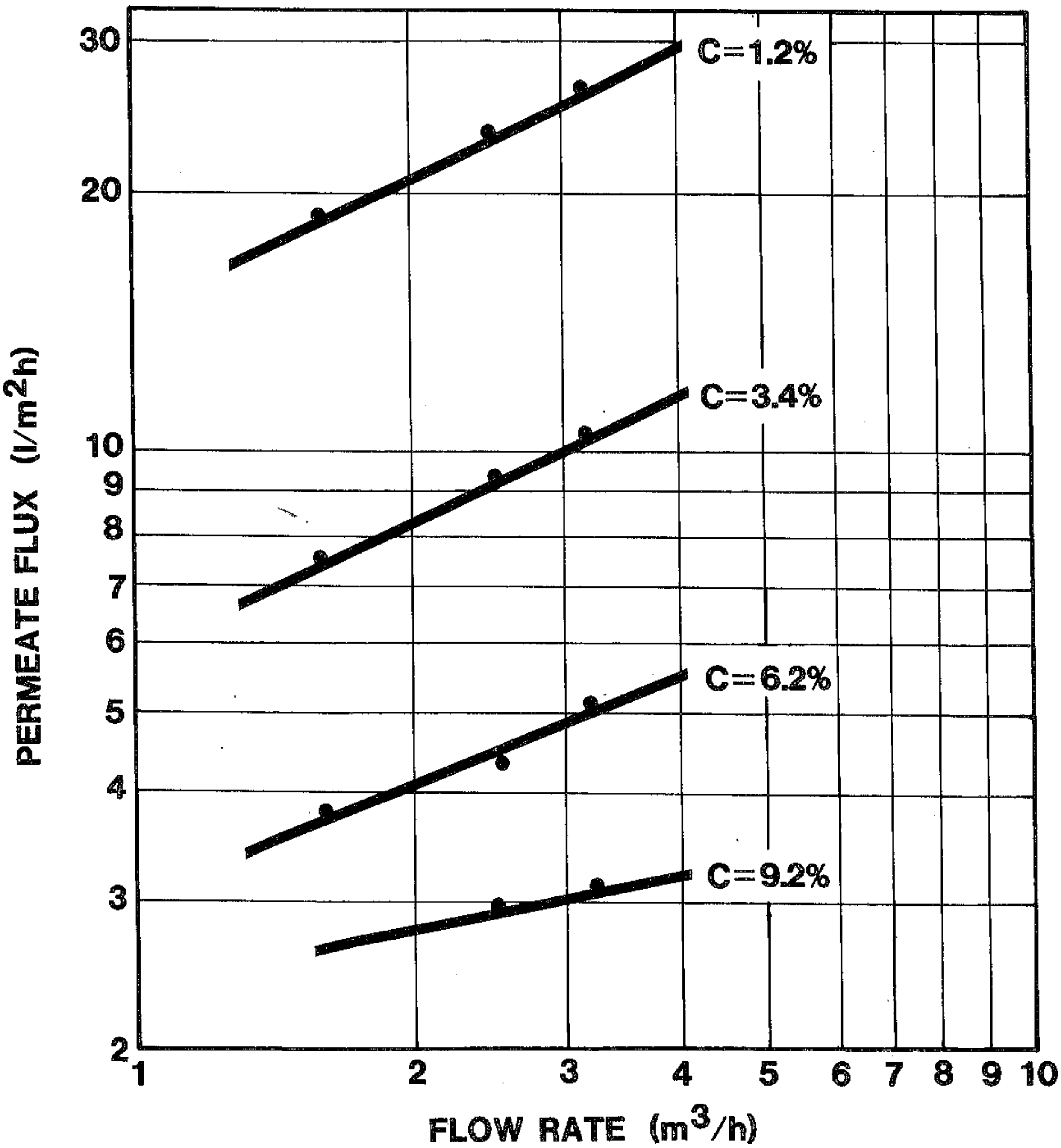


Figure 4.10: ABCOR Data — The Effect of Reject Flow Rate on Permeate Flux

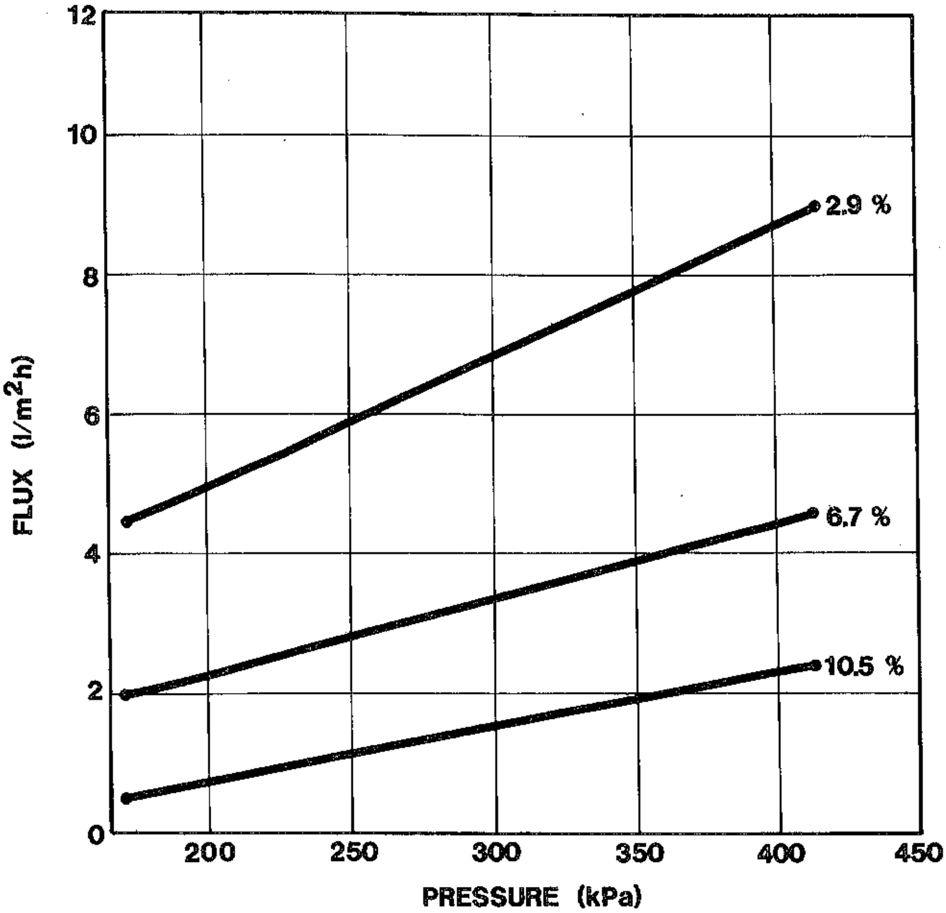


Figure 4.11: ABCOR Data — The Effect of Pressure on Permeate Flux

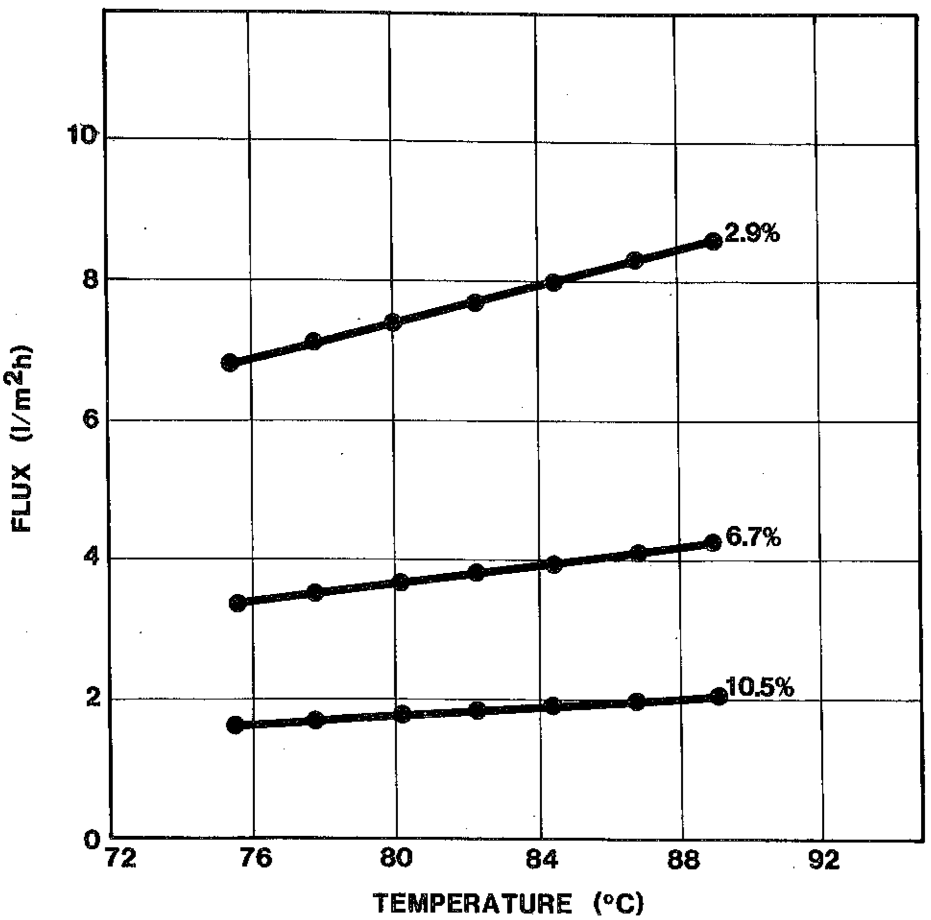


Figure 4.12: ABCOR Data — The Effect of Temperature on Permeate Flux

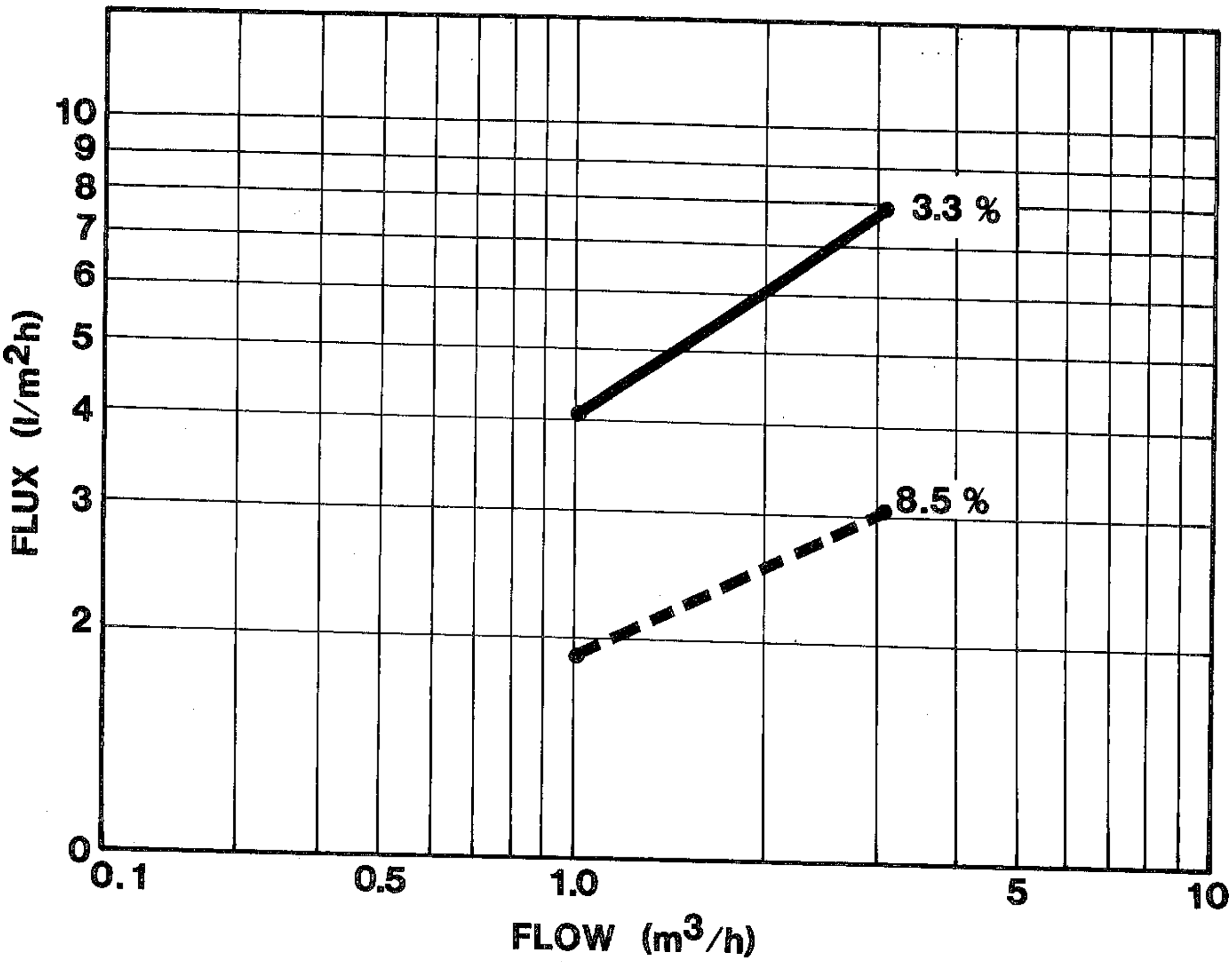


Figure 4.13: ABCOR Data – The Effect of Flow Rate on Permeate Flux

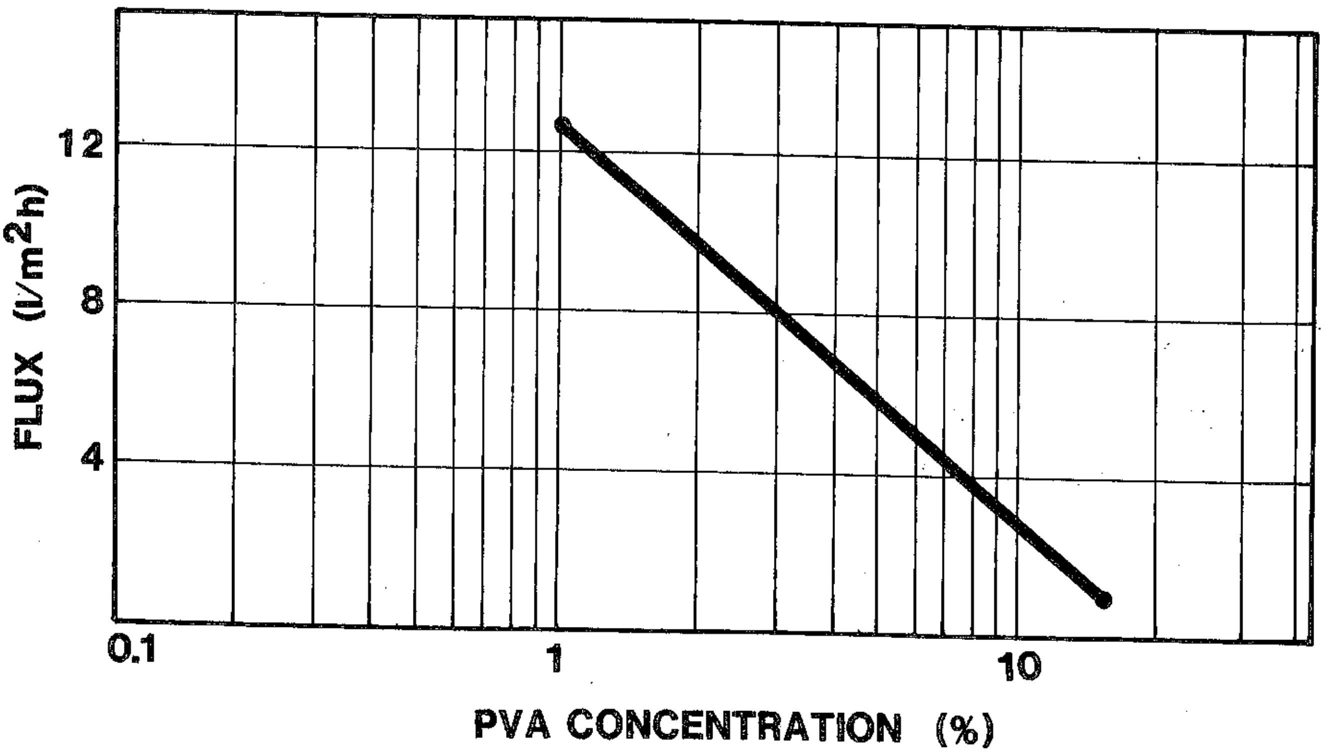


Figure 4.14: ABCOR Data – The Effect of PVA Concentration on Permeate Flux

Field tests at Springs Mills indicate that a 20% improvement in productivity is achievable using T66 size instead of T25G. In addition, the final PVA concentration may be raised to 12-14% (39).

Abcor conclude that operating at the pressure and temperature limits of the elements is generally prefered. The lint removal is achieved by a three phase prefiltration system consisting of a 115 micron vibrating screen filter, a 60 micron backflushable sock filter followed by 30 micron stringwound cartridge filters.

The permeate flux is maintained by weekly water rinses and periodic rinses with solutions of surfactants and/or dilute hydrogen peroxide to remove waxes and PVA or citric acid solutions to remove iron and other mineral foulants from the membrane surface.

In a series system the areas of each bank are often all equal so as to reduce the inventory of spares that are required. Between 1 and 4 banks are installed.

To date twelve systems have been installed in the USA, the largest of which has a capacity of 34 m^3/h.

Chapter 5

DESIGN OF A SIZING/ DESIZING EFFLUENT ULTRAFILTRATION TREATMENT/RECYCLE PLANT

5.1 IMPLEMENTATION OF A SIZE RECOVERY PLANT

In order to determine the economic and technical feasibility of size recovery at a particular mill a number of trials should be undertaken.

5.1.1 Sizing and Weaving

Sizing and weaving trials should be carried out using 100% PVA size. These trials should be started with heavy warps progressing to lighter warps as more experience is gained in sizing and weaving with PVA. A pure PVA should be used in preference to a "one-shot" size as the wax content must be decreased when reclaimed size is reused. The addition of a fugitive tint to the size assists in identifying the cloth after it has been cut off the loom.

5.1.2 Sizing with Polyvinyl Alcohol

Polyvinyl alcohol size needs a few precautions on solution formation.

The size solution is made by slurrying the PVA into cold water and then heating the slurry either with live steam or through a heat exchanger to 80-90°C for 30-45 minutes. The PVA solution can be cooled to room temperature without gelling.

The size box temperature should be maintained at 65-80°C as this temperature will ensure complete penetration of the yarn and allow stretching of the yarn if desired. This temperature range is low enough to reduce the tendency for the size to form a skin on the bath surface during stoppages or during creep operation of the slasher. The maintenance of correct spacing between individual warp yarns is important for optimum pickup of size and to prevent yarn breakages at the splitter rods after the drying cans. A double size box and split warp sheet drying is advantageous in this respect.

Adjacent warp ends should be separated by a space at least equal to the yarn diameter. After stoppages, when the warp is not removed from the size box, it is advantageous to spray water onto the section of the warp sheet that has been oversized. The addition of wax up to 5% of the mass of PVA helps ensure a clean yarn split.

The temperature of the drying cans should not exceed 140°C. As low a drying temperature as possible should be used to minimise crystallisation of the PVA.

Applicable size concentrations for these trials can be obtained from the relevant literature e.g. Du Pont Manual (40); and for example, a size concentration of 9% solids content (refractometer) is suitable for sizing 25 tex cotton/polyester with, for example, Du Pont type Elvanol T25G PVA size. Broken ends can occur at the split rods due to over-sizing if the warp has been allowed to stand in the size box for any length of time. The problem can be overcome by lowering the warp sheet into the size box just before the machine starts to run and by raising the warp sheet whenever any stoppages occur. Spraying water onto the warp between the nip rollers and the drying cans assists in removing the excess external size.

The cost of conventional size and 100% PVA size for each quality should be calculated together with the percentage by weight and length of the mill production that can be sized with 100% PVA. The weaving efficiencies for both conventional and PVA sized warps should be determined.

5.1.3 Preparation

The PVA sized cloth should be segregated after it has been cut off the loom and made up into batches containing only PVA sized cloth. After singeing, the cloth is quenched in a standing bowl of cold water and batched for a sufficient length of time to allow the PVA to swell (2 to 6 hours). The volume of water in the quench bath and the PVA concentration should be noted. The savings associated with not using an enzyme padding solution should be calculated.

5.1.4 Desizing

Desizing trials should be undertaken to determine the minimum water requirements for an acceptable cloth quality. Decreasing the water consumption increases the PVA concentration in the desizing effluent leading to a smaller ultrafiltration plant. At the same time, lowering the water consumption leads to a higher residual PVA content on the fabric. As high a temperature as possible should be used for desizing. The average water consumption per kilogram of fabric, the PVA concentration in the effluent and the PVA remaining on the fabric should be determined. The flow rate, composition and cost of disposing of conventional desizing effluent should be determined together with the cost of steam and water.

5.2 MAJOR DESIGN PARAMETERS

5.2.1 Design Basis

The design of an ultrafiltration system is based on the following parameters which determine the product rate and permeate flux performance:

(i) Size concentration range
(ii) Feed temperature
(iii) Feed flow rate
(iv) Inlet pressure
(v) Degree of membrane fouling.

In general, the membrane permeate flux decreases with increasing concentration and degree of fouling and increases with increasing temperature and inlet pressure. The flux dependence on flow rate is complex and is dependent on concentration, temperature and inlet pressure. It is usual to operate an ultrafiltration plant at the temperature and pressure limits of the membranes. The average membrane flux for the duty required is calculated as outlined in section 5.3.

Mechanical fouling of the membranes is prevented by removing all lint from the desizing effluent prior to ultrafiltration and chemical fouling is controlled by hot water rinses and occasional washing with caustic soda and hydrogen peroxide solutions.

5.2.2 System Configuration

An ultrafiltration plant for size recovery can be configured either as a batch concentration or a series-taper system. In a batch system, the effluent is recirculated past the membrane and returned to the feed tank and the permeate is continuously removed from the system. The permeate flux decreases with time as the PVA concentration increases. This system has the highest overall flux, however, buffer feed, product and permeate storage facilities have to be provided. This type of configuration is best suited to relatively small plants.

The series-taper configuration consists of a number of individual banks of membranes each with their own recirculation pump. This system is energetically efficient in that the outlet pressure from one stage is used in the next stage and is not lost through a back pressure valve as in the batch system. If, for example, the PVA concentration were to be increased from 1% to 6% then 83% of the water must be removed from the feed solution. Then for a 3-stage system, typically 50% would be removed in the first stage, 25% in the second and 8% in the third stage. The concentration in each of the stages would be about 2%, 4% and 6% respectively. To achieve the decreasing water recoveries, the membrane area of the successive stages is decreased. This configuration has the advantage of being a continuous system with the bleed from the last stage being automatically controlled at the desired concentration. A large buffer storage capacity is not required. This configuration is best suited to relatively large capacities.

5.2.3 Equipment Specification

5.2.3.1 INTRODUCTION

The equipment needs and specifications for a batch concentration UF plant are given in the following section. The major differences between the batch mode and the continuous multistage taper mode are the holding tank volumes and the recirculation pumping requirements.

The general design specifications are:

(i) process streams have temperatures of 80-100°C
(ii) the effluent contains suspended solids
(iii) the viscosity of several of the process streams is high and selection of pipeline diameters, pumps etc. should be considered carefully
(iv) the effluent and UF concentrate streams are prone to biological attack and should be kept above 60°C
(v) for textile operation, the general material of construction should be 304 stainless steel or better.

5.2.3.2 EQUIPMENT REQUIREMENTS

1. Effluent Transfer and Storage

1.1 Desizing Washer

1.1.1 Pipeline connection and valves for transfer or drain
1.1.2 Coarse screening
1.1.3 Pump sump
1.1.4 Transfer pump and controls
1.1.5 Transfer piping to prefiltration

1.2 Prefiltration

1.2.1 Fine screening
1.2.2 PVA gel dissolution
1.2.3 Backwashable filtration
1.2.4 Cartridge filtration
1.2.5 Filter backwash disposal system
1.2.6 Pump sump
1.2.7 Transfer pump and controls
1.2.8 Transfer piping to storage

1.3 Effluent Storage

.3.1 Batch storage tanks
.3.2 Interconnecting piping and valves
.3.3 Heat exchanger
.3.4 Heat exchanger loop pump

1.4 Controls

1.4.1 Pump motors, starters and interlocks
1.4.2 Flow and/or level sensors
1.4.3 Malfunction control interlocks
1.4.4 Flow, pressure indicators
1.4.5 Temperature controller

2. Ultrafiltration

2.1 Modules

2.1.1 Membrane elements and assemblies
2.1.2 Module housings
2.1.3 Piping and valves for feed, concentrate and permeates

2.2 Pumps

2.2.1 Feed pump
2.2.2 Recirculation
2.2.3 Piping and valves

2.3 Controls

2.3.1 Pump motors, starters and interlocks
2.3.2 Control panel
2.3.3 Flow and pressure measurement, indication and control
2.3.4 Concentration measurement, indication and control
2.3.5 Malfunction control interlocks

3. Recycle

3.1 Permeate

3.1.1 Permeate storage tank
3.1.2 Permeate transfer pump, piping and valves
3.1.3 Permeate connections to desizing washer
3.1.4 Water make-up systems
3.1.5 Flow and quality measurement

3.2 Concentrate

3.2.1 Concentrate storage tank
3.2.2 Concentrate circulation pump, piping and valves
3.2.3 Concentrate connections to sizing department
3.2.4 Size make-up system
3.2.5 Flow and concentration measurement

4. Cleaning

4.1 Cleaning tank
4.2 Cleaning pump, piping and valves

5 Ancillary

5.1 Electrical supply
5.2 Air supply
5.3 Steam supply
5.4 Water supply
5.5 Cleaning chemical storage
5.6 Pipeline and module insulation
5.7 Drains
5.8 Building
5.9 Effluent handling during breakdowns

5.2.3.3 PUMPS

The process stream specifications for pump selection are:

Desizing Effluent	1-2% PVA solution Temperature 90-95°C Lint 50 g/m³
Ultrafiltration Batch Concentration	1-2% to 7-9% PVA solution Temperature 75°C Pressure 550 kPa Viscosity 10-100 cP (working) 800 cP (cold start)
Concentrate	7-9% PVA solution Temperatures 60-70°C Viscosity 100 cP
Permeate	Water Temperature 75°C

Pumps will generally be of the centrifugal type in stainless steel construction and suitable for high viscosity process fluids where applicable. Pump seals should be water flushed to avoid PVA gelling.

5.2.3.4 PREFILTRATION

This is one of the major design considerations. A suitable sequence is as follows:

(i) coarse screening at the desizing washer to avoid pump blockages.

(ii) mixing to dissolve PVA gel.

(iii) fine screening to remove lint.
Suitable screening devices for duties (i) and (iii) are either vibrating screens or inclined screens. The final screenings, consisting of lint, are disposed of by the factory solids disposal method.

(iv) lint removal by filtration. A back-washable filter, such as porous stainless steel or polypropylene cartridges or a tubular shower filter, is preferred as this filtration duty is difficult. Filtration pore sizes of 30-60 micron are needed. The filter back-wash may be reprocessed if necessary to avoid PVA loss.

(v) cartridge filters of 20-30 micron. These are needed as a final barrier to prevent mechanical fouling of the ultrafiltration spiral-wrap membranes. Under normal operation they should have a reasonable cycle time and are incorporated into the design as a safety measure against prefiltration failure.

5.2.3.5 MEMBRANES

The pilot-plant investigations used 4 inch diameter Abcor HFM membranes of 3,3 m^2 area. Their expected lifetime is over 3 years from the pilot-plant investigation. This membrane is available in 4 inch or 8 inch diameters of 3,3 and 15 m^2. Most designs would use the larger diameter module because of its cost advantage.

Other membrane manufacturers may also be able to supply suitable membranes. The main design specifications for the membrane elements are:

(i) temperature capability of 75-85°C
(ii) no membrane — feed interactions
(iii) long life time
(iv) efficient hydrodynamics
(v) suitability for mechanical and chemical cleaning
(vi) cost effectiveness
(vii) reliability.

5.3 DESIGN BASIS

An outline design is presented for a mill having the following average production and processing conditions.

Cloth production	= 2 × 10^6 metres/month
Cloth weight	= 200 g/m
PVA add-on at sizing	= 15 kg/1000 m cloth
Size box PVA concentration	= 90 g/ℓ
Size losses	= 15%
Desizing water usage	= 4 ℓ/kg
Production time	= 600 h/month

Sizing PVA requirements	= (2×10^6)(10^{-3}) × (15)
	= 30 000 kg/month
PVA loss (15%)	= 4 500 kg/month
PVA make-up requirement	= 4 500 kg/month
PVA in effluent	= 25 500 kg/month
Desizing effluent volume	= (2×10^6) × (0,2) × (4/1 000)
	= 1 600 m^3/month = 2,667 m^3/h
PVA concentration of effluent	= 25 500/1 600 = 15,94 g/l
Reclaimed size concentration requirement	= 90 × (1 − 0,15) = 76,5 g/l
Concentrate required	= 1 600 × (15,94/76,5)
	= 333,4 m^3/month = 0,556 m^3/h
Permeate required	= 1 600 − 333,4
	= 1 266,6 m^3/month = 2,111 m^3/h

Thus the UF requirement is to process 2,667 m^3/h of effluent at 15,94 g/ℓ PVA and concentrate it to 76,5 g/ℓ PVA. The permeate production is 2,111 m^3/h.

From Figure 5.1, the average permeate flux for these conditions is about 5,2 ℓ/m^2h at an inlet flow rate of 5 m^3/h for 4 inch modules or 22,75 m^3/h for 8 inch modules.

Membrane area required	= 2 111/5,2 = 406 m^2
Number of 8 inch membranes (15 m^2 each)	= 27
Number of module housings for 3 membrane elements per housing	= 9

The module layout consists of 9 parallel streams each containing three membrane elements in series.

For a batch concentration system, the duplicate feed storage capacity needs for 8 hours retention are 2 feed tanks each of 21,33 m^3.

Permeate storage for 24 hours of UF production is 50,7 m^3.

Concentrate storage for 24 hours of UF production is 13,34 m^3.

Ultrafiltration feed pump required is:

Flow = 9 × 22,75 = 205 m^3/h

Pressure = 500 kPa

The layout of the UF treatment/recycle plant is shown in Figure 5.2.

5.4 MAINTENANCE

The size recovery UF plant requires no special maintenance. Attention should be paid to various aspects which would result in reduced plant capacity and these include:

(i) ensuring the minimum amount of water is used to desize the cloth
(ii) all the lint is removed from the feed to the UF plant
(iii) the feed temperature is maintained as high as possible
(iv) the reject flow rate from the modules is as high as possible
(v) the membranes are relatively clean
(vi) the size is returned at the lowest concentration that is possible

A detailed list of inspections is given in Table 5.1.

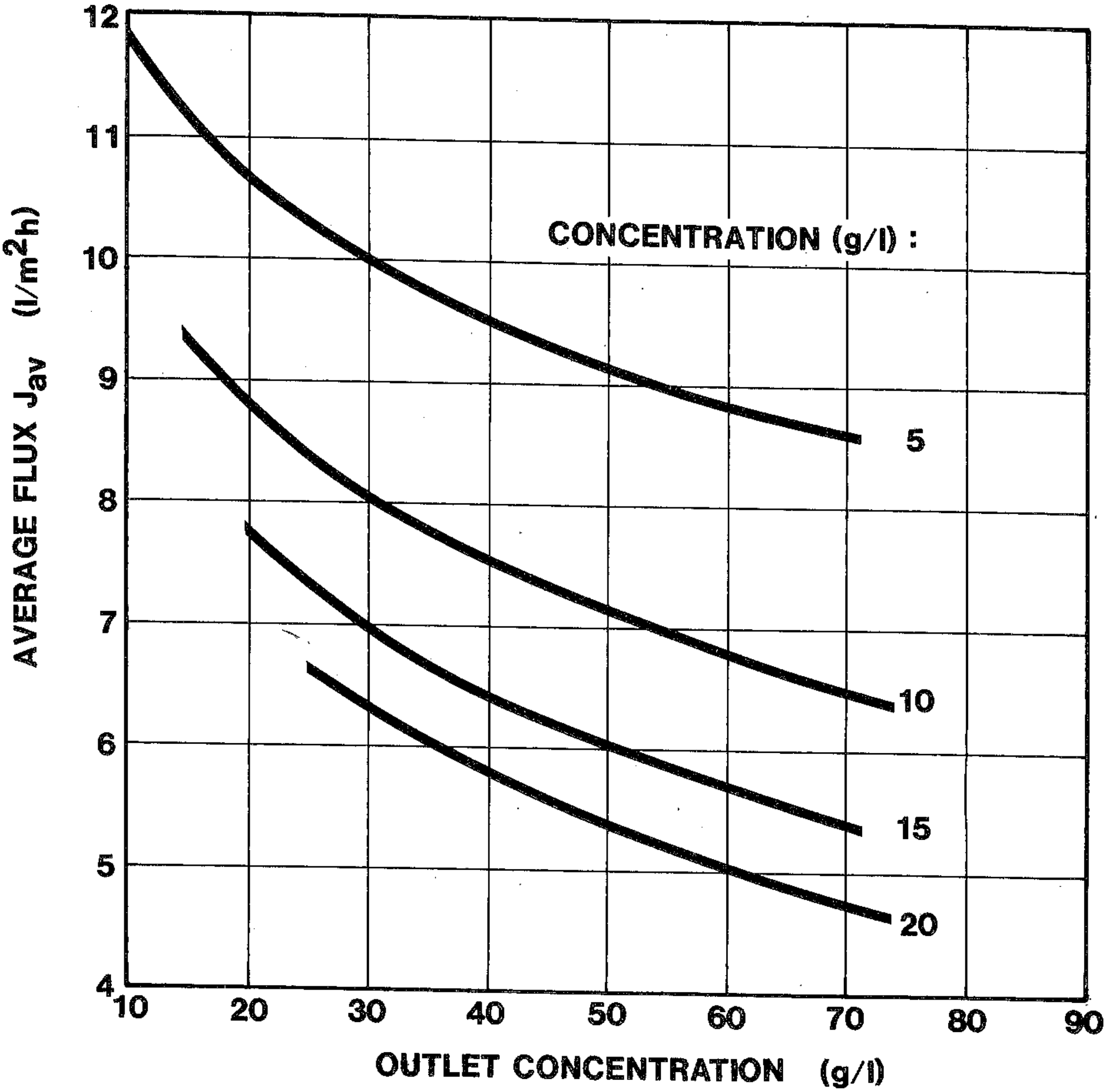


Figure 5.1: Average membrane flux for batch concentration

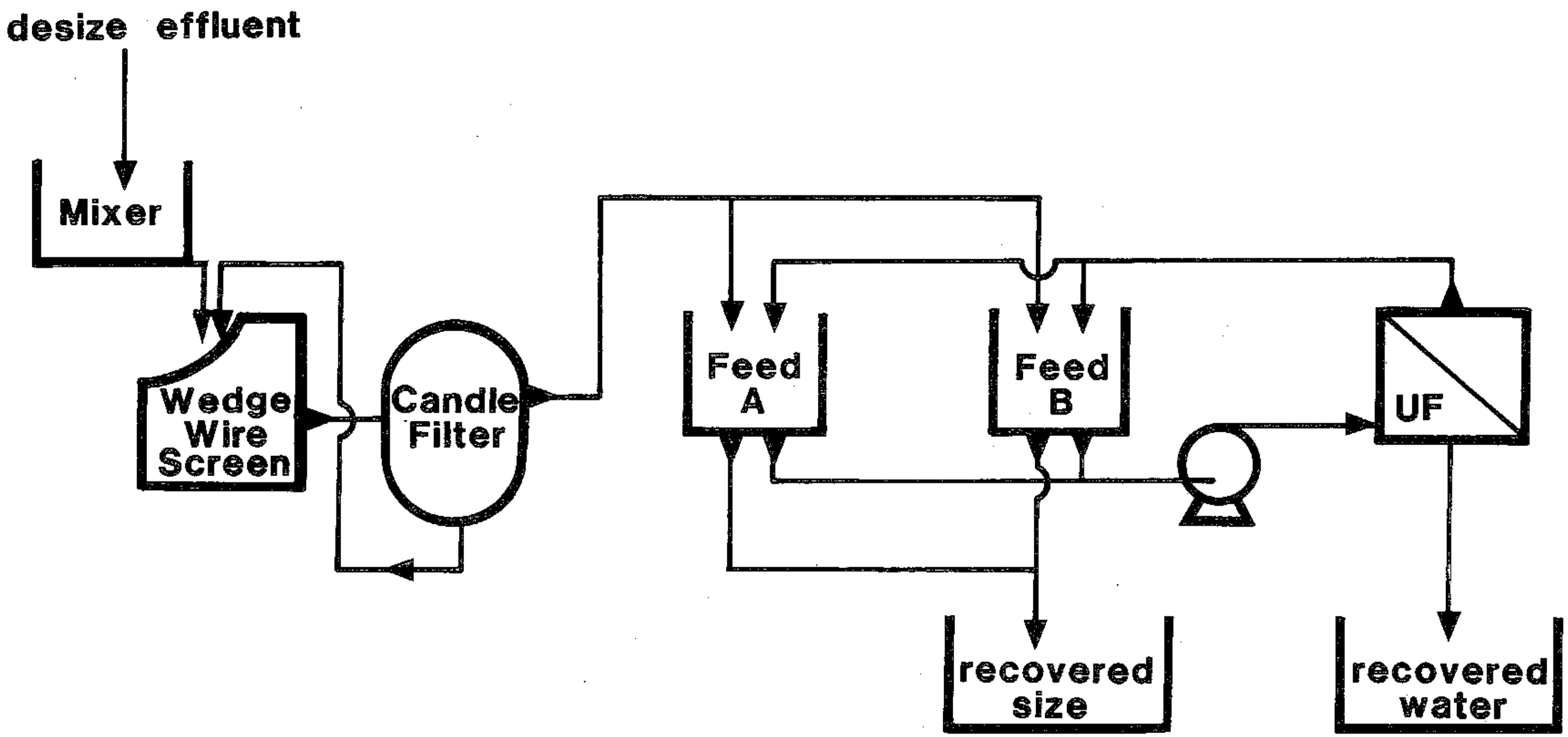


Figure 5.2: Proposed plant flow diagram

TABLE 5.1 PLANNED MAINTENANCE CHECK LIST

	Factor	Aspect
(i)	Minimum water usage	Automatic solenoid valve on washrange Feed rotameter
(ii)	Lint removal	Mixer to dissolve PVA gel Prefilter elements Prefilter cycle time Screen condition
(iii)	Feed temperature	Heat exchangers Temperature controllers Insulation
(iv)	Reject flow rate	Pump condition Back pressure valve Pressure relief valves
(v)	Membrane fouling	Regular water rinse Occasional sodium peroxide rinse Check for lint fouling
(vi)	Minimum recycle concentration	Always blend to the recovered size as much virgin PVA as possible

Particular attention during the design and operation of full scale plants should be paid to:

(i) prefilter section design
(ii) pump selection
(iii) routine maintenance
(iv) routine membrane cleaning.

Chapter 6

ECONOMICS

6.1 INTRODUCTION

A considerable variation exists in the types of cotton/polyester cloth that are produced by different textile mills and in the efficiency of desizing washing ranges. To illustrate the economics of the treatment of desizing effluent by ultrafiltration, several cases have been considered (Table 6.1).

The cloth types cover the range of fabrics commonly produced in South African mills. A typical mill (Code E) is represented by taking 25% of the production by length of cloth types A, B, C and D.

The two counter-current washing ranges, as covered in Section 4.3, are used as examples of those found in industry.

The economic analysis is extended in the later sections of this chapter to cover a range of cloth production rates (1-5 million metres/month) and determine the effect of ultrafiltration plant reject flow velocity.

Further assumptions made in the economic analysis are:

(i) membrane rejection of PVA is 100%

(ii) the water usage in desizing is determined at 95% PVA removal from Figure 4.1 for the two washers

(iii) the size loss prior to desizing is 10%

(iv) the PVA size add-on for the cloth types are mill values

(v) the conventional sizing cost is taken as 20% less than the PVA sizing cost.

As a background to assumption (v), Table 6.2 gives the typical size recipes used by the industry. Because of differences in sizing types, size concentrations and pick-ups between conventional and PVA sizing, detailed comparison is only possible on a mill basis. Using the figures provided by the mill weaving trials (Section 4.2), a detailed analysis of monthly PVA and conventional sizing costs gave ratios in the range 1 to 0,8755 – 0,8876 respectively. Thus assumption (v) is fairly conservative.

TABLE 6.1 CLOTH AND WASHER BASES FOR ECONOMIC ASSESSMENT

Code	Cloth Type	Washer Type
A1	PE/Co 20 tex 25 ends/cm	3 bowl C-C k=0,24
A2	PE/Co 20 tex 25 ends/cm	4 bowl C-C k=0,4
B1	PE/Co 15 tex 40 ends/cm	3 bowl C-C k=0,24
B2	PE/Co 15 tex 40 ends/cm	4 bowl C-C k=0,4
C1	Co 36 tex 33 ends/cm	3 bowl C-C k=0,24
C1	Co 36 tex 33 ends/cm	4 bowl C-C k=0,4
D1	Co 42 tex 30 ends/cm	3 bowl C-C k=0,24
D1	Co 42 tex 30 ends/cm	4 bowl C-C k=0,4
E1	25% by length of A B C & D	3 bowl C-C k=0,24
E1	25% by length of A B C & D	4 bowl C-C k=0,4

PE=Polyester Co=Cotton C-C=counter-current
k=washing efficiency parameter.

6.2 SIZING

The detailed analysis of the sizing requirements of the five cloth bases is given in Table 6.3. The PVA sizing costs range from R20-65/1000 m. The PVA loss that occurs between sizing and desizing, from

TABLE 6.2 TYPICAL SIZE RECIPES AND COSTS

Size Mix	Cost R/kg	Sizing Solids g/ℓ	Sizing Cost c/ℓ
Starch	0,76	40-180	4-17
Starch/Acrylate	—	47-100	8-16
Starch/PVA	—	20-130	4-30
Acrylate	0,81	15- 50	6-21
PVA	2,51	30-100	9-31
Wax	0,90	2- 6	0,2-0,5

Price at Sept 1982 (R1=$0,92)

the assumptions, is 14,5% of that added during sizing. The remainder of the size is recovered for reuse and hence the PVA loss represents the amount of virgin PVA that has to be added on each recycle.

6.3 DESIZING

Desizing of the cloth using the two washer configurations (# 1: 3 bowl counter-current and # 2: 4 bowl counter-current) is illustrated in Table 6.4. From Figure 4.1, for 95% size removal the water usages are 4,9 and 7,4 ℓ/kg respectively; these together with the cloth weights provide the water consumptions in litres per 1 000 m of cloth. The effluent PVA concentration and the sizing reuse PVA concentration provide the concentration factor needed in ultrafiltration. It is assumed that the virgin PVA make-up is added as dry solids and does not affect the volume required in sizing.

For the more efficient washer # 1, the effluent PVA concentrations are in the range 11,27 – 20,68 g/ℓ and in the range 7,52 – 13,79 g/ℓ for washer # 2.

6.4 ULTRAFILTRATION COSTS

6.4.1 Ultrafiltration Membrane Fluxes

The ultrafiltration model (section 4.5.2.2) may be used to predict the average membrane fluxes at different PVA effluent concentrations. These point membrane fluxes may be integrated over the concentration range from the initial PVA concentration in the effluent to the desired final reuse PVA concentration.

Figure 5.1 shows the average membrane flux for batch concentrations of initial PVA concentrations in the range 5-20 g/ℓ to any final PVA concentration (using a reject flow rate of 5 m^3/h on a 4 inch diameter module and 3 elements in series).

For the ten cases under consideration, the design membrane fluxes are given in Figure 6.1. There is considerable variation in the design membrane fluxes because of the different starting and finishing PVA concentration; this in turn reflects the different PVA add-ons, cloth weights and washer configurations.

Table 6.5 summarises these considerations at the high module flow rate; for washer # 1, the membrane area per 1000 m/h of cloth production varies from 76 – 175 m^2 and for washer # 2 from 103 – 242 m^2. This shows the variation that can be expected for light to heavy weight clothes and also the effect of washer efficiency. On a cloth weight basis, the membrane area requirements are less variable because size add-on and water usage in desizing are related to weight and vary in the range 617 – 815 m^2 per 1000 kg/h of cloth production for washer # 1 and 835 – 1 127 for washer # 2.

6.4.2 Ultrafiltration Capital Cost

The capital cost basis used is:

(i) ultrafiltration process carried out as a batch concentration

(ii) eight inch diameter Abcor spiral membranes (type HFM) of membrane area 15 m^2

(iii) three membrane elements are connected in series to form a module. Modules are arranged in parallel to provide the processing area required

(iv) inlet pressure of 500 kPa

(v) feed flow rate of 22,75 m^3/h per module (equivalent to 5 m^3/h for the 4 inch modules used in the pilot-plant).

TABLE 6.3 SIZING BASIS

Code # 	Wet Pick-up ℓ/1000m	PVA Conc g/ℓ	Cloth Wt g/m	PVA Add-on kg/1000m	PVA Cost R/1000m	PVA Loss kg/1000m
A	118	68,75	123	8,11	20,37	1,176
B	96	87,50	119	8,40	21,12	1,218
C	175	87,50	199	15,30	38,50	2,218
D	297	87,50	215	26,00	65,34	3,770
E	171	84,26	164	14,45	36,27	2,100

TABLE 6.4 DESIZING BASIS (PER 1000 m OF CLOTH)

Code #	Water Usage ℓ/1000 m	PVA in Effluent kg/1000 m	Effluent PVA Conc g/ℓ	Sizing Reuse Conc g/ℓ	Concentrate Volume ℓ/1000 m	Permeate Volume ℓ/1000 m	Conc Factor
A1	615	6,93	11,27	58,78	118	497	5,22
A2	922	6,93	7,52	58,78	118	804	7,82
B1	595	7,18	12,07	74,81	96	499	6,20
B2	892	7,18	8,05	74,81	96	796	9,29
C1	995	13,08	13,15	74,81	175	820	5,69
C2	1 493	13,08	8,76	74,81	175	1 318	8,54
D1	1 075	22,23	20,68	74,81	297	778	3,62
D2	1 613	22,23	13,79	74,81	297	1 317	5,42
E1	820	14,45	15,06	72,04	172	649	4,78
E2	1 230	14,45	10,04	72,04	172	1 059	7,18

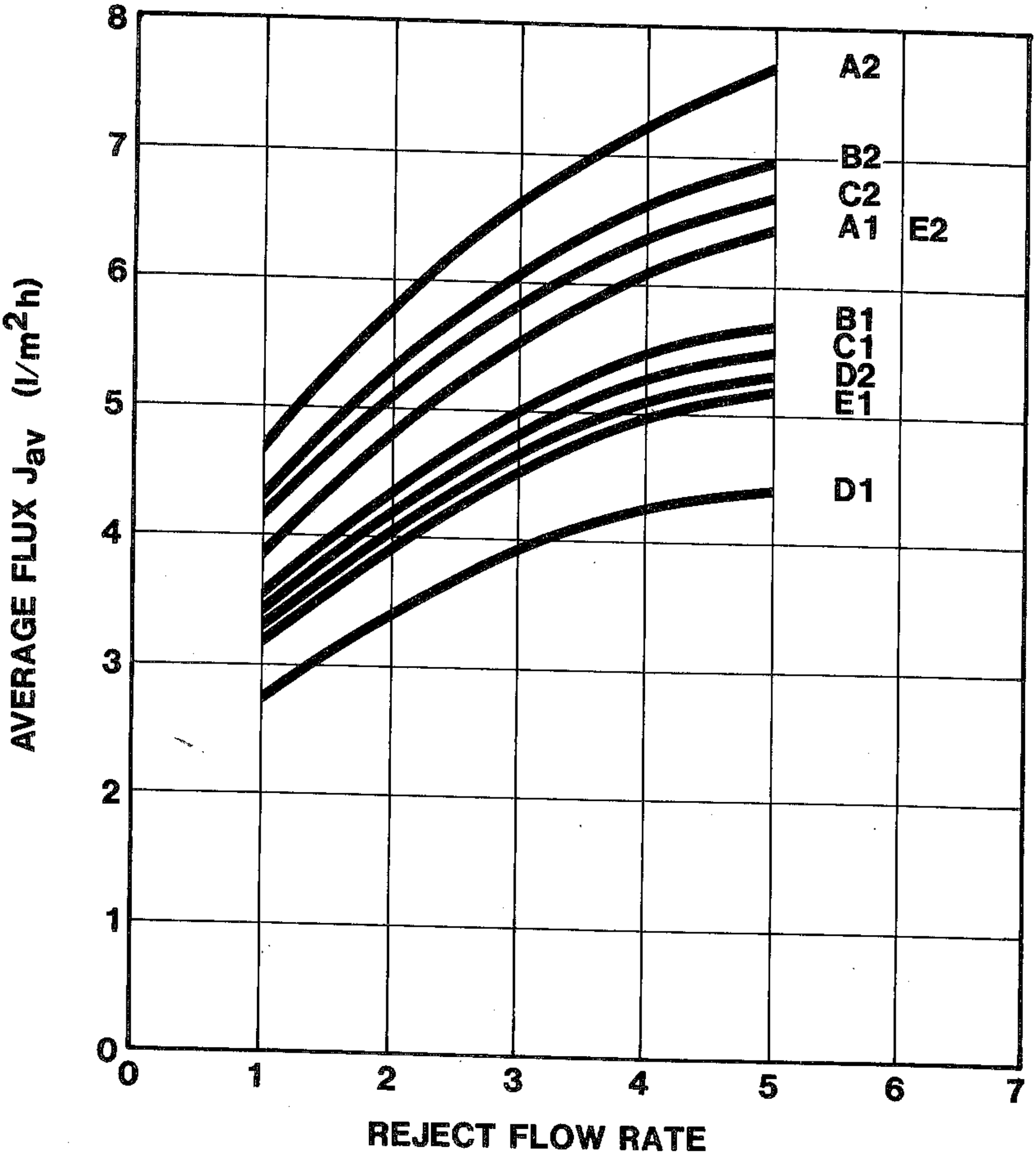


Figure 6.1: The Effect of Reject Flow Rate on Average Permeate Flux (1 reject flow rate unit = 4,55 m^3/h for 8 inch element)

TABLE 6.5 MEMBRANE AREA COMPARISONS.

Code	Cloth Weight	Permeate Volume	Average Permeate Flux	Membrane Area Length Basis	Membrane Area Weight Basis
#	g/m	ℓ/1000 m	ℓ/m²h	m²/1000 m/h	m²/1000 kg/h
A1	123	497	6,55	76	617
A2	123	804	7,83	103	835
B1	119	499	5,79	86	724
B2	119	796	7,04	113	950
C1	199	820	5,56	147	741
C2	199	1 318	6,76	195	980
D1	215	778	4,44	175	815
D2	215	1 316	5,43	242	1 127
E1	164	649	5,33	122	742
E2	164	1 059	6,46	164	1 000

The capital cost of the ultrafiltration plant is compiled from the membrane cost, the module cost and the ancillary equipment cost. The breakdown of the capital cost of a 9 housing ultrafiltration plant of 405 m² membrane area is given in Table 6.6 (41).

TABLE 6.6 COSTING OF ULTRAFILTRATION PLANT OF 405 m² MEMBRANE AREA FOR DESIZING EFFLUENT DUTY

	R
Membranes	82 000
Module Housings	108 000
Tanks	50 000
Pumps	62 000
Valves	12 500
Pipework	12 500
Prefiltration	30 000
Process Control	15 000
Electrical	8 000
Construction	15 000
Engineering	30 000
Contingency	35 000
TOTAL	460 000

Price Sept 1982 (R1 = $0,92)

For the economic analysis, the following capital cost bases are used:

(a) Membrane cost = R200/m²
(b) Module cost = R266,7/m²
(c) Equipment cost is estimated using the equation:
Equipment cost (R) = 2 215 (membrane area)^{0,8}

A production level of 1 million, 2 million and 5 million metres of cloth per month are considered in the economic analysis. However, to avoid confusion, only the first case is considered in detail in the following sections.

For each case, the membrane area is calculated from the average permeate flux, the production volume and the volume of permeate required for the batch concentration.

For example, the calculation for case #A1 at a production volume of 1 million metres of cloth per month is:

J_{av}	= 6,55 ℓ/m²h
Desizing Water Usage	= 615 ℓ/1 000 m
Conc in	= 11,27 g/ℓ
Conc out	= 58,78 g/ℓ
Permeate	= 497 ℓ/1 000 m
Production	= 1 × 10⁶ m/month
	= 1 390 m/h
Permeate volume	= 497 × 1,390
	= 690 ℓ/h
Membrane area	= 105,34 m²

From the membrane area, the membrane, module and equipment costs are calculated and summed to give the total capital cost of the UF plant. The analysis is idealised and does not consider that the membrane elements have to be assembled in multiples of either 3,3 m² (4 inch module) or 15 m² (8 inch module).

Thus for case #A1:

Membrane Cost	= 105,34 × R200	= R 21 070
Module Cost	= 105,34 × R267	= R 28 130
Equipment Cost	= 2 215 × (105,34)^{0,8}	= R 91 930
Total Plant Cost		= R141 130

6.4.3 Ultrafiltration Treatment/Recycle Savings

The savings provided by the UF treatment/recycle system are:

(i) difference in sizing costs between conventional sizing and the virgin PVA make-up requirement

(ii) enzyme savings, as conventionally sized cloth has to be enzyme desized but PVA sized cloth does not

(iii) savings in water, effluent discharge cost and heat energy associated with the permeate recycle to the washer.

The treatment/recycle system savings are summarised in Table 6.7 for the production rate of 1 million metres per month.

The costing date used is from Tables 6.2 and 6.3.

Recycle PVA Cost is the virgin PVA needed in R/annum (0,145 of original PVA added).

Conventional Size Cost is the annual conventional size cost, taken as 0,8 of the total PVA size cost (24 h/d; 330 d/annum).

TABLE 6.7 ULTRAFILTRATION TREATMENT/RECYCLE SAVINGS

Code #	PVA Add-on kg/1000m	Permeate ℓ/1000m	Recycle PVA Cost R/annum	Conventional Size Cost R/annum	Size Savings R/annum	Enzyme Savings R/annum	W+E+S Savings R/annum	Total Savings R/annum
A1	8,11	497	32 494	179 277	146 783	14 342	7 660	168 785
A2	8,11	804	32 494	179 277	146 783	14 342	12 392	173 517
B1	8,40	499	33 656	185 688	152 032	14 855	7 691	174 578
B2	8,40	796	33 656	185 688	152 032	14 855	12 268	179 155
C1	15,30	820	61 302	338 217	276 915	27 057	12 638	316 610
C2	15,30	1 318	61 302	338 217	276 915	27 057	20 313	324 286
D1	26,00	778	104 173	574 747	470 574	45 980	11 991	528 545
D2	26,00	1 316	104 173	574 747	470 574	45 980	20 283	536 837
E1	14,45	649	57 896	319 427	261 531	25 554	10 003	297 008
E2	14,45	1 059	57 896	319 427	261 531	25 554	16 322	303 407

Cloth Production: 1 million metres per month (1 390 m/h)
Price Sept 1982 (R1 = $0,92).

Size Savings is the conventional size cost minus the virgin PVA size make-up cost on an annual basis.
Enzyme Savings is the annual enzyme savings as PVA does not have to be enzyme desized (8% of conventional size cost).

W+E+S Savings is the annual savings on water, effluent discharge and steam for the recycle and are taken as R0,25/m^3, R0,15/m^3 and R1,00/m^3 respectively.
Total Savings is the annual savings on size, enzymes, water, effluent and steam.

TABLE 6.8 ULTRAFILTRATION OPERATING COSTS

Code	L+M+C Cost R/annum	Membrane Cost R/annum	Pump Power Cost R/annum	Anc. Power Cost R/annum	Total Operating Cost R/annum
A1	5 274	7 031	4 177	821	17 302
A2	7 136	9 515	5 652	1 328	23 631
B1	5 990	7 986	4 744	824	19 544
B2	7 858	10 478	6 224	1 314	25 874
C1	10 250	13 667	8 118	1 354	33 389
C2	13 550	18 067	10 732	2 176	44 526
D1	12 178	16 238	9 645	1 285	39 346
D2	16 844	22 458	13 340	2 173	54 816
E1	8 463	11 283	6 702	1 072	27 520
E2	11 393	15 191	9 023	1 749	37 357

Production Basis: 1 million metres per month.
Price Sept 1982 (R1 = $0,92)

The cost bases used in the table are:

L+M+C Cost is the annual labour, maintenance and cleaning operating costs (R20/m^2, R15/m^2 and R15/m^2 of membrane area respectively).
Membrane Cost is the annual membrane replacement cost, taken at one third of total membrane area. This assumes a membrane life of 3 years and in practice, the membranes would be replaced in total every third year.
Pump Power Cost is the main UF feed pump power annual cost. The pump is sized on the basis of the installed membrane modules at 1,5 kWh/45 m^2 membrane area module/4,55 m^3/h of flow. The flow used is 22,75 m^3/h. Electricity cost is taken as R0,03/kWh.
Anc. Power Cost is the ancillary pumping and control annual power costs on the basis of the annual permeate volume costed at 5 kWh/m^3 of permeate.
Total Operating Cost is the annual operating costs of labour, maintenance, cleaning, membranes, pumping power and ancillary power costs.

6.4.4 Ultrafiltration Plant Operating Costs

The treatment/recycle operating costs consist of:
(i) labour, maintenance and cleaning
(ii) membrane replacement
(iii) pumping power
(iv) ancillary power.

The operating costs are summarised in Table 6.8.

6.5 ECONOMICS OF ULTRA-FILTRATION TREATMENT/ RECYCLE SYSTEM FOR SIZING-DESIZING EFFLUENTS

6.5.1 Capital Pay-Back Time

The capital costs and pay-back times of the UF system are given in Table 6.9 for the ten cases considered at production volume of 1 million metres per month. The nett savings are calculated from the (total savings) minus the (total operating cost). The pay-back time in years is defined as the (total capital cost) divided by the (nett savings). No capital charge is assumed in these calculations.

The effect of washer efficiency is clearly shown. Capital pay-backs for the type #1 washers are 0,60 – 1,02 years and for type #2 are 0,81 – 1,30 years. Thus an improvement of about 30% is attainable by the use of high efficiency washers.

The annual capital charge (both depreciation and interest rates) is highly dependent on different mill situations. For a 25% annual capital charge, the pay-back times on capital are given in the last column of Table 6.8.

6.5.2 Effect of Production Volume

Figure 6.2 compares the pay-back times (no capital charge) against production volume for the cases of:

#E1 representing a typical mill
#D1 representing a heavy cloth weight mill, and
#B1 representing a light cloth weight mill.

At the optimum reject flow condition, capital pay-back times vary depending on the production volume from:

0,60 – 0,50 years for mill #D1
0,79 – 0,65 years for mill #E1
and 1,02 – 0,84 years for mill #B1.

The lower pay-backs refer to the higher production volumes.

6.5.3 Effect of Feed Velocity

Figure 6.3 highlights the effect of the flow velocity improvement on membrane flux and hence on the economics. The results show that increasing the reject flow to about 18,2 – 22,7 m^3/h for the eight inch modules (or 4 – 5 m^3/h for the four inch modules) provides significantly higher returns as the capital cost of the UF plant is minimised and the average permeate fluxes are higher. The optimum is close to 22,7 m^3/h flow rate, as at higher velocities, the large pressure drop results in lower average permeate fluxes and the pumping power cost becomes significant.

TABLE 6.9 ECONOMIC SUMMARY

Code #	Capital R	Gross Savings R/annum	Operating Cost R/annum	Nett Savings R/annum	Pay-back Time Years	Pay-back Time for 25% Capital Charge per annum Years
A1	141 130	168 785	17 302	151 483	0,93	1,21
A2	183 826	173 517	23 631	149 885	1,23	1,77
B1	157 796	174 578	19 544	155 034	1,02	1,37
B2	199 956	179 155	25 874	153 281	1,30	1,94
C1	252 268	316 610	33 389	283 222	0,89	1,15
C2	322 256	324 286	44 526	279 760	1,15	1,62
D1	293 418	528 545	39 346	489 200	0,60	0,71
D2	390 217	536 837	54 816	482 021	0,81	1,01
E1	213 328	297 088	27 520	269 567	0,79	0,99
E2	276 763	303 407	37 357	266 050	1,04	1,41

Production Level : 1 million metres per month
Price Sept 1982 (R1 = $0,92)

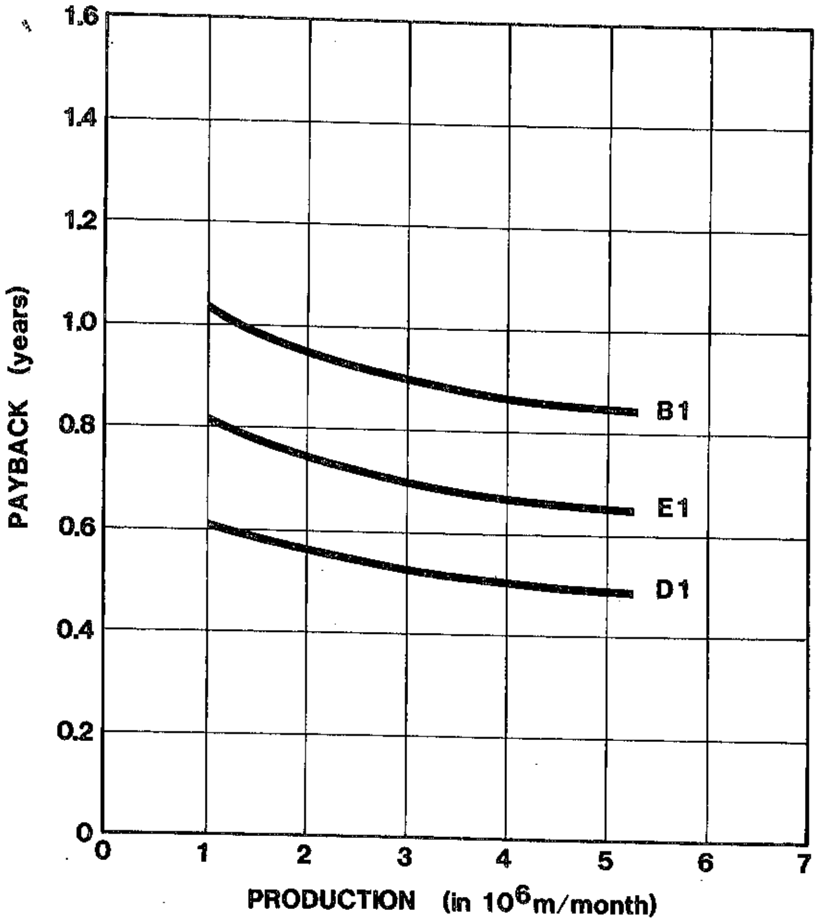


Figure 6.2: Economics of Ultrafiltration: The Effect of Cloth Production on Payback Time (reject flow rate 22,75 m³/h)

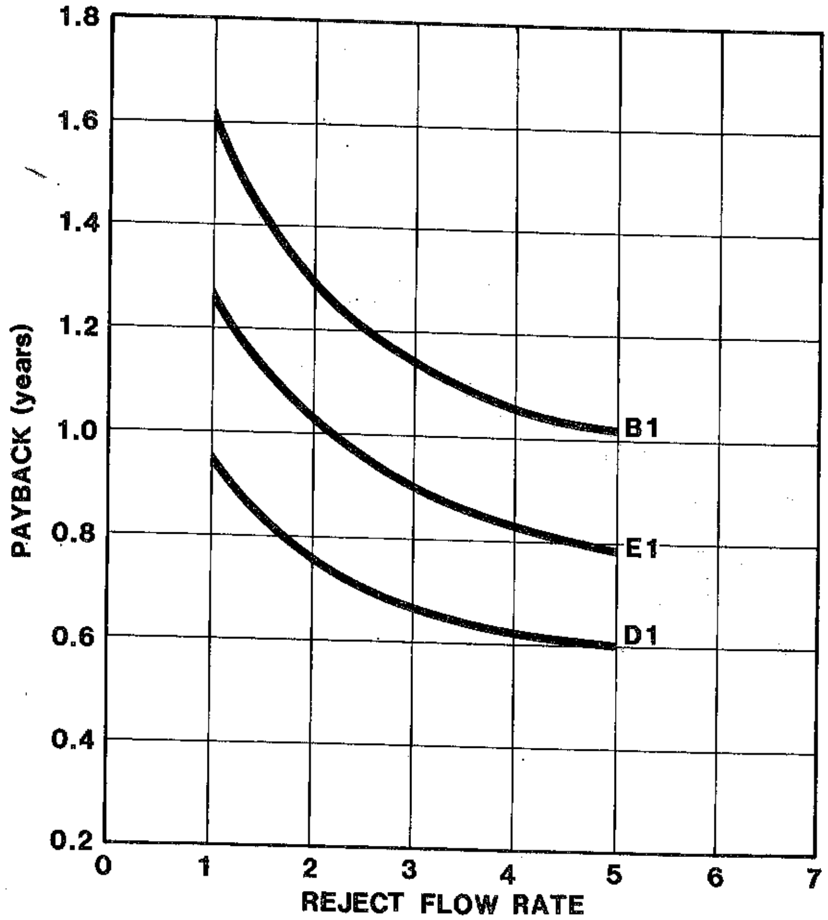


Figure 6.3: Economics of Ultrafiltration: The Effect of Reject Flow Rate on Payback Time (production 10^6 m/month; 1 reject flow rate unit = 4,55 m³/h for 8 inch element)

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