FINAL REPORT

DEVELOPMENT OF WASTEWATER PRETREATMENT TECHNOLOGIES: CROSS-FLOW MICROFILTRATION

AND

THE DEVELOPMENT OF SUPPORT SYSTEMS FOR CROSS-FLOW MICROFILTRATION AND TECHNICAL PERFORMANCE EVALUATION THEREOF ON INDUSTRIAL WATER AND WASTEWATER: RELATING TO THE DEVELOPMENT OF THE TUBULAR FILTER PRESS AND CROSS-FLOW MICROFILTRATION TECHNOLOGY

by

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EXECUTIVE SUMMARY

Microfiltration is one of the family of pressure driven separation processes, the others being ultrafiltration and hyperfiltration. Microfiltration fits between conventional filtration (1 to 5 μm) and ultrafiltration (0,01 μm) in particle size capture, and rejects colloidal and suspended solids.

Two types of microfiltration membrane systems exist :- synthetic membranes with a fixed pores size, and dynamic type membranes where flocculating agents, such as alum, are used to create a filtration medium inside the filtration tube.

Both types of membranes are operated in the cross-flow mode to minimise cake build-up and maximise product flux. Dynamic cross-flow microfiltration has several areas of application including :-

(i) the removal of colloidal and suspended solids from effluent streams.

(ii) the pretreatment of effluents prior to ultrafiltration and hyperfiltration.

(iii) the thickening of suspensions or dilute sludges.

Traditionally dynamic cross-flow membranes have been formed on rigid porous supports such as ceramic or stainless steel tubes. In 1979 the Pollution Research Group used a flexible woven filter tube (fire hose jacket) as a membrane support. Although rudimentary in design, results obtained from the pretreatment of dyehouse effluent were encouraging.

In 1984 the Pollution Research Group was contracted by the Water Research Commission for 1 year to further investigate and develop the use of cross-flow microfiltration, using woven filter tubes, as a pretreatment technique (Project No. 146).

The technical objectives of the project were :-

(i) to determine the technical feasibility of microfiltration for the treatment and pretreatment of a representative range of waters and wastewaters.

(ii) to evaluate process performance and estimate the cost effectiveness of the system.

(iii) to develop a detailed design and cost estimate of the system.

These objectives necessitated that investigation into aspects such as :-

(i) the effect of support hose construction.

(ii) the effect of different flocculants including polyelectrolyte.

(iii) the effect of pH, temperature, velocity and pressure.

(iv) the determination of dosage and pH range of flocculants.

be undertaken.

In addition a variety of waters and wastewaters were to be used to evaluate the usefulness of cross-flow microfiltration as a treatment or pretreatment technique.

This project was the forerunner of a further three year project entitled "*The Development of Support Systems for Cross-flow Microfiltration and Technical Performance Evaluation on Industrial and Waters and Wastewaters*" (Project No. 164).

During the course of this project, effluent from thirteen different industries were cross-flow microfiltered as well as biological and water works sludges. The ability of the designed units to also function as a tubular filter press was established and sufficient technical data collected to enable a full scale tubular filter unit to be designed and installed at a water works to dewater sludges.

The process has been licenced internationally and is marketed under the names EXXFLOW (for cross-flow microfiltration) and EXXPRESS (for the tubular filter press).

A final report has been prepared. It does not present a chronological history of the two Water Research Commission sponsored projects but is organised in terms of processes and effluent streams investigated so as to be of maximum benefit to the licensees of the technology.

SUMMARY OF PROJECT NO. 146 ; DEVELOPMENT OF WASTEWATER PRETREATMENT TECHNIQUES : CROSS-FLOW MICROFILTRATION (1984)

Four effluents were treated by cross-flow microfiltration :-

(i) secondary sugar effluent.

(ii) paper machine effluent.

(iii) alum sludge.

(iv) activated sludge.

Secondary effluent from a sugar mill was cross-flow microfiltered prior to treatment in a spiral reverse osmosis unit. Rejection of suspended solids was 100 % and the reverse osmosis membranes operated without fouling up to 85 % water recovery in batch concentration mode.

Paper machine effluents were treated as examples of a high colloidal industrial effluents. Effluent from the paper machine of a liner/fluting mill contained 200 to 400 mg/ℓ of colloidal and suspended solids after clarification. Cross-flow microfiltration achieved complete removal of these solids and reduce the total organic carbon content of the effluent by up to 40 %. Colloidal/suspended solids removal from noodle water (containing 4 g/ℓ suspended solids) was over 99 % and the total organic carbon concentration reduced by over 60 %.

Waste alum sludge from a water works contained 2 to 6 g/ℓ of total solids. The cross-flow microfilter was used as a sludge thickener and over 15 days increased the effluent total solids form 2 g/ℓ to 95 g/ℓ. Further dewatering was achieved by operating the cross-flow microfilter as a tubular filter press. A cake of 20 to 25 % total solids was produced.

Preliminary work on the cross-flow microfiltration of activated sludge from Durban's Northern Waste Water Treatment Works indicated that satisfactory total solids and colour rejections could be achieved but that further work was necessary to determine the effect that aspects such as, precoat type, sludge type and sludge viscosity would have on the effectiveness of cross-flow microfiltration.

SUMMARY OF PROJECT NO. 164 : THE DEVELOPMENT OF SUPPORT SYSTEMS FOR CROSS-FLOW MICROFILTRATION AND TECHNICAL PERFORMANCE EVALUATION ON INDUSTRIAL WATERS AND WASTEWATERS

During 1985, emphasis was placed on the mechanical design and operability of a prototype cross-flow microfilter using woven fabric hoses as a support system. Cleaning techniques, both chemical and mechanical, were investigated during the course of the prototype cross-flow microfilter applications.

Various Water Boards expressed interest in the ability of the technology to act as a sludge thickener, and so sludge thickening and dewatering were accorded highest priority in the applications programme.

Small scale plants were installed at the D.V. Harris Works of Umgeni Water Board in Pietermaritzburg and at Rand Water Board's Sludge Station in Vereeniging.

A sludge dewatering system, effected by using the cross-flow microfilter as a tubular filter press, was developed and patent rights applied for in the name of the Water Research Commission.

As a consequence of this work, Umgeni Water Board initiated a sub-project with the University and the Water Research Commission for the building of a prototype unit at the H.D. Hill Works in Pietermaritzburg to handle the whole sludge production emanating from the treatment of raw water.

Other applications investigated during 1985 included the cross-flow microfiltration of low suspended solids in surface water, undertaken at Wiggins Works and the treatment of secondary effluent at Durban's Northern Waste Water Treatment Works. In addition mathematical modelling of the cross-flow microfiltration process was undertaken.

During 1986 priority was given to the development design and construction of the prototype Tubular Filter Press at H.D. Hill, Pietermaritzburg. The work was undertaken jointly by the Umgeni Water Board and the University of Natal. The prototype unit was commissioned in November 1986.

Spadeable cake, having a solids concentration of 31 % m/m, could be produced at a rate of 1,5 kg dry solids/m^2h for a feed with a concentration of 25 g/ℓ at an operating pressure of 450 kPa. Operating manuals for the unit were written. The mechanical and electrical performance of the prototype unit was fault free but occasionally plugging of the filter tubes with cake occurred.

A cross-flow microfilter pilot plant was constructed at Durban Corporation's Northern Waste Water Treatment Works and coupled to a pilot scale anaerobic digester. The treatment capacity of the pilot digester was increased from 3,6 to 6,1 kg volatile solids per day, the digester solids concentration was increased from 2,7 to 5,3 % and the volumetric throughput increased from 72 to 134 ℓ/d. This increased solids and liquid loading had no adverse effects on digester performance, the volatile acids/volatile alkalinity ratio remaining constant at 0,15 and the volatile solids reduction remaining at 65 %.

Cross-flow microfilter mathematical modelling studies continued during the year for both steady-state and transient conditions.

The steady-state model enables the data obtained from a short single tube to be used in a mathematical model which takes into account engineering parameters (tube length and tube diameter) and operation variables (pressure, flow rate and solids concentration) and predicts the steady-state permeate flux. The unsteady-state model predicts the rate of flux decline and can be used to calculate the optimum cleaning procedure.

Short duration *ad hoc* investigations were undertaken to investigate the usefulness of cross-flow microfiltration as a treatment method for various industrial effluents, either to enable water reuse or to act as a pretreatment for reverse osmosis units.

During 1987 project work centred on upgrading the tubular filter press at H.D. Hill Water Treatment Plant to treat the full sludge flow from the plant. Operation of the tubular filter press was transferred to H.D. Hill personnel and 3 shifts per day were being run by June 1987. Plans for full automation of the plant are under way. In general the plant operation has been satisfactory and operating staff are happy with the technology.

Monitoring and operation of the pilot plant at Northern Waste Water Treatment Works was continued by works staff, using waste activate sludge.

Laboratory scale tests were undertaken on the cross-flow microfiltration of neutralised textile scour effluent prior to the electrolytic recovery of sodium hydroxide. The electrochemical membrane was susceptible to calcium and magnesium scaling and so high rejection of these ions by the cross-flow microfilter was required. Tests indicated that a precoat of Kulu 15 limestone, a feed velocity of 3 to 3,5 m/s and an operating pressure of 300 kPa should be used for all future cross-flow microfiltration of neutralised scour effluent.

ACKNOWLEDGEMENTS

The research in this report emanated from projects funded by the Water Research Commission to the University of Natal entitled :

Development of Wastewater Pretreatment Technologies :
Cross-flow Microfiltration

and

Development of Support Systems for Cross-flow Microfiltration and Technical Performance Evaluation thereof on Industrial Water and Wastewater :
The Tubular Filter Press and Cross-flow Microfiltration Technology

For completeness, included in this report are results relating to the development of the tubular filter press and cross-flow microfiltration technology which were obtained from other projects and *ad hoc* investigations.

The members, of the Steering Committee for the projects represented the following organisations :-

Chairman	:	Dr. O.O. Hart	-	Water Research Commission
Vice-Chairman	:	Dr. C.F. Schutte	-	Water Research Commission
Secretary	:	Mr. P.W. Weideman	-	Water Research Commission

Organisation Represented

Department of Water Affairs
Durban Corporation
ESKOM
Federated Chamber of Industries
Rand Water
SAPPI Limited
Umgeni Water
United Municipal Executive
University of Natal
Water Research Commission

Members	Year
Prof. M.R. Judd	1985/1986
Mr. G.J. Globbelaar	1985/1986/1987/1988
Mr. D.B. Smith	1985/1986/1987/1988
Mr. D.C. Macloed	1985/1986/1987/1988
Mr. A.J. Swierstra	1985/1986/1987/1988
Mr. W.N. Richards	1985/1986/1987/1988
Mr. C.M. Howarth	1985/1986/1987/1988
Mr. T. Spencer	1985/1986/1987/1988
Mr. C.J. Davies	1985/1986/1987/1988
Prof. D.J. Raal	1985/1986/1987/1988
Mr. L. Gravelet-Blondin	1985/1986/1987
Mr. A.N. Els	1985/1986
Mr. G.E. Rencken	1985/1986
Mr. N.E. Fortmann	1985/1986/1987/1988
Mr. F. Kelly	1985/1987/1988
Mr. N. Jory	1985
Mr. C.F. Schutte	1985/1986/1987/1988
Mr. W.N. van Eeden	1986
Mr. E. van der Hoven	1987

Project personnel were as follows :-

Persons	Year
Prof. C.A. Buckley	1985/1986/1987/1988
Mr. K. Treffry-Goatley	1985/1986/1987
Mrs. A.M. Bindoff	1986/1987/1988
Mr. K.R. Buijs	1986
Prof. F.G. Neytzell-de Wilde	1986/1987/1988
Mr. V.L. Pillay	1987/1988
Mrs. A.E. Simpson	1987
Mr. G.E. Rencken	1987/1988

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4 TREATMENT OF INDUSTRIAL EFFLUENTS

Industrial water management and effluent treatment is becoming of increasing concern due to the limited availability of future water supplies and the need to preserve water quality.

Projections indicate that demand over present usage will equal supply by the year 2010 (**Appendix 4.1, 4.2**). Although non-agriculture use of water is presently about 25 %, this will rise to over 38 % by the year 2010. As the ratio of industrial to domestic water usage is about 60 : 40, it is evident that, in the future, industry will have a major role to play in the South African water economy.

Effluents from thirteen major industries were treated to evaluate the role of cross-flow microfiltration in eliminating or reducing pollution potential of the effluents and in reducing the external water demands of the industries. A literature review of the use of cross-flow microfiltration in treating industrial effluents prior to this work is given in **Appendix 4.3**.

4.1 CROSS-FLOW MICROFILTRATION OF EFFLUENTS FROM THE PULP AND PAPER INDUSTRY

4.1.1 Introduction

Processes used in the pulp and paper industry generate several chemically dissimilar effluent streams. A generalised flow sheet of the source of these effluents is shown in Figure 4.1.

Effluents from the pulping process have high organic contents and are generally treated by an evaporation/chemical recovery boiler system in which the organic fraction is burnt and the inorganic fraction is reconstituted for use as process chemicals.

There are two types of bleaching effluents, an acid effluent and an alkaline effluent from what is known as the E-stage process. Of these, the acid bleach effluent is problematical as it is highly concentrated and its high chloride content renders it unsuitable for reuse without effluent treatment (**4.23**). Alkaline extraction liquor offers possibilities for water reuse if dissolved total solids can be removed.

Six effluent streams generated during the pulp and paper making processes were treated by cross-flow microfiltration to assess its effectiveness in enabling water reuse within the plant.

4.1.2 Cross-flow Microfiltration of Spent Liquor

Spent liquor is the concentrated stream obtained by draining the digested wood pulp. A typical analysis of spent liquor is given in Table 4.1.

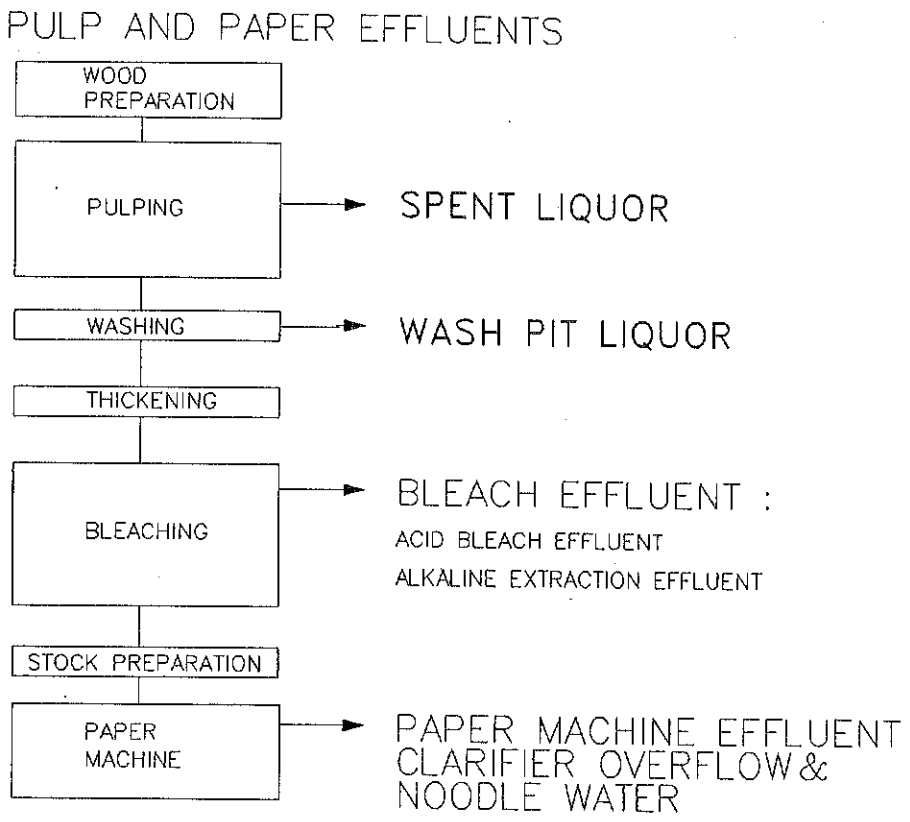

FIGURE 4.1 : SCHEMATIC FLOW DIAGRAM OF THE SOURCE OF EFFLUENTS WITHIN THE PULP AND PAPER INDUSTRY

TABLE 4.1
ANALYSIS OF SPENT LIQUOR

TDS	(g/ℓ)	183,29
Ash	(g/ℓ)	19,06
Organic solubles	(g/ℓ)	164,32
Conductivity	(mS/cm)	13,54
pH		1,81
Ca	(mg/ℓ)	6 675
Na	(mg/ℓ)	40
Cl	(mg/ℓ)	408
Lignin	(g/ℓ)	70,61
Sugars	(g/ℓ)	49

The cross-flow microfilter had the following specifications :-

Tube type	:	woven nylon.
Tube length	:	1,94 m.
Tube diameter	:	12 mm.

Tests were undertaken in total recycle and batch concentration mode (**Appendix 4.5** and **4.6**). Flux values were low (5 to 8 ℓ/m^2h) with total carbon rejection of ±30 % and lignin rejection of 26 % in total recycle and 59 % in batch concentration mode.

4.1.3 Cross-flow Microfiltration of Wash Pit Liquor

After the wood chips have undergone chemical digestion, the pulp is drained and then washed. The resultant dilute liquor is known as wash pit liquor.

The effluent was treated by cross-flow microfiltration to investigate whether CFMF could :-

(i) provide a method of pretreatment for SAICCOR liquor,

(ii) provide a direct treatment process.

The results obtained (**Appendix 4.7**) show that with no chemical addition and during total recycle, the effluent formed a membrane of its own. After 5 minutes the flux was 30 ℓ/m^2h dropping to 16 ℓ/m^2h after 26,5 hours. Suspended and colloidal matter was removed. In addition, 39 % of the lignin and 20 % of sugar present in the feed was rejected.

Following these preliminary results, further tests were conducted under conditions of constant concentration and circulation velocity, but with varying feed pressure and temperature.

The effluent was diluted 50 % by volume with water so that any trends in permeate flux or quality at different operating conditions could be detected easily.

Results showed that the time required for satisfactory membrane formation varied with temperature and pressure. The rate of permeate flux decline was higher with an increase in temperature.

Runs carried out at the same temperature but at different feed pressures (120 and 240 kPa) indicated that permeate fluxes were almost identical over a 10 hour period.

Permeate flux was dependant on feed concentration. At a dissolved solids concentration of 180 g/ℓ the permeate fluxes obtained on diluted wash pit liquor ranged from 78 to 54 ℓ/m^2h, whereas at a feed concentration of 44 g/ℓ, the fluxes ranged from 13 to 8 ℓ/m^2h, over similar periods of time.

At a feed pressure of 120 kPa, similar rejections of total organic carbon, total dissolved solids, organic solubles and calcium were obtained. At temperatures up to 50 °C, lignin rejections of 30 to 50 % were obtained.

At a feed pressure of 240 kPa, the rejections of total organic carbon, total dissolved solids, organic solubles and calcium did not vary over temperatures ranging from 26 to 80 °C. Lignin rejections of 35 to 70 % were obtained.

At operating temperatures of 50 °C and 60 °C, the flux declined to below 10 ℓ/m^2h for feed concentrations above 42 g/ℓ total dissolved solids, within an hour of operation.

The average rejection of total carbon, total dissolved solids, and calcium was between 10 and 30 % for feed TDS concentrations up to 130 g/ℓ and feed temperatures up to 40 °C. Lignin rejections were above 30 %. At operating temperatures of 50 °C, average rejection of constituents decreased to zero for feed concentrations of 130 g/ℓ total dissolved solids.

Examination of the permeate flux with time, for feed TDS concentrations between 42 and 170 g/ℓ and at temperatures of 30 °C and 40 °C indicates that initially the flux decreases steeply to a low value which is dependant on feed concentration. Thereafter, the rate of flux decline is similar regardless of concentration.

In the runs carried out at 30 °C, the flux/time curves are similar for feed total dissolved concentrations of 42 and 84 g/ℓ.

4.1.4 Cross-flow Microfiltration of Acid Bleach Effluent

Acid bleach waste water typically contains up to 5 g/ℓ of total solids. Major constituents being 1 to 2 g/ℓ of chloride and 0,3 to 0,8 g/ℓ of organics, measured as TOC. The effluent has a low pH (2 to 4) and a temperature of 50 to 60 °C. Preliminary investigations carried out on treatment methods for bleach effluents indicated that reverse osmosis was suitable. Cross-flow microfiltration was envisaged as a pretreatment process for the reverse osmosis feed.

4.1.4.1 Laboratory Investigations

The bleach effluent was cross-flow microfiltered, after lime addition to raise the pH, in serial batch concentration mode to 95 % water recovery. Permeate fluxes were above 400 ℓ/m²h throughout the batch at a pressure of 300 kPa. The performance of the CFMF is summarized in Table 4.2.

TABLE 4.2
COMPARISON OF THE BLEACH EFFLUENT FEED AND THE CFMF PERMEATE

Parameter	Feed	CFMF permeate after neutralisation
pH	2,0	7,5
Mg (g/ℓ)	0,14	0,001
Ca (g/ℓ)	0,12	0,680
TOC (g/ℓ)	0,53	0,290

It was found **(Appendix 4.8)** that high calcium levels in lime pretreated bleach effluent caused fouling of the reverse osmosis membranes.

Figure 4.2 shows that 44 % of the total organic carbon is removed at pH 11,5 to 12,0, but that the amount of calcium in the supernatant is above 1 000 mg/ℓ. This could be removed by adding carbon dioxide to the effluent, thus decreasing the pH and precipitating calcium as calcium carbonate but decreasing the percentage of TOC removed.

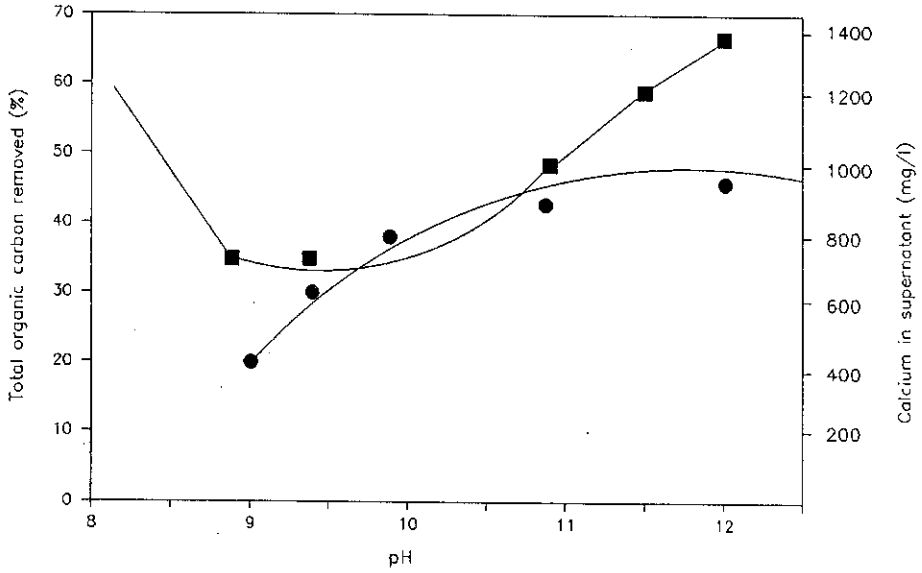

FIGURE 4.2 : REMOVAL OF EXCESS CALCIUM WITH CARBON DIOXIDE RESULTING IN A DECREASE OF TOTAL ORGANIC CARBON REMOVED

The use of a ferric hydroxide precoat in the cross-flow microfilter was investigated. This would alleviate the large acid/alkali dosages required if the effluent was pretreated with lime and would not give rise to excess calcium concentrations.

Results **(Appendix 4.9)** showed that the total organic carbon rejection with a ferric hydroxide precoat was only 20 to 30 %, compared to 40 and 50 % with lime flocculation. In addition, marked fouling of the FilmTec reverse osmosis membrane, shown by declining permeate flux, (Table 4.3), occurred when the membrane was subjected to effluent pretreated with a ferric hydroxide precoat.

A two stage pretreatment sequence was then investigated to optimise the removal of organics and to reduce the high levels of calcium in the feed to the reverse osmosis membranes.

TABLE 4.3
CROSS-FLOW MICROFILTER FLUXES WITH FERRIC HYDROXIDE PRECOAT

Time (min)	Flux (ℓ/m^2h)	Pressure (kPa)
11,54	510	300
12,05	405	-
12,30	332	-
14,00	332	-
15,00	300	-

In the first stage of lime flocculation followed by cross-flow microfiltration, organics were removed at pH 11,5 to 12,0. Addition of carbonate reduced the pH and precipitated the excess calcium which was removed in a second pass through the cross-flow microfilter.

The compositions of the feed and the permeate, after the first stage of cross-flow microfiltration, are given in Table 4.4 and after the second stage in Table 4.5.

Results **(Appendix 4.8)** indicate that a two stage cross-flow microfiltration pretreatment results in a permeate with low organic concentrations of approximately 300 mg/ℓ and a negligible calcium concentration of 2 to 3 mg/ℓ.

The performance of the cross-flow microfilter at various water recoveries is given in Tables 4.6 and 4.7.

TABLE 4.4
FEED AND FILTRATE COMPOSITION AFTER FIRST STAGE CFMF

	Run 1			Run 2			Run 3		
	Feed	Composite filtrate	% removed	Feed	Composite filtrate	% removed	Feed	Composite filtrate	% removed
pH	2,6	11,8	-	2,5	11,6	-	2,6	11,9	-
Cond	5,6	6,9	-	5,4	6,5	-	5,7	9,5	-
TS	3 900	5 300	-	4 100	4 900	-	4 200	5 700	-
TOC	532	301	43	592	306	48	549	267	51
Na	655	594	-	627	604	-	605	589	-
Mg	144	0,6	99	141	0,5	99	139	0	99
Ca	55	682	-	220	638	-	110	770	-
Cl	1 359	1 529	-	1 364	1 364	-	1 386	1 400	-
SO_4	68	48	-	56	64	-	-	-	-

All units in mg/ℓ expect pH and conductivity - mS/cm

TABLE 4.5
FEED AND FILTRATE COMPOSITION AFTER SECOND STAGE CFMF

	Run 2			Run 5		
	Feed	Composite filtrate	% removed	Feed	Composite filtrate	% removed
pH	11,1	11,4	-	12,0	12,0	-
Cond	5,3	8,8	-	9,9	10,1	-
TS	4 800	6 900	-	8 600	5 600	-
TOC	489	-	-	313	271	-
Na	2 442	2 442	-	2 080	2 032	-
Mg	9,2	3,5	-	0	0	-
Ca	440	1,3	99	650	2,4	99
Cl	1 556	1 535	-	1 300	1 273	-
SO_4	80	67	-	-	-	-

All units in mg/ℓ expect pH and conductivity - mS/cm

TABLE 4.6
FLUX VS WATER RECOVERY FIRST STAGE CFMF
(Pressure 300 kPa and Temperature 25 °C)

% Water recovery	Runs						
	1	2	3	4	5	6	7
			No cleaning				
0	1 152	1 100	586	1 206	1 098	1 033	1 134
25	936	849	676	1 098	1 000	810	1 033
50	864	756	385	946	896	774	946
75	792	709	385	921	810	709	849
87	792	709	414	849	756	666	774
95	792	460	378	453	547	680	-

Flux in ℓ/m^2h

The permeate from the two stage cross-flow microfiltration sequence was tested against FilmTec and Du Pont membranes to determine whether any fouling tendencies remained.

4.1.4.2 <u>Pilot Scale Plant at SAPPI - Enstra</u>

Arising out of laboratory investigations, a pilot scale plant was installed at SAPPI - Enstra, to collect on-site technical performance data with which to evaluate the treatment process and to provide necessary design information (**Appendix 4.10**).

TABLE 4.7
FLUX VS WATER RECOVERY SECOND STAGE CFMF
(Pressure 200 kPa and Temperature 25 °C)

% Water	Runs				
recovery	1	2	3	4	8
	No cleaning	No cleaning			No cleaning
0	428	464	1 033	849	526
25	666	471	831	666	480
50	-	464	792	493	440
75	558	453	774	435	420
87	522	417	738	417	390
95	-	460	-	-	225

Flux in ℓ/m^2h

The pilot plant consisted initially of one cross-flow microfiltration unit and a reverse osmosis unit. The cross-flow microfilter unit was comprised of a 20 m long curtain of 20 tubes, manifolded to form 5 parallel flow paths. The total length of each path was 80 metres and each individual tube had a diameter of 25 mm. The curtain was hung in a spiral from a frame which was suspended over the permeate collection tank. The permeate overflowed into the reverse osmosis feed tank.

The cross-flow microfilter was over-designed relative to the bench scale results to ensure a continuous feed to the reverse osmosis unit. No large buffer tank capacity between the units was incorporated because of space limitations and no tube cleaning facilities were provided. The units were containerised for ease of transport and handling.

The CFMF unit was required to produce 4,3 m^2/h or 135 ℓ/m^2h of treated bleach effluent as feed to the reverse osmosis unit. However, a decrease in flux from 350 to 25 ℓ/m^2h was monitored over 24 hours on start-up. Following laboratory test work and several system modifications, the unit was redesigned as a linear system with a high pressure spray cleaning head.

The impact of the installation of a cleaning head is seen by comparing Figures 4.3 and 4.4. Figure 4.3 shows a run prior to the installation of the cleaning head. The flux was below that required to provide sufficient feed for the reverse osmosis unit and various attempts to improve the filtration rate, such as sponge ball cleaning and acid washing, gave only temporary improvement. The installation of the spray cleaning head had an immediate effect, (Figure 4.4) with permeate flux well above the minimum required. In the subsequent operational period, down time on the cross-flow microfiltration units amounted to only 16 % of operational time. With regular cleaning, permeate fluxes were maintained at 300 ℓ/m^2h which was above

the required rate of 135 ℓ/m^2h needed for continuous flow to the reverse osmosis unit. Table 4.8 gives typical analyses of the acid bleach effluent before and after CFMF.

TABLE 4.8
A TYPICAL ANALYSES OF THE EFFLUENT BEFORE AND AFTER CFMF

	pH	Cond	TS	SS	TC	TOC	Na	Mg	Ca	Cl	SO_4
Bleach	3,0	434	3 664	24	603	596	530	124	130	1 390	112
CFMF feed 1	9,5	414	4 938	428	545	-	-	113	316	-	-
CFMF reject 1	9,8	424	5 502	1 056	524	-	-	138	334	-	-
CFMF permeate 1	8,9	410	4 418	0	502	-	-	88	318	-	-
CFMF feed 2	9,9	521	5 957	924	616	-	-	100	143	-	-
CFMF reject 2	10,0	544	8 376	3 128	565	-	-	190	135	-	-
CFMF permeate 2	9,7	521	4 996	40	539	-	-	104	37	-	-

All units in mg/ℓ expect conductivity - mS/cm

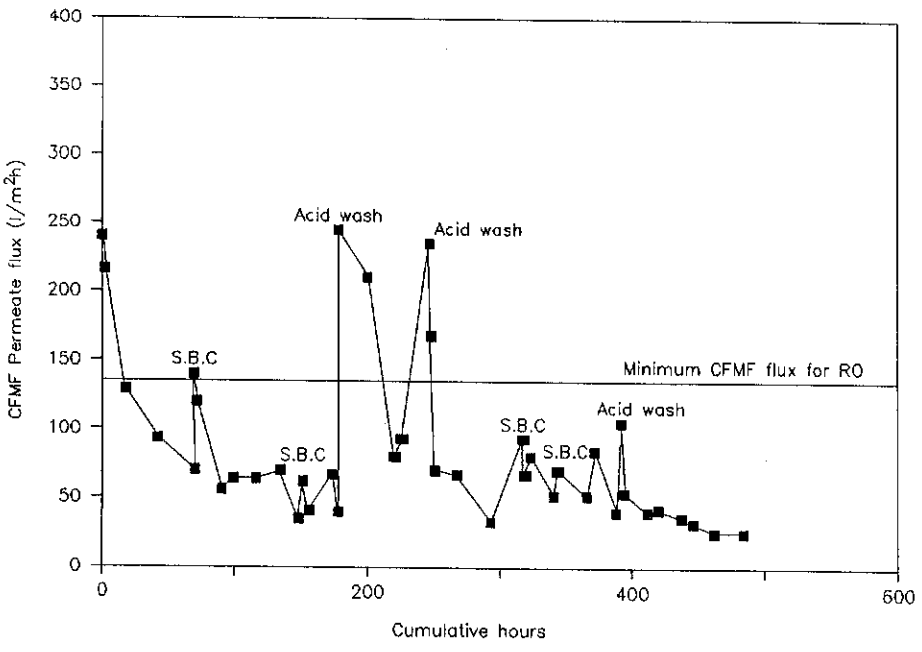

FIGURE 4.3 : PLOT OF CFMF PERMEATE FLUX WITH TIME BEFORE INSTALLATION OF SPRAY CLEANING HEAD

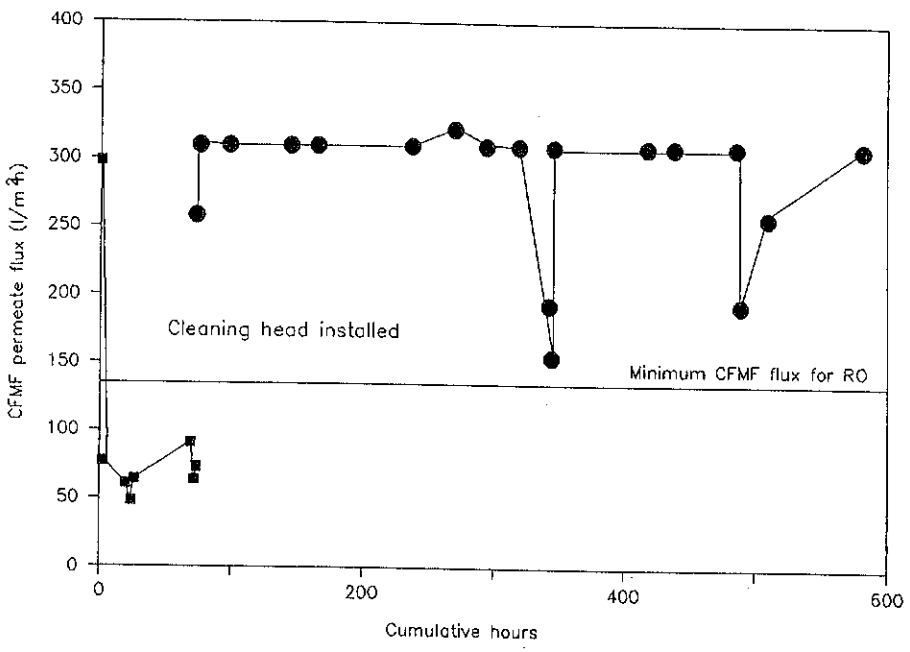

FIGURE 4.4 : PLOT OF CFMF PERMEATE FLUX WITH TIME AFTER INSTALLATION OF SPRAY CLEANING HEAD

The reverse osmosis unit gave unsatisfactory results due to fouling. Following laboratory tests, the foulant was found to be calcium oxalate. Sodium carbonate was added to the permeate from the cross-flow microfilter, causing precipitation of calcium carbonate. This was removed from the effluent in a second cross-flow microfiltration unit and resulted in a substantial decrease in the rate of fouling, thus confirming laboratory results that a two stage microfiltration process could produce a feed to the reverse osmosis unit that was essentially non-fouling.

4.1.5 Cross-flow Microfiltration of Alkaline Extraction Bleach Effluent

The alkaline extraction (E-stage) liquor arises from the bleaching circuit when after chlorination, the pulp is extracted in a caustic medium. E-stage liquor is a yellow/brown colour and contains about 1 % dissolved solids of low molecular mass. A typical analysis is given in Table 4.9.

The alkaline extraction liquor was cross-flow microfiltered **(Appendix 4.11)** using an experimental unit with the following specifications :-

Tube type	:	Single polyester - Swiss woven
Tube dimensions	:	1,95 m x 12 mm
Pump	:	532 Mono pump

Circulation velocity	:	1,7 m/s
Feed pressure	:	120 kPa
Temperature during tests	:	30 to 33 °C

TABLE 4.9
TYPICAL ANALYSIS OF ALKALINE EXTRACTION BLEACH EFFLUENT

pH		7,9
Cond	(mS/cm)	8,4
TOC	(g/ℓ)	4,87
TDS	(g/ℓ)	12,6
Ash	(g/ℓ)	5,8
SS	(g/ℓ)	0,08
Sodium	(g/ℓ)	2,6
Chloride	(g/ℓ)	0,798

TABLE 4.10
PERMEATE FLUX FOR TOTAL RECYCLE TEST

Elapsed time (minutes)	Permeate flux (ℓ/m^2h)
3	46
10	36
25	25
35	24
67	22
80	21
120	20

Permeate fluxes obtained in total recycle mode are given in Table 4.10 and in batch concentration mode in Table 4.11.

A 68 % permeate recovery was achieved at the end of the batch concentration run. Analysis of permeate samples indicated that only the undissolved material present in the effluent was rejected. There was no rejection of dissolved organic/inorganic constituents.

4.1.6 Cross-flow Microfiltration of Paper Machine Effluent

The Cape Kraft paper machine effluent was treated by cross-flow microfiltration **(Appendix 4.12)** using an experimental unit with the following specifications :-

Woven tube length	:	2,7 m
Pump	:	Hydrocell D10
Tube velocity	:	1 m/s
Feed pressure	:	200 to 500 kPa
Precoat	:	Aluminium hydroxide in water slurry
Chemical addition	:	500 mg/ℓ and 2 g/ℓ of alum was added to the effluent, and the pH adjusted to 5,2 and 5,8 respectively

A summary of the performance of the cross-flow microfilter for two separate tests is given in Tables 4.12 and 4.13

TABLE 4.11
PERMEATE FLUX FOR BATCH CONCENTRATION TEST

Elapsed time (hours)	Permeate flux (ℓ/m^2h)
2,00	17
4,00	16
8,17	14
20,75	11

TABLE 4.12
FLUX PERFORMANCE ON THE FIRST TEST

		Effluent permeate	Effluent permeate	Effluent permeate	Effluent permeate
Time	(mins)	0	5	15	25
Flux	(ℓ/m^2h)	423	156	116	105
Specific flux	($\ell/m^2h.MPa$)	2 115	559	464	420
Outlet pressure	(kPa)	200	280	250	250

TABLE 4.13
FLUX PERFORMANCE ON THE SECOND TEST

Time (hour)		0	0,5	1,5	3,0	3,5	4,0
Flux	(ℓ/m^2h)	354	172	150	208	163	146
Pressure	(kPa)	600	375	500	400	375	375

Analysis of the feeds and rejection performance of the cross-flow microfilter are given in Tables 4.14 and 4.15

TABLE 4.14
REJECTION PERFORMANCE ON THE FIRST TEST

Sample		Raw effluent	Permeate B	Permeate C	Permeate D
pH		4,85	-	-	-
Cond	(mS/cm)	3,02	2,70	2,70	2,39
TS	(g/ℓ)	3,99	2,98	2,76	2,55
TC	(g/ℓ)	1,55	0,44	0,41	0,35
Ca	(mg/ℓ)	140	-	-	-
TC rej	(%)	-	72	73	77
TS rej	(%)	-	25	31	36
Cond rej	(%)	-	11	17	21

TABLE 4.15
REJECTION PERFORMANCE ON THE SECOND RUN

Time (hour)		0,5	1,5	3,0	3,5	4,0
Feed TS	(g/ℓ)	9,48	8,82	10,31	9,85	9,62
Permeate TS	(g/ℓ)	7,51	7,60	8,27	8,27	8,39
Rejection	(%)	21	20	20	16	13
Feed cond	(mS/cm)	7,13	7,09	7,76	7,80	7,80
Perm cond	(mS/cm)	7,07	7,07	7,70	7,76	7,79

4.1.7 Cross-flow Microfiltration of Clarifier Overflow, Clarifier Feed and Noodle Water

The SAPPI Cape Kraft Mill was designed with a closed loop effluent system using polyelectrolyte dosing and clarification. The mill produces both test liner and fluting from waste paper.

The clarifier overflow contained a high level (200 to 400 mg/ℓ) of colloidal and suspended solids which caused corrosion problems and possibly effected paper quality.

To overcome this problem an effluent bleed stream of 200 to 300 m^3/d was discharged to Milnerton Sewerage Works.

Cross-flow microfiltration was investigated as a method of :-

(i) removal of colloidal and suspended solids from the clarifier overflow,

(ii) removal of TDS and sulphate to provide for higher water recycle or to meet the discharge specification without dilution.

The microfiltration pilot-plant **(Appendix 4.13)** consisted of a single tube element of diameter 40 mm and 30 m in length.

The experiments were carried out with an inlet pressure of 300 kPa, a pressure drop of 100 kPa and a tube velocity of 2 m/s.

Alum was used as a precoat layer and where required as an effluent coagulant.

The effect of the following chemicals on permeate flux was investigated : HTH, polyelectrolyte, starch, rosin and caustic.

Experiments were conducted on clarifier overflow, clarifier feed and noodle water, analyses of which are given in Tables 4.16 and 4.17.

TABLE 4.16
CLARIFIER OVERFLOW FEED ANALYSIS

Date	29.2	2.3	5.3	6.3	7.3	9.3	13.3	18.3	19.3	21.3
Type	Fluting	Fluting	Fluting	Fluting	Linear	Linear	Fluting	Export	Export	Export
pH	4,33	4,30	4,20	4,29	4,09	3,75	4,34	4.24	4,17	4,74
Cond	1,81	1,77	1,62	1,66	1,68	1,95	1,89	1,70	1,67	1,72
TS	3,61	3,42	2,86	2,99	3,11	4,67	1,95	3,26	3,30	4,11
TDS	3,45	-	2,67	2,65	2,86	4,02	1,60	2,93	3,02	-
SS	0,16	-	0,19	0,34	0,26	0,66	0,34	0,33	0,27	-
TOC	1,90	1,90	1,86	1,75	1,94	2,00	1,69	1,63	1,65	1,80
Ca	0,20	-	-	-	-	-	-	-	-	-
Mg	0,02	-	-	-	-	-	-	-	-	-
Al	0,12	-	-	-	-	-	-	-	-	-
SO_4	0,27	-	-	-	-	-	-	-	-	-

All determinands in g/ℓ except pH and conductivity - mS/cm

TABLE 4.17
CLARIFIER FEED AND NOODLE WATER

Type		Clarifier feed	Clarifier feed	Noodle water	Noodle water
pH		4,26	4,28	5,70	5,68
Cond	(mS/cm)	1,83	1,85	3,67	4,73
TS	(g/ℓ)	5,56	6,01	18,15	17,48
TDS	(g/ℓ)	3,19	3,39	13,88	-
SS	(g/ℓ)	2,37	2,37	4,27	-
TOC	(g/ℓ)	1,89	1,94	5,78	7,83

Results of the cross-flow microfiltration of clarifier overflow are summarised in Table 4.18 and 4.19

Product quality did not deteriorate at high water recoveries. No major differences were found with or without alum addition.

TABLE 4.18
MICROFILTRATION OF CLARIFIER OVERFLOW - SUMMARY OF RESULTS

Time	Type	Flux	Water	Feed Tank			Point Product			
(h)		(ℓ/m^2h)	recovery (%)	TDS (mg/ℓ)	SS (mg/ℓ)	TOC (mg/ℓ)	TS (mg/ℓ)	TDS (mg/ℓ)	SS (mg/ℓ)	TOC (mg/ℓ)
23	Fluting	48	97	11 595	5 925	3 035	4 330	4 296	34	1 775
40	Fluting	32	68	4 597	-	2 080	4 668	4 628	40	1 774
16	Fluting	40	80	5 588	4 652	2 014	4 250	4 208	42	1 626
20	Fluting	40	60	4 472	3 632	2 048	3 980	3 952	28	1 812
44	Linear	37	50	4 300	3 774	2 016	3 880	3 848	32	1 756
88	Linear	20	65	5 350	3 516	2 943	-	-	-	1 738
27	Lin/Flut	27	92	9 212	5 052	1 993	3 500	3 472	28	1 097
16	Effluent	64	96	13 747	5 747	3 085	4 163	4 151	12	1 677
20	Effluent	42	96	10 348	4 486	2 640	4 244	4 234	10	1 642
20	Effluent	19	78	5 857	4 603	2 560	4 993	4 974	19	2 463

TABLE 4.19
MICROFILTRATION OF CLARIFIER OVERFLOW - PRODUCT QUALITY

Water	Feed				Calculated Overall Product			
Recovery (%)	TS (mg/ℓ)	TDS (mg/ℓ)	SS (mg/ℓ)	TOC (mg/ℓ)	TS (mg/ℓ)	TDS (mg/ℓ)	SS (mg/ℓ)	TOC (mg/ℓ)
97	3 610	3 451	159	1 900	3 380	3 380	0	1 867
68	3 425	3 266	(159)	1 903	-	-	-	1 820
80	2 860	2 672	188	1 860	2 174	2 174	-	1 821
60	2 994	2 653	341	1 752	1 984	1 984	0	1 550
50	3 114	2 856	258	1 943	1 972	1 972	0	1 873
65	4 674	4 018	656	2 008	-	-	-	1 487
92	1 948	1 604	344	1 694	1 293	1 293	-	1 667
96	3 258	2 928	330	1 628	2 807	2 807	0	1 565
96	3 297	3 023	274	1 654	2 951	2 951	0	1 606
78	4 113	3 839	274	1 798	3 624	3 624	0	1 584

The results of microfiltration of clarifier feed and noodle water are given in Table 4.20 and the estimated overall product in Table 4.21.

TABLE 4.20
MICROFILTRATION OF CLARIFIER FEED AND NOODLE WATER - SUMMARY OF RESULTS

Time (h)	Flux (ℓ/m^2h)	Water recovery (%)	Feed Tank				Point Product			
			SS (mg/ℓ)	TDS (mg/ℓ)	SS (mg/ℓ)	TOC (mg/ℓ)	TS (mg/ℓ)	TDS (mg/ℓ)	SS (mg/ℓ)	TOC (mg/ℓ)
Clarifier Feed										
20	9	55	10 125	5 102	5 023	2 720	3 847	3 799	48	1 310
26	9	55	10 662	4 871	5 791	3 550	4 318	4 318	28	1 512
Noodle Water										
3	18	50	26 490	18 000	8 490	8 173	8 591	8 591	59	3 488
7	15	50	19 713	-	-	8 754	(3 642)	(3 642)	-	2 042

TABLE 4.21
MICROFILTRATION OF CLARIFIER FEED AND NOODLE WATER - PRODUCT QUALITY

Water recovery (%)	Feed				Calculated Overall Product			
	TS (mg/ℓ)	TDS (mg/ℓ)	SS (mg/ℓ)	TOC (mg/ℓ)	TS (mg/ℓ)	TDS (mg/ℓ)	SS (mg/ℓ)	TOC (mg/ℓ)
Clarifier Feed								
55	5 557	3 187	2 370	1 885	1 476	1 476	0	1 139
55	6 007	3 389	2 618	1 940	2 166	2 166	0	612
Noodle Water								
50	18 146	13 878	4 268	5 781	9 711	9 711	0	3 363
50	17 480	-	-	7 840	-	-	-	6 916

The product quality in terms of suspended solids was excellent and significant TDS and TOC removals were achieved.

It was found that the polyelectrolyte used in the clarifier had no effect on membrane flux but that the rosin used in liner production and the starch additive gave large flux declines. Removal of both colloidal and suspended solids was almost complete for the three types of effluent, and product quality did not deteriorate at high water recoveries.

4.2 CROSS-FLOW MICROFILTRATION OF TANNERY EFFLUENTS

4.2.1 Introduction

Tanneries are processing factories that take in raw or semi-processed animal hides and convert them to a usable end-material. They can be divided into chrome tanneries or vegetable tanneries according to the tanning agent used. Recently "*wet-blue*" tanneries have become more common. In these, the raw hide is processed only to the chrome tanning stage, rather than to the final leather product. While the processes within each tannery vary in detail, a general outline of operations remains common.

Tannery effluent is in general characterised by high levels of organic material (proteins and fats), suspended solids and dissolved solids. It may also contain salt, antiseptic, chrome, vegetable tannin, dyes and lacquers, depending on the particular processes used.

Disposal of such effluents is problematical. Lagooning and spray irrigation are possible but not advocated by the Department of Environmental Affairs. Discharge to municipal sewers after some on-site pretreatment is extremely expensive, as the effluents exceed the discharge limits imposed by municipalities.

Cross-flow microfiltration was investigated as a method of pretreating tannery effluent, prior to discharge, spray irrigation or reverse osmosis. A number of different tannery effluents were treated.

4.2.2 Cross-flow Microfiltration of Chrome Tannery Effluents

Effluents from three chrome tanneries, Hanni and Sons (Pty) Ltd., SA Bata Co. Ltd, and Silverton Tannery **(Appendix 4.14)** were treated by cross-flow microfiltration in an experimental unit with the following specifications :-

Tube description	:	Single - Swiss Woven Polyester
Tube dimensions	:	1,9 m x 12 mm
Pump	:	Mono pump S32
Circulation velocity	:	1,3 to 1,7 m/s
Inlet pressure	:	120 to 170 kPa

The single hose was suspended above a gutter in a linear configuration.

The effluents were first passed through a bare microfilter tube prior to testing the effect of diatomaceous earth and aluminium hydroxide precoats. The effect of adding a polyelectrolyte to the effluents was investigated. Chemical analyses of the effluents are given in Table 4.22.

TABLE 4.22
ANALYSIS OF CHROME TANNERY EFFLUENTS

Analysis		SA Bata Co. Ltd.	Hanni & Sons Pty. Ltd.	Silverton Tannery Co. Ltd.
pH		7,6	5,0	7,9
Cond	(mS/cm)	26,2	28,7	16,1
TDS	(g/ℓ)	17,6	19,5	10,2
Organic solubles	(g/ℓ)	2,4	2,4	1,4
Ash	(mg/ℓ)	15,2	17,1	8,8
Chloride	(mg/ℓ)	6 753	7 072	2 960
Sodium	(mg/ℓ)	5 128	5 712	2 861
Protein (Folin)	(mg/ℓ)	1 712	1 012	432
TOC	(mg/ℓ)	-	465	409
IC	(mg/ℓ)	-	3	71
TC	(mg/ℓ)	1 028	468	480

The effluent from Hanni and Sons (Pty) Ltd., contained flocculated suspended matter. The flux obtained ranged from 316 ℓ/m²h after one hour to 250ℓ/m²h after 2,6 hours. The effluent formed a deposit on the hose during cross-flow microfiltration. The permeate obtained was clear.

When diatomaceous earth was used as a precoat, the flux obtained was 20 ℓ/m²h over a two hour period. The permeate obtained was clear.

Aluminium hydroxide at pH 7 was used as precoat to filter effluent from SA Bata Ltd. Co. The flux dropped to 64 ℓ/m²h after one hour and then to 10 ℓ/m²h after 23 hours. Analysis of the permeate samples showed no significant rejection of constituents. Using a diatomaceous earth precoat, a batch concentration test was conducted over a twenty hour period. The permeate flux decreased from 43 to 9 ℓ/m²h for a permeate recovery of 72 %. At a higher flow velocity, the permeate flux decreased from 71 ℓ/m²h, after half an hour, to 67 ℓ/m²h after 6 hours. A clear permeate was obtained, with no significant rejection of constituents.

When effluent from Silverton Tannery was filtered without any precoat, the permeate obtained was not clear. Using diatomaceous earth as a precoat and a flow velocity of 1,7 m/s, a permeate flux of 20 ℓ/m²h was obtained after 2 hours of operation, decreasing to 10 ℓ/m²h after 4,5 hours. At a higher feed velocity of 2,7 m/s, the permeate flux decreased from 69 ℓ/m²h, after half an hour, to 41 ℓ/m²h after 4,75 hours. A clear permeate was obtained, with no rejection of dissolved constituents.

The effect of polyelectrolytes on permeate flux was tested by first forming a diatomaceous earth precoat on a filter tube. This gave a water flux of 120 ℓ/m²h after 24 hours. Polyelectrolyte, Zeetag 92, was added to the circulating water at a dosage of 50 mg/ℓ. The water flux decreased to 58 ℓ/m²h after two hours, and to

53 ℓ/m^2h after 4 hours. The test was repeated using Magnafloc-1011. The initial water flux of 84 ℓ/m^2h decreased to 65 ℓ/m^2h after one hour and to 62 ℓ/m^2h after 4 hours, upon addition of the polyelectrolyte.

4.2.3 Cross-flow Microfiltration of Wet-Blue Tannery Effluents

Composite samples of wet-blue tannery effluents from General Hide Corporation were obtained **(Appendices 4.15 to 4.19)**. An outline of the operational sequence and the source of these effluents is given in Table 4.23.

Analyses of the effluents referred to in Table 4.23 are given in Table 4.24.

The cross-flow microfiltration of sample 1 ('soaks' effluent) without pH correction (pH 7) and without a precoat, gave a permeate that was turbid.

Laboratory tests showed that at pH 4,5 and 5,0, sample 1 formed a precipitate. Cross-flow microfiltration at pH 5,0, gave permeate fluxes that decreased with time and increasing feed concentration. Suspended solids were rejected. With an alum precoat, fluxes of between 18 and 28 ℓ/m^2h were obtained over a wide range of total solids concentration. Permeate samples gave a total carbon rejection of 53 % and a protein rejection of 64 % after 15 hours of total recycle. At a total solids concentration of 210 g/ℓ the total carbon and protein rejection was 49 % and 56 % respectively. The permeates were clear. At high water recoveries, the pH of the effluent tended to rise quickly from pH 5,5 to above pH 7,0.

Cross-flow microfiltration of sample 1, using a diatomaceous earth precoat, gave inconsistent results. In the first test, the permeate flux dropped from 164 ℓ/m^2h to 30 ℓ/m^2h over 4 hours. The permeate flux in a second test decreased from 391 ℓ/m^2h to 34 ℓ/m^2h over 4,8 hours, dropping to 16 ℓ/m^2h after 75 hours. A total carbon rejection of between 14 % and 30 %, and a protein rejection of between 12 % and 30 % was obtained. In a third test the permeate flux decreased from an initial 1 072 ℓ/m^2h to 26 ℓ/m^2h after 6,2 hours and to 12 ℓ/m^2h after 38,4 hours. Total carbon rejections of between 7 % and 13 % were obtained. In all three tests permeate samples were clear. These discrepancies in flux values are thought to be due to cleaning of the filter tubes after test one and to the fitting of a new filter tube after test two.

Alum and diatomaceous earth precoats were used for the cross-flow microfiltration of sample 2 effluent. Using an alum precoat, and after 4 hours, the permeate flux was 50 ℓ/m^2h and after 48 hours, 32 ℓ/m^2h at 60 % permeate recovery. Total carbon rejections of 35 % were obtained as well as low rejections of sodium, chloride, calcium and sulphate ions.

With a diatomaceous earth precoat, the flux was 24 ℓ/m^2h after 4 hours and 14 ℓ/m^2h after 19 hours at 75 % permeate recovery. Total carbon rejections of between 12 % and 30 % were obtained and permeate samples were clear.

TABLE 4.23
SUMMARY OF THE OPERATIONAL SEQUENCE AT GENERAL HIDE CORPORATION AND SOURCE OF THE EFFLUENT

	Operation number		Volume of effluent involved kℓ/d
Lime Section	Soak de-hair	1	33,0
	Liming	2	17,6
	Wash	3	33,0
	Fleshing	4	
Chrome Section	First wash	5	20,9
	Second wash	6	20,9
	Delime including bate	7	13,1
	Wash	8	20,9
	Pickle, chrome tan & basify	9	-
	Wash	10	20,9
	Total		180,3

Examination of the chemical analyses indicate that the effluents can be divided into the following groups :-

Group A	:	Numbers 1, 5, 6, 7,8	Total volume = 180,8 kℓ
Group B	:	Numbers 2, 3	Total volume = 50,6 kℓ
Group C	:	Number 10	Total volume = 20,9 kℓ

Effluent A is relatively 'clean' effluent.
Effluent B comprises the high pH, high organic content effluents.
Effluent C is the only acidic effluent.

TABLE 4.24
ANALYSIS OF SAMPLES FROM BLUE-WET TANNERY

Sample	Sample 1: Effluent A Supernatant liquor from prelime soak 1 + pre-chrome effluents 5, 6, 7 and 8	Sample 2: B + C Supernatant liquor from 2 and 3 + 10 before ferric chloride addition	Sample 3: B + C + Ferric chloride Supernatant liquor from 2 and 3 + 10 after ferric chloride addition	Sample 4: Clari-flocculator Supernatant
pH	7,51	7,38	3,40	2,91
Cond (mS/cm)	4,03	17,55	9,75	20,8
COD	5 630	6 260	13 610	3 220
TOC	1 987	2 359	882	613
IC	53	167	60	50
TC	2 040	2 526	942	663
TDS	6 954	18 628	17 826	20 820
Organic solubles	3 814	14 036	11 063	13 960
Ash	3 150	4 592	6 763	6 860
Chlorides	996	3 123	5 080	6 236
Sodium	715	4 230	4 200	4 300
Calcium	23	263	385	336
Sulphide $S^{=}$	4,5	4,0	ND	ND
Sulphate	103	4 630	960	5 170
$Cr^{=}$	0	14	28	20
Fe Free and saline NH_3	0,9	5	165	970
Protein (Folin)	3 520	7 750	3 900	4 400

All values except pH and conductivity in mg/ℓ.
ND not detected.

Cross-flow microfiltration of sample 3, taken from a pilot plant, and containing ferric chloride as a flocculant, gave a permeate that was as clear as the settled clarifier

supernatant. This sample had a pH of 3,1 and a high soluble iron content, some of which was in the ferrous state. The flux, in batch concentration mode, ranged from 87 to 35 ℓ/m^2h over 6 hours.

Ferric chloride was added to sample 2 to simulate sample 3. However a flux of only 11 ℓ/m^2h was obtained. This difference in permeate flux may be related to pH and and total ferric ions. Samples 3, 4 and the permeate from sample 2 treated with ferric chloride, all contain ferrous ions. This is undesirable for subsequent hyperfiltration, as the effluents have an extremely low redox potential. Ferric chloride is considered unsatisfactory either as a floc for clarifier treatment, or as a membrane medium. Aluminium hydroxide (alum) was therefore used as a precoat for cross-flow microfiltration in subsequent investigation.

4.2.4 Cross-flow Microfiltration of Curing Store Effluent

This effluent was a blend of skin drainage and salt washing effluents containing ferric chloride and ferric hydroxide. Prior to cross-flow microfiltration, the effluent was passed through a 4 mm mesh screen to remove hair. No further coagulation/ flocculation was undertaken.

When the effluent was filtered by cross-flow microfiltration (**Appendix 4.20**), the permeate flux dropped from 39 ℓ/m^2h to 34 ℓ/m^2h after 24 hours, and then to 18 ℓ/m^2h after 78 hours in the total recycle mode. After two continuous sets of batch concentration and total recycle runs, the flux had dropped to 13 ℓ/m^2h at a feed concentration of 510 g/ℓ.

Analysis of samples taken indicate an initial total carbon rejection of 8,5 % increasing to 25 % with increasing total solids. Sodium chloride, ferric and sulphate ions were also rejected. Permeate samples were clear.

4.3 CROSS-FLOW MICROFILTRATION OF COOLING TOWER BLOW-DOWN

A cross-flow microfilter plant was installed at the Eskom Grootvlei Power Station, to treat cooling tower blow-down water to a standard suitable for feed to a reverse osmosis plant (**Appendix 4.21**).

Chemical analyses of the blow-down water and the permeate from the cross-flow microfilter are given in Table 4.25. For comparison, an analysis of recarbonated water is also given.

Permeate production rate was good, with a flux of 240 ℓ/m^2h after 23 hours. Flux performance data for the cross-flow microfilter are given in Table 4.26

A suspended solids rejection of 100 % and a silt density index of 3,1 were recorded. Due to alum addition there was a 2 % increase in dissolved solids.

The fluxes indicate that an acceptable cleaning frequency of 24 to 48 hours would be required by a production unit and that a high quality water can be produced.

TABLE 4.25
ANALYTICAL ANALYSES OF BLOW-DOWN WATER, RECARBONATED WATER AND CROSS-FLOW MICROFILTRATION PERMEATE

Analysis		Cooling tower water	Recarbonated water	CFMF permeate
pH		8,13	7,71	8,51
Cond	(mS/cm)	1,01	0,97	1,13
TDS	(mg/ℓ)	831	806	847
SS	(mg/ℓ)	64	14	0
SO_4	(mg/ℓ)	315	339	345
Cl	(mg/ℓ)	87,6	85,0	89,1
Na	(mg/ℓ)	156	160	179
Fe	(mg/ℓ)	0,5	0	0
Al	(mg/ℓ)	1,85	0	0
Organic carbon	(mg/ℓ)	30,0	23,5	25,0
Inorganic carbon	(mg/ℓ)	35,5	23,0	39,0
SDI	(mg/ℓ)	-	-	3,11

TABLE 4.26
CFMF FLUX PERFORMANCE DATA

Running time (hrs)	Operating pressure (kPa)	Flux (ℓ/m^2h)
0,9	500	540
1,5	500	350
6,5	340	310
23,0	390	240

4.4 CROSS-FLOW MICROFILTRATION OF SIMULATED FISH EFFLUENT

4.4.1 Introduction

I & J fish packaging in Cape Town, produce an effluent from the washings in the fish processing factory. The effluent has a high COD. Cross-flow microfiltration was considered as a process which could be used to pretreat the effluent **(Appendix 4.22)**.

4.4.2 Experimental Data and Results

The fish effluent was simulated by adding 100 g of minced hake (I & J Frozen Hake Fillets) to 25 ℓ of water. This was mixed well and allowed to stand overnight before being passed through a 2 mm mesh size screen. Analysis of the simulated effluent is given in Table 4.27.

TABLE 4.27
ANALYSIS OF SIMULATED FISH EFFLUENT

Run no.	TS (g/ℓ)	SS (g/ℓ)	pH	Cond (mS/cm)	TC (mg/ℓ)	TOC (mg/ℓ)	COD (mg/ℓ)
1	0,312	1,70	7,1	0,23	220	125	619
2	0,294	2,3	6,9	0,23	75	325	216
3	1,160	0,14	7,6	0,43	160	71	191
4	1,150	0,87	7,7	0,44	180	76	188
5	1,50	1,27	8,7	0,29	115	72	309

The experimental unit used had the following specifications :-

Tube type	:	Single Swiss woven polyester
Tube dimensions	:	12 mm x 1,9 m
Tube configuration	:	Linear, suspended above a gutter
Feed velocity	:	1,0 to 2,6 m/s
Feed pressure	:	200 to 350 kPa
Time of run	:	2,0 to 23 hours
Precoat	:	Limestone and diatomaceous earth

Cross-flow microfilter performance data are given in Table 4.28 and analyses of the permeate obtained in Table 4.29.

4.5 CROSS-FLOW MICROFILTRATION OF SORGHUM BEER

4.5.1 Introduction

An investigation was conducted on sorghum beer (iJuba from the Congella Brewery) to determine the feasibility of clarification using the cross-flow microfiltration process **(Appendix 4.22)**. Sorghum beer is made up of suspended solids (starch) in a liquid containing dissolved solids, sugar, yeast, alcohol and salts. The total solids concentration is 47 g/ℓ, comprising 22 g/ℓ of dissolved solids and 25 g/ℓ of suspended solids.

TABLE 4.28
RESULTS OF THE CROSS-FLOW MICROFILTRATION OF FISH EFFLUENT

Run no.	Time (hrs)	Temp (°C)	Pressure in (kPa)	Velocity in (kPa)	Perm rate (ℓ/h)	Flux (ℓ/m²h)
1	5,5	-	210	1,8	3	42
2	5,5	-	200	1,8	2	27
3	6,5	37	250	1,0	1,4	18,1
4	5,3	36	260	2,6	4,7	62
5	4,4	40	350	3,2	4,4	59
6	4,3	31	250	2,1	5,3	71
7	4,0	30	250	2,2	4,8	64
8	2,0	26	250	2,6	5,5	74
	5,4	39	300	-	9,6	128
8a	0,0	25	350	-	6	80
	1,0	-	350	-	5,1	69
	23,3	35	280	-	2,1	69

Note : Run no. 8a is the continuation of run no. 8 after the addition of 25 ℓ of fresh, screened fish effluent.

TABLE 4.29
LABORATORY RESULTS FROM THE CROSS-FLOW MICROFILTRATION OF FISH EFFLUENT

Run	TS (g/ℓ)		SS (g/ℓ)		pH		Cond (mS/cm)		TC (mg/ℓ)		TOC (mg/ℓ)		COD (mg/ℓ)	
no.	Feed	Perm	Feed	Perm	Feed	Perm	Feed	Perm	Feed	Perm	Feed	Perm	Feed	Perm
1	0,312	-	1,7	-	7,1	-	0,23	-	220	-	125	-	619	-
	-	0,09	-	0,004	-	8,4	-	0,185	-	30	-	21	-	26,8
	-	0,13	-	0,012	-	8,0	-	0,187	-	30,5	-	21,5	-	33,2
2	0,294	-	2,3	-	6,9	-	0,23	-	75	-	32,5	-	216	-
	-	0,20	-	0,08	-	7,9	-	0,208	-	40	-	29	-	32,8
	-	0,116	-	0,076	-	7,9	-	0,214	-	40	-	0	-	-
3	1,16	-	0,14	-	7,6	-	0,43	-	160	-	71	-	191	-
	-	0,18	-	0,06	-	8,1	-	0,23	-	30,5	-	16,5	-	31,2
	-	0,18	-	0,04	-	8,1	-	0,29	-	30,5	-	9,5	-	32,4
4	1,15	-	0,87	-	7,7	-	0,44	-	180	-	76	-	188	-
	-	0,20	-	0,056	-	7,9	-	0,23	-	25	-	15	-	25,2
	-	0,17	-	0,01	-	8,0	-	0,28	-	25	-	9,5	-	25,6
5	1,5	-	1,27	-	8,7	-	0,29	-	115	-	72	-	309	-
	-	0,17	-	0,066	-	9,1	-	0,16	-	30,5	-	17	-	39,2
	-	0,11	-	0,002	-	9,0	-	0,18	-	30	-	15,5	-	28

4.5.2 Experimental Data and Results

The experimental unit had the following specifications :-

Tube type	:	Single Swiss woven polyester
Tube dimension	:	12 mm x 1,9 m
Tube configuration	:	Linear, suspended above a gutter
Feed velocity	:	2 m/s
Feed pressure	:	250 kPa
Run times	:	1 hour
Precoat	:	1) None 2) A combination of coarse and fine grade diatomaceous earth

Cross-flow microfilter performance data is given in Table 4.30 and analytical results in Table 4.31.

TABLE 4.30
RESULTS OF THE CROSS-FLOW MICROFILTRATION OF SORGHUM BEER

Precoat	Temp (°C)	Perm rate (ℓ/h)	Pressure in (kPa)	Flux (ℓ/m²h)	Velocity (m/s)
None	25	0,42	150	6,0	2,0
50 mℓ Celite 560	25	3,6	220	51,8	2,2
150 mℓ Celite 500	36	4,2	240	59,5	2,2

TABLE 4.31
ANALYSIS OF SORGHUM BEER AND PERMEATE PRODUCT

Total solids		Total dissolved solids		Suspended solids	
Feed	Perm	Feed	Perm	Feed	Perm
(g/ℓ)	(g/ℓ)	(g/ℓ)	(g/ℓ)	(g/ℓ)	(g/ℓ)
-	31,9	-	21,8	-	10,14
46,66	34,5	21,9	21,9	24,76	1,45

4.6 CROSS-FLOW MICROFILTRATION OF SUGAR PROCESSING EFFLUENT

4.6.1 Introduction

A lignin/alcohol slurry is produced from lignin during fermentation experiments conducted at the Sugar Milling Research Institute. Cross-flow microfiltration was investigated as a method of concentrating the slurry **(Appendix 4.24)**.

In addition, the Union Co-operative Bark and Sugar Company, motivated by a critical water shortage during the 1983/84 drought, investigated cross-flow microfiltration as a means of treating factory effluent for reuse purposes. A cross-flow microfiltration/hyperfiltration plant was installed on site.

4.6.2 Experimental Data for the Cross-flow Microfiltration of Lignin/Alcohol Slurry

The experimental unit used had the following specifications :-

Tube description	:	Single Swiss woven polyester
Tube dimensions	:	12 mm x 1,9 m
Tube configuration	:	Linear, suspended above a gutter
Precoat	:	1) None
		2) Diatomaceous earth.

With no precoat, and a feed total solids concentration of 66 g/ℓ, the resulting permeate had a total solids concentration of 17 g/ℓ with a flux of 60 ℓ/m²h after 40 minutes.

With a precoat, and a feed total solids concentration of 50 g/ℓ, the resulting permeate had a total solids concentration of 17 g/ℓ with a flux of 100 ℓ/m²h at 40 minutes.

4.6.3 Experimental Data for the Cross-flow Microfiltration of Activated Sludge Clarifier Overflow from the Union Co-operative Bark and Sugar Company

The pilot plant had the following specifications :-

Tube type	:	Woven polyester single tube
Tube dimensions	:	25 mm x 118 m
Tube configuration	:	Spiral - supported in a tray
Design flux	:	50 ℓ/m²h
Pump	:	D25 Hydracell
Run time	:	5 to 72 hours
Inlet pressure	:	600 kPa
Outlet Pressure	:	0 to 100 kPa
Velocity	:	1,8 to 1,9 m/s
Precoat	:	None
Chemical dosage	:	Ferric chloride

The composition of the activated sludge clarifier overflow is given in Table 4.32

TABLE 4.32
EFFLUENT CHARACTERISTICS

pH		7,9
SS	(mg/ℓ)	19
TS	(mg/ℓ)	1 400
TDS	(mg/ℓ)	1 380
COD	(mg/ℓ)	131

A total of 11 tests were conducted on the cross-flow microfilter pilot plant (**Appendix 4.25**). Tests over 72 hours showed that a flux of 40 to 60 ℓ/m^2h could be expected from the unit. Over this time period, the flux dropped from 80 to 45 ℓ/m^2h at 600 kPa inlet pressure to 28 ℓ/m^2h at 500 kPa.

Pressure drop tests were conducted. These show an average pressure drop of 3 kPa/m at an inlet velocity of 2 m/s. However, there is an increase in pressure drop as the coil diameter decreases.

A COD rejection of 14 % was obtained, and an average of 3 mg/ℓ suspended solids in the permeate was measured.

4.7 CROSS-FLOW MICROFILTRATION OF RAINBOW CHICKEN EFFLUENT

4.7.1 Introduction

Effluent from the Rainbow Chicken Farm (Pty) Ltd. was treated using cross-flow microfiltration (**Appendix 4.26**). The effluent arises from the daily washings of the slaughter house and is characterised by high COD concentrations.

4.7.2 Experimental Data and Results

The experimental unit had the following specifications :-

Tube type	:	Single Swiss woven Polyester
Tube dimensions	:	1,9 m x 12 mm
Tube configuration	:	Linear - supported above a gutter
Feed velocity	:	1,5 m/s
Feed pressure	:	100 to 140 kPa
Run time	:	1,3 to 1,5 hours
Precoat	:	1) None
		2) Aluminium hydroxide
Run mode		1) Total recycle
		2) Batch concentration

Chemical analyses of the effluent is given in Table 4.33.

TABLE 4.33
RAINBOW CHICKEN FEED ANALYSIS

		Feed (screened)
pH		6,78
Cond	(mS/cm)	0,23
SS	(mg/ℓ)	0,73

Initially the effluent was cross-flow microfiltered, in total recycle mode, without a precoat on the filter tubes. Continual pinholing occurred, with the flux dropping from 1 121 ℓ/m^2h to 35 ℓ/m^2h over 1,3 hours. The permeate quality was poor.

A second test, with an alum precoat, was conducted. In total recycle mode the flux decreased from 828 ℓ/m^2h to 473 ℓ/m^2h after 15 minutes. In batch concentration mode the flux was 106 ℓ/m^2h at 80 % water recovery. The permeate showed a 100 % rejection of suspended solids.

4.8 CROSS-FLOW MICROFILTRATION OF VARIOUS SASOL PROCESS STREAMS

4.8.1 Introduction

Five process streams were tested on a bench scale cross-flow microfilter unit **(Appendix 4.27).**

4.8.2 Laboratory Scale Cross-flow Microfilter

The laboratory scale experimental unit had the following specifications :-

Tube type	:	Single Swiss woven polyester tube
Tube dimensions	:	5 x 1 m x 12 mm
Feed velocity	:	1 m/s
Feed pressure	:	80 to 100 kPa
Tube configuration	:	5 x 1 m linear tubes in parallel

Tests were conducted with and without a diatomaceous earth precoat.

4.8.3 Cross-flow Microfiltration of Stripped Gas Liquor

The composition of the stripped gas liquor and of the permeate from the microfilter is given in Table 4.34. A precoat of diatomaceous earth was used.

4.8.4 Cross-flow Microfiltration of Cooling Tower Blow-down

The composition of the cooling tower blow-down water and that of the cross-flow microfiltration permeate is given in Table 4.35. No precoat was used.

4.8.5 Cross-flow Microfiltration of Bio-effluent (activated sludge supernatant)

The composition of the bio-effluent and that of the cross-flow microfiltration permeate is given in Table 4.36. Diatomaceous earth was used as a filter aid.

TABLE 4.34
COMPOSITION OF STRIPPED GAS LIQUOR (SGL) AND CFMF PERMEATE

		Feed	CFMF permeate
pH		965	-
Cond	(mS/cm)	2 700	2 160
TDS	(mg/ℓ)	1 168	1 888
Fe	(mg/ℓ)	110	-
Cl	(mg/ℓ)	55	-
SO_4	(mg/ℓ)	257	-
NH_3	(mg/ℓ)	362	-
P Alkali	(mg/ℓ)	100	-
M Alkali	(mg/ℓ)	825	-
COD	(mg/ℓ)	1 960	1 980
PO_4	(mg/ℓ)	0,5	-
TKN	(mg/ℓ)	475	-
Turbidity		15	-
TSS (GFA)	(mg/ℓ)	80	36
Na	(mg/ℓ)	10,6	-
K	(mg/ℓ)	1,6	-
Ca	(mg/ℓ)	1,6	-
Mg	(mg/ℓ)	0,4	-
Fe	(mg/ℓ)	6,3	-

TABLE 4.35
COMPOSITION OF COOLING WATER BLOW-DOWN AND CFMF PERMEATE

		Feed	CFMF permeate
Cond	(mS/cm)	7 210	7 340
TDS	(mg/ℓ)	4 800	4 408
COD	(mg/ℓ)	1 840	1 040
Turbidity		160	1,8
TSS (GFA)	(mg/ℓ)	542	154

TABLE 4.36
COMPOSITION OF BIO-EFFLUENT AND CFMF PERMEATE

		Feed	CFMF permeate
Cond	(mS/cm)	3 050	1 396
COD	(mg/ℓ)	840	360
Turbidity		140	1,2
TSS (GFA)	(mg/ℓ)	390	10,8

4.8.6 Cross-flow Microfiltration of Dual Media Filtrate

The composition of the dual media filter and the cross-flow microfilter permeate is given in Table 4.37. This effluent was tested on an experimental unit at Secunda **(Appendix 4.28)**. A diatomaceous earth precoat was used.

TABLE 4.37
COMPOSITION OF DUAL MEDIA FILTRATE (DMF) AND CFMF PERMEATE

		Feed	CFMF permeate
pH		7,55	-
Cond	(mS/cm)	2 948	2 830
TDS	(mg/ℓ)	1 376	1 184
F	(mg/ℓ)	120	-
Cl	(mg/ℓ)	100	-
SO_4	(mg/ℓ)	409	-
NH_3	(mg/ℓ)	301	-
P Alkali	(mg/ℓ)	405	-
M Alklai	(mg/ℓ)	-	-
COD	(mg/ℓ)	475	360
PO_4	(mg/ℓ)	0,12	-
TKN	(mg/ℓ)	376	-
Turbidity		51	0,74
TSS (GFA)	(mg/ℓ)	158	92
Na	(mg/ℓ)	52,6	-
K	(mg/ℓ)	33,5	-
Ca	(mg/ℓ)	6,4	-
Mg	(mg/ℓ)	2,2	-
Fe	(mg/ℓ)	9,5	-
Cr	(mg/ℓ)	1,1	-

4.8.7 Cross-flow Microfiltration of Mine Water

The composition of the mine water and that of the cross-flow microfilter permeate is given in Table 4.38. A diatomaceous earth precoat was formed on the tubes.

TABLE 4.38
COMPOSITION OF MINE WATER (MW) AND CFMF PERMEATE

		Feed	CFMF permeate
Cond	(mS/cm)	2 190	2 160
TDS	(mg/ℓ)	1 530	1 192
F	(mg/ℓ)	2,1	2,9
Cl	(mg/ℓ)	85	84
SO_4	(mg/ℓ)	480	500
P Alkali	(mg/ℓ)	0	26
M Alkali	(mg/ℓ)	650	620
Turbidity		73	0,8
TSS (GFA)	(mg/ℓ)	68	8
Na	(mg/ℓ)	542	660
K	(mg/ℓ)	5,5	12,1
Ca	(mg/ℓ)	21	19
Mg	(mg/ℓ)	14,6	14,9
Fe	(mg/ℓ)	1	1
Total oil		5	2,6

4.8.8 Cross-flow Microfilter Performance Data

The five streams were treated on the cross-flow microfilter without any flocculation or pH correction.

The flux data given in Tables 4.39 to 4.42 are not true quantitative results. They can only be used to differentiate between an easily filterable effluent and a problematic effluent.

The decrease in flux rates of the bio-effluent and dual media filtrate are probably due to the colloidal particles present. The decrease in flux rate on the DMF is not as pronounced as the bio-effluent and can be attributed to lower solids concentration and to the diatomaceous earth precoat.

TABLE 4.39
CROSS-FLOW MICROFILTRATION OF COOLING WATER BLOW-DOWN (CWBD)

Time (hrs)	Flux (ℓ/m^2h)	Pressure (kPa)	Comments
0,00	32,1	80	Batch
2,00	26,1	80	Batch
3,75	23,9	80	Batch
5,20	22,0	90	Batch
6,20	22,6	90	Batch
22,00	18,2	90	Recycle

TABLE 4.40
CROSS-FLOW MICROFILTRATION OF BIO-EFFLUENT

Time (hrs)	Flux (ℓ/m^2h)	Pressure (kPa)	Comments
0,00	70	85	Turbid - added diatomaceous earth
0,16	12,1	85	Turbid - added diatomaceous earth
0,50	14,5	85	Batch
1,25	10,4	85	Batch
2,25	9,4	85	Batch
2,75	8,4	85	Batch
4,75	8,1	85	Batch
6,00	7,2	80	Batch
6,50	6,8	80	Batch

TABLE 4.41
CROSS-FLOW MICROFILTRATION OF DUAL MEDIA FILTRATE (DMF)

Time (hrs)	Flux (ℓ/m^2h)	Pressure (kPa)	Comments: Precoat: diatomaceous earth
0,00	52,0	100	Effluent
0,50	36,0	100	Batch
0,75	30,2	100	Batch
1,00	36,3	100	Batch
3,00	20,0	100	Batch
5,50	13,0	100	Batch
Stop to clean tube and precoat			
0,00	59,00	100	Batch
1,00	28,00	100	Batch

TABLE 4.42
CROSS-FLOW MICROFILTRATION OF MINE WATER (MW)

Time (hrs)	Flux (ℓ/m^2h)	Pressure (kPa)	Comment: Precoat: diatomaceous earth
0,00	300	100	Batch
2,0	100	100	Batch

From the analytical data it can be seen that cross-flow microfiltration is capable of treating the effluent streams, either to eliminate suspended solids and colloidal matter or as a pretreatment for reverse osmosis.

4.9 CROSS-FLOW MICROFILTRATION OF METAL FINISHING INDUSTRY EFFLUENTS

A cross-flow microfiltration, hyperfiltration pilot plant was established at a metal finishing jobbing shop, in an attempt to provide an alternative effluent treatment process which would allow recycling of water within the works and containment of toxic chemicals **(Appendix 4.29)**.

Cross-flow microfiltration performance data and analytical results are given in Table 4.43

The effluent contained nickel, cadmium, aluminium, iron, zinc, copper and cyanide. The cyanide contaminated effluent was oxidised in the conventional manner after which it was mixed with the acid effluent. The combined effluent was treated by in-line precipitation followed by cross-flow microfiltration **(Appendix 4.30)**.

TABLE 4.43
PILOT PLANT PERFORMANCE

Flux start batch (ℓ/m^2h)	Flux end batch (ℓ/m^2h)	Water recovery (%)	pH	Cross-Flow Microfilter Feed					Composite Permeate Quality				
				Cond (mS/cm)	TS (g/ℓ)	Fe	Cr	Cd	Cond (mS/cm)	TS (g/ℓ)	Fe	Cr	Cd
41	24	92	3,4	0,62	0,53	1,1	13,8	3,2	0,22	0,06	ND	ND	ND
34	24	96	3,1	1,76	1,05	2,2	25,4	2,3	0,84	0,16	ND	1,65	0,60
36	5,2	65	8,8	0,97	0,72	-	-	-	0,12	-	-	-	-
29	31	34	3,1	1,40	-	-	-	4,0	-	-	-	ND	ND
23	2,9	96	7,6	0,9	0,75	-	1,6	0,5	0,21	0,17	-	-	-
34	-	0	2,9	1,28	0,74	-	17,4	1,5	-	-	-	ND	ND
31	15	96	3,9	5,07	4,9	15,2	21,8	-	1,57	1,28	ND	-	-
29	28,4	80	3,4	1,2	0,53	0,7	4,6	1,3	0,41	0,12	ND	ND	ND
26	25	92	2,4	1,7	0,74	-	9,5	3,2	-	ND	-	ND	ND
35	6,5	70	9,4	1,25	1,02	0,4	-	-	0,22	0,12	-	-	-

ND = Not detected.

4.10 CROSS-FLOW MICROFILTRATION OF TEXTILE SCOUR EFFLUENTS

Cross-flow microfiltration was investigated as a treatment method for scour effluents. Initial tests examined the effect of cross-flow microfiltration on the effluents and based on results full scale treatment processes were developed for a number of effluents.

4.10.1 Cross-Flow Microfiltration of Neutralised Scour Effluent

Textile scour effluent contains high concentrations of sodium hydroxide, organics such as waxes and oils, and inorganic salts.

Scour effluent from David Whiteheads & Sons, Tongaat was treated by cross-flow microfiltration in an attempt to remove suspended solids from the effluent and to reduce the COD, calcium and magnesium concentrations **(Appendix 4.31)**.

The experimental unit had the following specifications :-

Tube type	:	Single Swiss woven polyester
Tube dimension	:	12 mm x 1,9 m
Tube configuration	:	Linear, suspended above a gutter
Feed velocity	:	1,5 to 3,6 m/s
Feed pressure	:	250 to 380 kPa
Run times	:	24 hours
Precoat	:	1) kaolins + diatomaceous earth 2) none 3) limestone + diatomaceous earth 4) diatomaceous earth 5) limestone 6) limestone + aluminium sulphate to reduce the feed pH to 6

Prior to cross-flow microfiltration, the effluent was treated with solid carbon dioxide (dry ice) to a pH of 8,5. Performance data for the cross-flow microfilter are given in Table 4.44 and analytical results in Table 4.45.

TABLE 4.44
CROSS-FLOW MICROFILTER PERFORMANCE DATA FOR SCOUR EFFLUENT

Pressure in (kPa)	Velocity (m/s)	Temp (°C)	Flux (ℓ/m^2h) 6 hrs	Flux (ℓ/m^2h) 20 hrs	Precoating slurry
250	1,2	39	33	-	Kaolin + DE
250	2,8	40	7	-	None
360	2,5	38	55	-	Limestone 15 + DE
300	2,1	23	28	26	Limestone 15 + DE
380	1,5	19	30	24	Diatomaceous Earth
320	3,5	20	52	48	Limestone 15
300	3,6	19	64	55	Limestone 15

DE - Diatomaceous earth

TABLE 4.45
A SUMMARY OF LABORATORY RESULTS FROM THE CROSS-FLOW MICROFILTRATION OF SCOUR EFFLUENT

Run	TS (g/ℓ)		SS (g/ℓ)		Ca (mg/ℓ)		Mg (mg/ℓ)	
no.	Feed	Perm	Feed	Perm	Feed	Perm	Feed	Perm
1	25,7	25,6	3,6	0,7	33,4	17,5	10,2	9,5
2	30,5	30,6	3,1	2,2	41,7	23,4	12,2	11,7
3	27,7	22,3	6,1	2,6	62,1	3,3	12,5	7,6
4	-	-	3,0	0,0	21,3	5,5	7,4	6,4
5	-	-	2,9	1,1	24,9	24,1	7,5	7,6
6	27,6	25,5	1,6	0,9	27,2	2,3	4,4	3,0
7	33,8	23,2	8,3	0,0	132,5	32,1	8,4	3,9
Original feed	34,1	-	2,9	-	29,4	-	4,8	-

Run no. 7 hads alum added to the feed to reduce the pH to 6.

4.10.2 Cross-flow Microfiltration of Chlorinated Scour Effluent

A sequence involving prechlorination, cross-flow microfiltration, nanofiltration and electrolysis in a chlor-alkali type of electrochemical cell has been developed for the recovery of sodium hydroxide from scour effluent **(Appendix 4.32)**. The final products of the process are a high quality concentrated sodium hydroxide solution, an acidic depleted brine solution and organic filtration concentrates. Pilot plant trials were conducted at David Whiteheads and Sons, Tongaat.

The pilot plant cross-flow microfilter had the following specifications :

Tube type	:	Single Swiss Woven Polyester
Tube dimensions	:	12 mm x 30 m
Tube area	:	1,13 m^2
Pressure in	:	200 to 300 kPa
Pressure out	:	100 to 200 kPa
Feed velocity	:	2,9 m/s
Tube configuration	:	Spirally coiled, supported in a round plastic dish
Run mode	:	Batch concentration
pH Range	:	7,5 to 8,5
Chemical addition	:	Prechlorinated to suitable pH range, with addition of diatomaceous earth and bisulphite

The effluent tested was collected from the first wash bowl of the counter-current scour wash range. A chemical analysis is given in Table 4.46.

TABLE 4.46 ANALYSIS OF SCOUR EFFLUENT		
pH		13,7
Cond	(mS/cm)	58
TS	(g/ℓ)	51
COD	(g/ℓ)	31
TC	(g/ℓ)	14
TOC	(g/ℓ)	12
TIC	(g/ℓ)	2
Na	(mg/ℓ)	21
Mg	(mg/ℓ)	20
Ca	(mg/ℓ)	90
OH^-	(g/ℓ)	16
CO_3^{2-}	(g/ℓ)	2
Cl^-	(g/ℓ)	0,5

A summary of the species point rejections achieved by cross-flow microfiltration is given in Table 4.47.

The average cross-flow microfilter flux was 5 ℓ/m²h. Cross-flow microfiltration removed the suspended solids from the chlorinated scour effluent to produce a turbid concentrate and a clear brown filtrate. Table 4.48 shows that the suspended solids in the chlorinated scour effluents were composed of organics and calcium. Filtrate volume recoveries of 85 to 95 % were achieved.

TABLE 4.47 SUMMARY OF AVERAGE POINT REJECTION ACHIEVED BY CFMF				
Experiment number	Point Rejection (%) on cross-flow microfilter			
	TC	Ca	Mg	TS
2, 3, 4	13	71	0	6
6, 7, 8	26	55	3	-
9 (3)	3	50	90	8
10, 11, 12	16	50	0	-
Note : (i) All rejections based on composite feed and permeate concentration.				
(ii) Unneutralised scour effluent used in experiment 9.				

TABLE 4.48
COMPARISON OF CFMF ON RAW SCOUR EFFLUENT AND CHLORINATED SCOUR EFFLUENT

Analysis		Raw Scour Effluent			Chlorinated Scour Effluent		
		Feed	Filtrate	Rejection %	Feed	Filtrate	Rejection %
pH		13,5	13,3	-	8,1	7	-
TC	(mg/ℓ)	17	16,5	3	8	22	12
COD	(mg/ℓ)	44	34	23	27	20	19
Ca	(mg/ℓ)	70	34	50	70	15	71
Mg	(mg/ℓ)	10	1	90	16	-	6

4.10.3 Pilot Plants Results for Neutralised Scour Effluents

A treatment sequence for scour effluent involving neutralisation (with an acidic gas), cross-flow microfiltration, nanofiltration and electrolysis to recover water and chemicals was devised **(Appendix 4.33)**.

A pilot plant was installed to treat scour effluent from the Vaporloc range and to recover sodium hydroxide and water for reuse in the factory. A typical analysis of cotton scour effluent is given in Table 4.49

TABLE 4.49
COMPOSITION OF SCOUR EFFLUENT (VAPORLOC RANGE)

pH		13 to 14
Cond	(mS/cm)	30 to 90
TC	(g/ℓ)	2,0 to 4,0
TIC	(g/ℓ)	0,1 to 0,4
TOC	(g/ℓ)	1,9 to 3,6
COD	(g/ℓ)	4 to 14
Na	(g/ℓ)	4 to 12
Ca	(mg/ℓ)	10 to 50
Mg	(mg/ℓ)	1 to 10
CO_3^{2-}	(g/ℓ)	1 to 3
OH^-	(g/ℓ)	2 to 8
TS	(g/ℓ)	15 to 36

The cross-flow microfilter unit in the pilot plant had the following specifications:-

Tube type	:	Single Swiss woven polyester
Tube dimensions	:	12 mm x 20 m
	:	12 mm x 12 m
Tube configuration	:	The tube was wound into a spiral, and supported in a 1 m diameter circular tray.
Pressure in	:	200 to 300 kPa
Pressure drop	:	100 kPa
Feed velocity	:	1,5 to 2 m/s
pH range	:	8,5
Chemical additions	:	Neutralization of the feed with carbon dioxide gas. Diatomaceous earth or limestone were used as filter aids.
Run mode	:	Batch concentration

The feed to the cross-flow microfilter after carbonation from pH 14 to pH 8,5 was generally a clear brown supernatant containing a suspension which had the appearance of a 'floc'. Cross-flow microfiltration removed the floc type suspension from the effluent. A thick turbid concentrate and a clear dark filtrate were produced. When using diatomaceous earth or limestone as a filter aid, the rejecting membrane formed was waxy to the touch but the filter tube could be cleaned using dilute sodium hydroxide.

Approximately 70 to 90 % of the initial feed volume to the cross-flow microfilter was recovered as filtrate.

The species point rejections achieved by cross-flow microfiltration are given in Table 4.50 and the composition of the effluent in Table 4.51.

Fluxes during cross-flow microfiltration were low at less than 5 ℓ/m^2h. This was due to the cross-flow microfilter not being run under optimal conditions. This could be improved by :-

(i) settling the effluent after carbonation and using the clear supernatant from the settleable floc,

(ii) increasing the velocity down the tube,

(iii) precoating the filter tube prior to cross-flow microfiltration.

4.10.4 Cross-flow Microfiltration of Kier Wash-off Effluent

Pilot plant trials were conducted at Smith and Nephew, Pinetown. A treatment sequence for the recovery of potassium hydroxide from kier liquor was devised **(Appendix 4.34)**. The sequence involved pretreatment by chlorination, cross-flow microfiltration and nanofiltration followed by potassium hydroxide recovery in a chlor-alkali electrochemical membrane cell.

A typical chemical analysis of the kier liquor is given in Table 4.52.

TABLE 4.50
SPECIES POINT REJECTION ACHIEVED BY CROSS-FLOW MICROFILTRATION

Experiment number	% Rejection on Cross-Flow Microfiltration							
	OC	IC	COD	Na	Ca	Mg	TS	Total CO_2
1	72	0	35	3	48	0	35	10
2	33	14	39	0	12	0	13	2
3	25	25	36	2	28	0	7	25
4	100	0	91	0	0	-	62	15
5	67	0	90	0	54	0	14	16
6	-	-	-	-	-	-	45	-
7	25	30	70	2	26	62	15	3
8	28	25	65	4	64	38	27	15
9	65	28	58	15	77	50	28	17
10	50	4	-	1	54	40	-	5
11	20	20	35	12	50	15	18	18
12	12	10	63	0	65	29	17	5
13	71	31	-	6	86	78	26	21
14	83	3	-	25	81	63	32	34
15	78	2	-	5	68	52	28	5
16	67	25	95	26	62	50	40	30
17	78	2	-	0	70	82	30	13
18	-	-	-	7	70	10	4	0
19	-	-	-	7	50	20	10	15
Average	55	14	61	6	54	35	25	15

TABLE 4.51
EFFECT OF TREATMENT SEQUENCE ON SCOUR EFFLUENT

Analysis		Raw scour effluent	After carbonation	After CFMF
pH		13,1	8,7	8,4
Cond	(mS/cm)	64	24	25
TC	(g/ℓ)	4,0	7,9	7,6
TIC	(g/ℓ)	0,3	4,3	4,6
TOC	(g/ℓ)	3,7	3,6	3,0
COD	(g/ℓ)	8,3	8,3	5,3
OH^-	(g/ℓ)	4,1	0	0
CO_3^-	(g/ℓ)	2,6	1,9	2,0
HCO_3^-	(g/ℓ)	0	16,1	16,5
TIC as CO_2		1,9	13,0	13,4
Na	(g/ℓ)	8,4	8,2	8,8
Ca	(mg/ℓ)	45	45	23
Mg	(mg/ℓ)	7	5	6
TS	(g/ℓ)	22	22	20

TABLE 4.52
A TYPICAL ANALYSIS OF KIER LIQUOR

pH		14
Cond	(mS/cm)	83
TC	(g/ℓ)	17
TIC	(g/ℓ)	2
TOC	(g/ℓ)	15
K	(g/ℓ)	30
Na	(g/ℓ)	1
Ca	(mg/ℓ)	50
Mg	(mg/ℓ)	50
OH^-	(g/ℓ)	5
CO_3^-	(g/ℓ)	8
Cl^-	(g/ℓ)	0,7
COD	(g/ℓ)	53
TS	(g/ℓ)	87

The cross-flow microfiltration unit had the following specifications :-

Tube type	:	Single Swiss woven polyester
Tube dimensions	:	12 mm x 30 m
Tube configuration	:	Spirally wound supported in a round plastic tray
Inlet pressure	:	200 to 300 kPa
Outlet pressure	:	150 to 250 kPa
Feed velocity	:	2,9 m/s
pH range	:	7,5 to 8,5
Chemical addition	:	Prechlorination to pH range then addition of diatomaceous earth and metabisulphite
Run mode	:	Batch concentration

Table 4.53 gives a summary of the cross-flow microfilter results.

The cross-flow microfiltration fluxes were low at 10 ℓ/m^2h and produced a clear, brownish permeate and a thick, turbid, dark concentrate. The rejecting membrane formed on the tube was waxy to the touch and could be cleaned from the tube by circulating sodium hydroxide solution through the system.

4.11 CROSS-FLOW MICROFILTRATION OF DYEHOUSE EFFLUENTS

One of the main pollution sources in the textile industry are the dye-house effluents. Dyehouse effluents in general are complex and reflect the types of dyeing undertaken. They have poor biodegradability and a high level of colour and salts.

TABLE 4.53
SUMMARY OF SPECIES POINT REJECTION ACHIEVED BY CFMF

Experiment number	% Point Rejection on cross-flow microfilter			
	TC	Ca	Mg	TS
1	16	86	2	11
2	30	92	32	8
3	35	76	35	15
4	14	29	30	6
6	40	90	0	20
7	20	62	0	2
8	0	44	4	-
10	23	77	25	10
11	-	-	-	-
13 & 14	58	94	20	50
Average	26	72	16	15

Coagulation and flocculation tests have been carried out on disperse dye wastewaters. Poor settling characteristics are often observed and are due to the effect of the dispersing agent. The floc has poor dewatering characteristics. A study was undertaken using cross-flow microfiltration rather than settling, to overcome these problems.

The aims of the study were to :-

(i) investigate the effectiveness of alum coagulation and cross-flow microfiltration at high water recovery, for the removal of the disperse dyestuff colour,

(ii) assess the potential of the product water, which would contain the organics and a percentage of the dispersing agent for reuse in polyester dying.

4.11.1 Cross-flow Microfiltration of Polyester Dyeing Effluent

Effluent from a polyester dyeing machine was pumped from the dyehouse to the effluent storage tank. The feed to the pilot plant entered the mixing tank under level control. The alum dosage was delivered by level control and matched to the rate of feed flow. The pH was controlled by the addition of hydrochloric acid or sodium hydroxide **(Appendix 4.35)**.

The product water (permeate) from the cross-flow microfilter was collected in a tank and pumped to the storage tank for delivery back to the polyester dyeing machine.

The pilot plant had the following specifications :-

Tube type	:	Knitted polyester - similar to fire hose
Tube dimensions	:	25 mm x 6 m x 25 x 4
Total area	:	47 m^2
Tube configuration	:	4 modules connected in series with 25 tubes in each module arranged in parallel
pH range	:	5 to 7
Alum dosage	:	50 to 100 mg/ℓ as Al^{+3}
Pump rate	:	120 m^3/h at 450 kPa
Feed velocity	:	2 to 3 m/s
Operating mode	:	Feed and bleed to give 90 % water recovery

The characteristics of the polyester dyeing effluent are given in Table 4.54. and Table 4.55.

TABLE 4.54
POLYESTER DYEING EFFLUENT CHARACTERISTICS

Type	Effluent	Dye usage g/kg	Water usage ℓ/kg/d	Effluent Parameter Loadings g/kg				
				TDS	Na	TOC	OA	COD
A. WOVEN								
Dark shade	D	10,5	15	41,0	2,0	15,0	6,4	-
	D+R1+R2	-	45	52,7	4,4	16,4	6,8	-
Medium shade	D	6,35	27,5	54,0	2,4	6,3	2,3	-
	D+R1+R2	-	82,5	80,6	7,0	8,5	2,5	-
Light shade	D	0,12	25,3	55,1	2,3	12,4	3,0	-
	D+R1+R2	-	75,8	91,6	7,3	16,8	3,4	-
B. KNITTED								
Optical white	D	2,51	12,8	8,7	0,9	12,7	-	35,8
	R1+D+R2	-	38,3	27,8	1,4	54,6	-	123,5
	PS	-	10,8	4,3	0,15	5,1	-	16,1
Medium shade	D	4,71	10,8	10,2	0,8	4,1	-	12,4
	PS+R1+D+R2+R3	-	53,8	23,7	1,7	12,6	-	41,2
	PS	-	10,7	6,4	0,16	7,2	-	20,3
Dark shade	D	8,9	10,7	11,7	1,2	5,0	-	13,9
	PS+R1+D+R2+R3	-	53,3	25,8	2,0	14,4	-	36,5
	PS	-	11,3	2,0	0,16	1,0	-	3,2
Black	D	-	11,3	21,5	2,0	9,8	-	25,5
	AT	39,0	11,3	77,0	23,8	4,1	-	14,2
	PS+R1+D+R2+ R3+AT+R4+R5	-	90,6	128,0	32,0	19,0	-	47,7

Key : D - Dyebath
R - Rinse
PS - Prescour
AT - After treatment

Analyses of the feed to the pilot plant and the cross-flow microfilter permeate are given in Table 4.56.

TABLE 4.55
OVERALL EFFLUENT COMPOSITIONS FOR POLYESTER DYEING

Dyeing	TDS	Na	TOC	OA	COD	ADMI Colour
	mg/ℓ					Units
A. WOVEN						
Dark	1 170	97	365	150	-	1 990
Medium	975	84	103	31	-	320
Light	1 210	97	222	44	-	245
B. KNITTED						
Optical white	725	36	1 425	-	3 225	-
Medium	440	31	235	-	766	810
Dark	484	37	270	-	684	715
Black	1 415	355	210	-	520	1 235

TABLE 4.56
PILOT PLANT RESULTS

Sample	Run time (hr)	Al^{3+} Dosage (mg/ℓ)	Feed				Product			
			pH	TDS (mg/ℓ)	TOC (mg/ℓ)	ADMI colour	pH	TDS (mg/ℓ)	TOC (mg/ℓ)	ADMI Colour
A	2	100	10,9	1 605	272	2 155	7,0	1 825	49	220
	5						5,6	1 790	67	200
B	1	100	6,4	420	319	1 095	5,0	1 010	52	93
	4						5,0	888	62	56
C	2,5	50	4,9	635	477	3 595	6,7	680	98	96
	8						6,5	665	97	100
D	2	70	6,3	565	408	3 020	6,9	668	89	109
	6	90					6,7	795	100	55
E	4	90	6,4	505	348	2 125	7,0	560	69	71
F	5	60	6,6	490	340	1 345	7,0	526	63	130
G	2	60	6,9	432	310	1 425	6,8	530	85	180
H	2	60	6,5	390	307	1 940	6,7	505	73	85
I	3	70	6,9	602	308	1 610	6,8	590	96	260
J	2	70	9,7	1 070	308	1 775	7,1	890	130	405

The permeate from the cross-flow microfilter pilot plant had adequate colour removal with alum dosage of 50 to 100 mg/ℓ as aluminium over the pH range 5,5 to 6,5. However the coagulation range was less sensitive and could be extended to pH 5 to 7. Synthetic polyester dyeing solutions gave colour rejections of greater than 99 %,

boiled solutions and actual polyester dyeing effluents gave lower rejections, particularly for certain disperse dyestuffs. This may be attributed to a relatively high water solubility.

The cross-flow microfilter gave steady-state product fluxes of 50 to 120 ℓ/m^2h. Samples A to J in Table 4.56 were the effluents from the dyeing of dark shades and hence the total dissolved solids (TDS) and colour were higher than normal.

The total organic carbon (TOC) and ADMI colour value rejections were in the range 58 % to 78 % and 77 % to 97 % respectively. The permeate (product water) TOC consisted mainly of the organic and dispersing agent, which represented background levels of about 20 mg/ℓ and 40 to 60 mg/ℓ respectively assuming zero rejections across the membranes.

4.11.2 Cross-flow Microfiltration of Polyester and Polyester/Viscose Dyehouse Effluents

Difficulties had arisen with the pretreatment of used dyehouse effluent prior to hyperfiltration, **(Appendix 4.36)** with very short runs being experienced with the cross-flow microfiltration of these effluents. This work investigates the use of woven fibre tubes for the cross-flow microfiltration of polyester and polyester/viscose dyeing effluent.

The experimental unit used in laboratory tests was as follows :-

Tube type	:	Close weave fire hose jacket
Tube dimensions	:	38,1 mm x 3 m x 4
Tube configuration	:	Tubes connected in series with U-bends
Pressure	:	400 kPa

Laboratory scale batch concentration tests were conducted. The effluent was a mixture of yellow, red and navy dyes with dispersing agents. An analysis is given in Table 4.57.

Analytical results are summarised in Tables 4.58 and 4.59.

The initial flux from Test 1 with 200 ℓ of effluent was 140 to 190 ℓ/m^2h, and the average after 5,7 hours was 113 ℓ/m^2h. The initial feed TOC was 158 mg/ℓ and this was reduced to 64 mg/ℓ in the permeate.

Test 2 was conducted with the concentrate from Test 1, reduced to half the starting volume, as feed. An overall 90 % (Run 1 and Run 2) water recovery was achieved. The average permeate flux was 104 ℓ/m^2h and the permeate TOC was 61 mg/ℓ.

TABLE 4.57
EFFLUENT COMPOSITION

Yellow, red and navy dye	0,1 g/ℓ
Dispersing agent	0,5 g/ℓ

TABLE 4.58
ANALYTICAL RESULTS OF LABORATORY TESTS 1 AND 2

Solution	Absorbance and Rejection (%)		
	422 nm	542 nm	570 nm
Initial feed	0,70	0,63	0,58
Permeate from Run 1	0,065 (91)	0,02 (97)	0,02 (97)
Permeate from Run 2	0,03 (96)	0,01 (96)	0,008 (99)

Rejection figures in brackets

TABLE 4.59
ANALYTICAL RESULTS OF LABORATORY TEST 3

Initial Feed				Overall Permeate			
TOC	Absorbance			TOC	Absorbance		
(mg/ℓ)	482 nm	542 nm	670 nm	(mg/ℓ)	482 nm	542 nm	670 nm
230	0,80	0,80	0,68	71	0,028 (97)	0,024 (97)	0,014 (98)

Rejection figures in brackets

Test 3 was conducted with the 3 dyes at 0,1 g/ℓ and 0,5 g/ℓ of Ionet dispersing agent. The starting fluxes were 140 to 200 ℓ/m²h dropping to 80 to 95 ℓ/m²h, with an average of 105 ℓ/m²h, after 7 hours.

The cross-flow microfiltration unit installed at the factory had the following specifications :-

Tube dimensions	:	38,1 mm x 30 m
Tube configuration	:	30 m coil placed in a collection tank
Chemical addition	:	Coagulation with aluminium sulphate
pH range	:	6,0
Pressure	:	200 to 250 kPa
Feed flow	:	30 to 50 ℓ/min

Factory effluent was pumped to a coagulation tank. The effluent contained un-exhausted dyestuffs (colloidal disperse, soluble reactive and direct), organic auxiliary chemicals, inorganic salts, detergents, oils and organic acid buffers. The low values of effluent pH indicate a high percentage of polyester dyeing waste water present in the effluent.

Results of preliminary factory tests are given in Table 4.60 and of subsequent tests in Table 4.61.

Permeate flow rates were in the range 3 to 5 ℓ/min (50 to 85 ℓ/m²h).

TABLE 4.60
PRELIMINARY FACTORY CROSS-FLOW FILTER EXPERIMENTS

Dosage Al^{3+} (mg/ℓ)	Test duration (h)	Item	pH	Cond (mS/cm)	TDS (mg/ℓ)	Na (mg/ℓ)	TOC (mg/ℓ)	OA (mg/ℓ)	ADMI Colour
20	0,5	Feed Permeate % Rejection	7,7 6,7	1,62 1,62	1 475 1 375	295 275	163 109 33	223 155 30	610 275 55
30	2	Feed Permeate % Rejection	9,2 6,7	2,28 2,84	2 040 2 530	465 550	140 123 12	157 135 14	262 244 7
30	3	Feed Permeate % Rejection	9,95 7,3	3,79 3,64	4 650 4 265	1 200 1 000	244 133 45	88 32 64	955 284 70
50	2	Feed Permeate % Rejection	9,95 7,7	3,79 3,52	4 650 4 200	1 200 995	244 137 44	88 32 64	955 463 52
50	3	Feed Permeate % Rejection	7,7 4,4	1,42 2,06	1 245 1 900	290 365	111 93 16	232 144 38	163 56 66

TABLE 4.61
FACTORY CROSS-FLOW FILTER EXPERIMENTS

Dosage Al^{3+} (mg/ℓ)	Test duration (h)	Item	pH	Cond (mS/cm)	TDS (mg/ℓ)	Na (mg/ℓ)	TOC (mg/ℓ)	OA (mg/ℓ)	ADMI Colour
30	1	Feed Permeate % Rejection	7,5 7,6	1,25 1,44	1 208 1 338	300 320	168 128 24	104 76 27	370 84 77
30	3	Feed Permeate % Rejection	8,3 7,4	1,43 1,43	1 280 1 320	330 200	141 123 13	86 81 6	105 35 67
30	4	Feed Permeate % Rejection	8,5 6,6	2,28 2,57	2 155 2 390	640 695	250 132 47	78 59 24	440 110 75
30	2	Feed Permeate % Rejection	9,6 7,7	3,25 2,95	3 280 2 920	1 175 940	150 121 19	76 51 33	1 360 175 87
30	2	Feed Permeate % Rejection	9,8 7,6	3,02 3,26	3 825 3 675	925 875	205 114 44	75 29 61	824 233 72
30	6	Feed Permeate % Rejection	8,1 6,8	2,18 3,0	1 980 3 440	400 625	200 106 47	82 41 50	740 115 84
330	3	Feed Permeate % Rejection	10,3 7,2	4,2 5,6	7 050 6 420	1 845 1 615	263 114 57	105 41 61	1 154 300 74
30	4	Feed Permeate % Rejection	9,6 6,95	2,98 3,68	3 700 4 030	690 900	215 94 56	78 36 54	1 150 132 89
30	3	Feed Permeate % Rejection	9,8 7,1	2,26 4,11	2 815 4 730	460 1 000	327 99 70	68 44 35	746 174 77
50	3	Feed Permeate % Rejection	9,2 6,6	2,98 3,38	2 655 3 215	700 665	171 114 33	234 124 47	686 200 71

4.11.3 Cross-flow Microfilter Pilot Plant for the Closed Loop Recycle of Polyester Dyeing Effluents

After a survey of a particular factory to characterise the effluents from the dyeing and printing of cotton/synthetic fibre knit fabrics, it was found that 43 % of the total effluent volume of the factory was due to the polyester dyeing effluent. A study was conducted to determine the effect of alum coagulation followed by cross-flow microfiltration on this effluent. Successful treatment and reuse of this portion of the factory effluent would result in a large reduction of both the total effluent volume and the volume of make up water used.

Initially experiments were carried out on a cross-flow microfilter module of shell and tube heat exchanger design. It consisted of 19 parallel woven fibre tubes each of 25 mm in diameter and 3 m in length, operated under the following conditions.

Pressure in	:	200 kPa
Pressure out	:	120 kPa
Pump rate	:	132 m^3/h
Feed velocity	:	3,9 m/s
Alum dosages	:	90 to 150 mg/ℓ as Al^{+3}
Steady state fluxes	:	50 to 55 ℓ/m^2h

After preliminary trials it was necessary to undertake laboratory tests to determine the nature of the residual colour remaining in the product water. Analytical results for the preliminary trials are given in Table 4.62.

Subsequently, the cross-flow microfilter unit was modified to the specification given below. The plant was in operation for a total of 10 weeks during which three series of experiments (A, B and C) were carried out. Design specifications are given in **Appendix 4.37**.

Tube type	:	Woven fabric (fire hose jackets)
Tube dimension	:	6 m x 25 mm x 4 modules of 25 tubes in each module
Total membrane area	:	47 m^2
Tube configuration	:	Each module was connected in series, the tubes in each module were connected in parallel
Maximum inlet pressure	:	460 kPa
Pressure drop	:	300 kPa
Pump delivery	:	120 m^3/h
Tube velocity	:	2,6 m/s
pH range	:	5 to 7
Chemical dosage	:	Alum at 50 to 100 mg/ℓ as Al^{3+}
Run mode	:	a) Batch concentration to 90 % water recovery, b) feed and bleed adjusted to give 90 % water recovery

TABLE 4.62
PRELIMINARY CROSS-FLOW MICROFILTER PERMEATE ANALYSES

Length of run		Al^{3+} dosage	Item	pH	Cond	TDS	TOC	Al	ADMI colour	Permeate rejection	
(hrs)	(min)	(mg/ℓ)			(mS/cm)		(mg/ℓ)		unit	TOC	ADMI
			F*	6,7	0,239	372	500	0	1 982		
	30	90	P*	7,0	0,87	-	80	0	88	84	96
2	00	90	P	6,9	0,73	564	75	0	29	85	99
	40	100	P	7,0	0,89	654	75	0	31	85	98
	30	110	P	7,1	0,94	750	95	0	42	81	98
1	00	120	P	7,2	0,84	606	90	0	194	82	90
	20	130	P	7,3	0,96	718	95	0	298	81	85
1	00	150	P	6,95	0,98	720	95	0	85	81	96
	15	80	P	7,0	1,04	792	110	0	153	78	92
	30	90	P	7,0	1,0	704	85	0	92	83	95
			F	6,6	0,296	276	188	0	1 130		
	30	90	P	6,1	0,92	1 148	41	0	63	78	94
	20	90	P	6,8	0,89	666	27	0	62	86	95
1	40	90	P	6,75	0,705	518	43	0	44	77	96
1	50	90	P	6,86	0,635	922	27	0	33	86	97
1	30	90	P	7,0	0,575	398	31	0	37	84	97
2	00	90	P	3,93	0,5	256	29	0	46	85	96
			F	6,7	0,285	276	191	0	1 131		
2	15	90	P	6,8	0,44	302	25	0	45	87	96
6	00	90	P	6,8	0,35	234	24	0	41	87	96
2	00	90	P	6,8	0,292	684	42	0	105	78	91
			F	11,8	1,63	1 220	430	0	2 118		
	30	50	P	7,0	1,18	1 094	76	0	416	82	80
1	00	80	P	5,4	1,34	1 128	60	0	211	86	90
1	00	130	P	6,7	1,35	-	52	0	274	88	87
1	00	50	P	6,2	1,33	1 178	113	0	214	74	90
1	30	90	P	6,6	1,28	1 154	93	0	270	78	87
1	30	50	P	6,7	1,27	1 168	90	0	317	79	85
	15	110	P	6,5	1,36	1 230	85	0	292	80	86

Note : F* = Feed ; P* = Permeate

Polyester dyeing effluents contain only un-exhausted dyestuff, an organic acid and a dispersing agent. Chemical analysis of the polyester dyeing effluent used in runs A, B and C are given in Table 4.63.

Steady fluxes of 50 to 120 ℓ/m^2h were achieved. However blockage of the tubes with floc occurred and this may have been aggravated by settling on shut down.

Cross-flow microfilter permeate analyses from tests A, B and C are given in Tables 4.64, 4.65 and 4.66.

Test A, was conducted on a maroon colour polyester dye, giving a slightly pink permeate.

Test B, gave a permeate with a light pink colour.

Test series C gave a permeate ranging in colour from pale straw to yellow.

TABLE 4.63
ANALYSES OF POLYESTER DYEING EFFLUENT FEEDS

No. Reduction Cleaning	pH	Cond (mS/cm)	TDS (mg/ℓ)	TOC (mg/ℓ)	ADMI Colour
1	11,8	1,63	1 220	430	2 118
2	10,93	1,42	1 606	272	2 153
3	9,69	0,939	1 072	308	1 775
Normal					
4	6,7	0,239	372	500	1 982
5	6,6	0,296	276	188	1 130
6	6,7	0,285	276	191	1 131
7	6,5	0,485	612	240	735
8	6,55	0,313	424	214	637
9	6,9	0,374	466	463	1 504
10	6,38	0,385	420	319	1 094
11	5,9	0,679	954	380	1 268
12	4,9	0,278	634	477	3 596
13	6,3	0,267	566	408	3 019
14	6,35	0,239	506	348	2 126
15	6,62	0,230	490	340	1 347
16	6,92	0,213	432	310	1 423
17	6,52	0,209	390	307	1 941
18	6,88	0,44	602	308	1 611
19	6,65	0,626	924	322	1 373
20	6,43	0,592	998	369	2 254
21	6,22	0,472	1 034	211	3 497
22	6,3	0,435	690	268	1 504
23	6,58	0,30	506	216	2 045

TABLE 4.64
RESULTS OF TEST A

Length of run (hrs)	Al^{3+} dosage (mg/ℓ)	Item	pH	Cond (mS/cm)	TDS	TOC (mg/ℓ)	Al	ADMI colour (unit)	Permeate rejection	
									TOC	ADMI
		F	6,5	0,485	612	240	0	735	-	-
1,0	150	P	5,9	1,55	1 290	20	4	84	91	88,5
3,0	350	P	5,4	2,17	1 912	20	4	81	91	88,9
	150	P	6,6	2,44	1 980	20	0	73	87,5	90
1,0	200	P	6,7	2,37	2 064	25	0	68	89,5	90,7
	200+10 mg/ℓ AC	P	6,5	2,15	2 158	29	1	60	87,9	91,8
1,5	200+10 mg/ℓ AC	P	6,7	1,4	1 170	39	2	42	83,7	94,2

Note : P = Permeate
F = Feed
AC = Activated Carbon

TABLE 4.65
RESULTS OF TEST B

Length of run (hrs)	Al^{3+} dosage (mg/ℓ)	Item	pH	Cond (mS/cm)	TDS	TOC (mg/ℓ)	Al	ADMI colour (unit)	Permeate rejection	
									TOC	ADMI
		Feed	10,93	1,42	1 606	272	0	2 153		
2,0	100	Permeate	7,0	2,27	1 826	49	30	220	81,9	89,7
4,0	150	Permeate	6,35	2,05	1 934	64	0	229	76	89,3
5,0	100	Permeate	5,55	1,85	1 790	67	4	300	75,3	90,7
		Feed	6,55	0,313	424	214	0	637		
3,0	100	Permeate	5,62	0,54	512	49	0	125	77	80,3
		Feed	6,9	0,374	466	436	0	1 504		
3,5	100	Permeate	6,08	0,92	898	77	1	189	82	87,4
		Feed	6,38	0,385	420	319	0	1 094		
1,0	100	Permeate	4,9	1,15	1 010	52	2	93	83,6	91,4
2,0	100	Permeate	4,99	0,97	818	62	2	114	80,5	89,5
4,0	100	Permeate	5,0	1,1	888	62	4	56	80,5	94,8
		Feed	5,9	0,697	954	380	0	1 268		
6,5	100	Permeate	6,2	1,36	1 240	84	0	92	77,8	92,7

TABLE 4.66
RESULTS OF TEST C

Length of run (hrs)	Al^{3+} dosage (mg/ℓ)	Item	pH	Cond (mS/cm)	TDS	TOC (mg/ℓ)	Al	ADMI colour (unit)	Permeate rejection	
									TOC	ADMI
		Feed	4,9	0,278	634	477	0	3 596		
8,0	50	Permeate	6,45	0,602	666	97	0	100	80	97
2,5	50	Permeate	6,72	0,586	682	98	0	96	80	97
		Feed	6,3	0,267	566	408	0,6	3 019		
2,0	70	Permeate	6,89	0,633	668	89	0	109	78	96
6,0	90	Permeate	6,7	0,685	796	100	0	55	75	98
		Feed	6,35	0,239	506	348	0	2 126		
4,0	90	Permeate	7,00	0,490	560	69	0	71	80	97
		Feed	6,62	0,230	490	304	0	1 347		
5,0	60	Permeate	7,00	0,471	526	63	0	130	81	90
		Feed	6,92	0,213	432	310	0	1 423		
2,0	60	Permeate	6,85	0,460	530	85	1,0	181	73	87
		Feed	6,52	0,209	390	307	0	1 941		
2,0	60	Permeate	6,69	0,422	506	73	0	85	76	96
		Feed	6,88	0,44	602	308	0	1 611		
3,0	70	Permeate	6,79	0,555	588	96	0	260	69	84
		Feed	9,69	0,939	1 072	308	0	1 775		
2,0	70	Permeate	7,15	0,890	890	129	0,6	407	58	77
		Feed	6,65	0,626	924	322	0	1 373		
	70	Permeate	6,62	0,832	1 120	171	0	351	47	74
		Feed	6,43	0,592	998	369	0	2 254		
	70	Permeate	6,89	0,8	968	184	0,9	381	50	83
		Feed	6,22	0,472	1 034	(211)*	0	3 497		
	70	Permeate	6,5	0,705	1 074	235	3,0	740	0	79
		Feed	6,3	0,435	690	268	0	1 504		
	70	Permeate	6,55	0,782	886	94	0	202	65	87
		Feed	6,58	0,3	506	216	0	2 045		
	70	Permeate	6,65	0,622	752	73	0	203	66	90

* = Seems low

4.11.4 Cross-flow Microfiltration of Wool/Synthetic Dyehouse Effluents

Textile effluents from wool/synthetic dyehouses are acidic, contain residual colour from a variety of dyestuffs used, anion, cationic, non-ionic and amphoteric surfactants, a variety of organic and inorganic auxiliary chemicals and, in many cases

heavy metal ions, such as copper, chromium, cobalt and nickel. The residual dyes constitute an unacceptable visible pollution load, and coupled with the remaining organic auxiliaries used in dyeing are responsible for COD values of the order of 1 000 mg/ℓ.

The inorganic salts used in large quantities are sodium sulphate and sodium chloride.

Effluents from wool/synthetic dyeing may in general be discharged into municipal sewers. However, in cases where sewers do not exist, the storage and evaporation or spray irrigation of these effluents presents a serious problem. A treatment sequence was devised to treat the effluent to a point where it could be reused in the process from which it originated **(Appendix 4.38).**

The treatment consisted of the following stages :-

(i) removal of surfactants by ion exchange,

(ii) removal of colour and heavy metal ions by electrolysis using iron electrodes,

(iii) ferrous hydroxide flocculation,

(iv) ferrous to ferric oxidation,

(v) ferric hydroxide flocculation,

(vi) filtration,

(vii) detection and control of colour and ferric ions.

A pilot plant **(Appendix 4.39)** was linked to five production machines covering the full range of fibres and dyeing productions used in a wool/synthetic dyehouse :-

(i) wool top dyeing,

(ii) wool piece dyeing,

(iii) polyester/viscose piece dyeing,

(iv) yarn dyeing,

(v) polyester top dyeing.

The objective of the investigation was to demonstrate that a pilot plant was capable of treating the dyehouse effluent from wool/synthetic fibre dyeing on a continuous basis.

The cross-flow microfiltration unit had the following specifications :-

Tube type	:	Fire-hose jacket
Tube dimensions	:	3,35 m x 25 mm
Tube configuration	:	9 banks of 8 columns
Feed pressure	:	270 kPa
Reject pressure	:	0 kPa
Design flux	:	167,5 ℓ/m²h
Filtration rate per bank of 8 tubes	:	1 340 ℓ/h

Operating cycle	:	6,5 to 7,5 hours
Operating steady state flux	:	31,2 ℓ/m^2h
Time to reach steady state flux	:	36 to 48 hours
Chemical addition on filtration	:	ferric hydroxide

The feed to the cross-flow microfilter was a composite sample taken from the effluent storage feed to the electrolysis cell, after the anion and cationic surfactants had been removed by ion exchange. Analyses are given in Table 4.67.

TABLE 4.67
ANALYSIS OF FEED TO CFMF

Analysis (mg/ℓ)						
Na	IC	OC	TC	COD	Cr	ADMI
550	24,5	137	161	440	0,8	1 079
462	16,5	145	161	472	1,4	970
775	23,5	213	236	372	3,0	1 300
613	26,5	204	230	614	1,6	1 215
1 540	24,8	141	166	253	0,3	970
613	32	178	210	248	0,9	1 000
665	21	279	300	808	0,5	1 475
244	18,7	225	244	447	0,6	920
900	15,7	184	200	491	0,6	650
288	1,0	174	175	248	0,5	875
309	0,7	127	128	115	1,2	715
402	2,0	66	68	189	1,7	430
470	3,5	78,5	82	256	1,3	390
362	15	101	116	198	1,3	805
402	24	112	136	250	1,4	525
281	16	98	114	173	1,8	965
413	11	93	104	192	1,2	870
450	13	108	121	267	0,7	1 030
388	10	196	206	406	0,4	1 300
575	2	157	159	676	0,3	940
490	2	153	155	533	0,9	870
540	3	127	130	263	1,1	525
535	13	152	165	390	0,8	565
586	12	140	152	485	0,6	735
480	7	93	100	285	0,4	940

The performance of the cross-flow microfilter with time is summarised in Table 4.68 **(Appendix 4.40)**.

TABLE 4.68
VARIATION IN FILTRATION FLUX WITH TIME

Time (hrs)	Filtration flux (ℓ/m^2h)							
	1,1	1,2	1,3	1,4	1,5	1,6	1,7	1,8
0,5	528,9	358,8	346,6	346,6	372,3	346,6	372,3	358,8
12	134,0	108,6	108,6	112,9	101,0	105,7	99,5	104,7
24	51,9	41,9	43,5	44,4	40,2	42,7	41,0	43,5
36	35,2	31,8	30,2	31,8	28,5	30,1	30,1	30,1
	9,1	9,2	9,3	9,4	9,5	9,6	9,7	9,8
0,5	271,5	379,3	372,2	372,2	386,5	402,0	372,2	372,2
12	98,5	105,7	99,5	102,5	96,6	103,5	85,4	88,4
24	43,5	45,2	41,9	43,5	45,2	41,9	43,5	41,9
6	31,8	31,8	31,8	30,2	33,5	35,2	35,2	31,8

Table 4.69 gives the analysis of composite samples of filtered effluent before being mixed with municipal make-up water for recycle.

Comparison of analytical data in Tables 4.68 and 4.69, shows that the sodium concentration increased. This was due to the addition of sodium hydroxide during effluent treatment. The increase in inorganic carbon was due to sodium carbonate impurity in industrial grade sodium hydroxide. The mean organic carbon reduction was 54 %. The major component of the remaining 46 % organic carbon in the treated effluent was sodium acetate buffer as well as the non-ionic and amphoteric surface active agents which are required for reuse.

An ADMI colour and iron detector was installed. The colour acceptance limit was set at an ADMI value of 65 and the iron acceptance limit at 2 mg/ℓ. No permeate from the cross-flow microfilter was rejected by the detector.

Rejection on the cross-flow microfilter was very high with low iron contents (below 0,01 mg/ℓ) in the filtrate. However, this filter was subject to severe flux decline over two weeks of operation.

4.11.5 Cross-flow Microfiltration of Cotton/Polyester Dyehouse Effluents

The effluents from cotton and cotton/polyester dyeing contain high concentrations of salts, which are not removed by conventional physiochemical or biological treatment. For both end-of-line pollution control and internal reuse of these effluents, salt removal is necessary.

TABLE 4.69
ANALYSIS OF FILTERED EFFLUENT

Analysis mg/ℓ						
Na	IC	OC	TC	COD	Cr	ADMI
675	23	78	101	337	0	<65
565	17	79	96	203	0	
844	40	99	139	193	0	
925	40	116	156	167	0	
749	32	110	133	152	0	
740	22	87	109	98	0	
740	20	83	103	602	0	
190	34	157	191	432	0	
950	39	129	168	283	0	
555	21	46	67	70	0	
413	9	31	40	83	0	
440	22	42	64	94	0	
510	20	46	66	123	0	
490	26	47	73	123	0	
469	30	45	75	51	0	
431	36	60	96	86	0	
405	24	46	70	32	0	
500	20	40	60	67	0	
510	20	55	75	187	0	
586	17	63	80	138	0	
610	13	51	64	142	0	
510	14	54	68	146	0	
495	6	23	29	35	0	
564	20	52	72	154	0	
636	22	50	72	137	0	

Experiments to test the long term performance of a spiral wound module of the poly (ether/amide) type on the mixed effluent from cotton, cotton/polyester and polyester dyeing were undertaken **(Appendix 4.41)**.

A candle filter was used initially but later replaced by a cross-flow microfilter. Following laboratory experiments, the use of cross-flow microfiltration as a pretreatment process prior to hyperfiltration was investigated. A pilot plant consisting of a cross-flow microfiltration unit and a hyperfiltration unit was installed at a factory.

The experimental cross-flow microfilter had the following specifications :-

Tube type	:	Fire hose jacket
Tube diameter	:	25 mm
Feed rate	:	66 ℓ/min
Pressure in	:	180 kPa
Flux rates	:	70 to 150 ℓ/m^2h
Chemical dosing	:	Coagulation with aluminium sulphate at 20 mg/ℓ

Analysis of the effluent before and after cross-flow microfiltration are given in Table 4.70 and 4.71. The effluent contained significant quantities of a gelatinous agglomerate.

TABLE 4.70
ANALYSIS OF MIXED EFFLUENT

Total organic carbon	(mg/ℓ)	109
Oxygen absorption	(mg/ℓ)	30
ADMI colour		271

TABLE 4.71
ANALYSIS OF EFFLUENT AFTER CFMF AND COAGULATION

Total organic carbon	(mg/ℓ)	69
Oxygen absorption	(mg/ℓ)	13
ADMI colour		174

Following the laboratory experiments described above the use of cross-flow microfiltration as a pretreatment process for hyperfiltration was examined **(Appendix 4.42).**

The experimental unit used had the following specifications :-

Feed pressure	:	200 kPa
Feed velocity	:	1 m/s
Chemical addition	:	(a) pH control
		(b) Alum coagulation at 20 to 80 mg/ℓ as Al^{+3}
Run mode	:	Feed and bleed to give a 50 % water recovery

The feed to the cross-flow microfilter consisted of a blend of effluent and recycled reject. Chemical analyses of the feed is summarised in Table 4.72.

TABLE 4.72
ANALYSIS OF EFFLUENT FEED TO THE CROSS-FLOW MICROFILTER

	pH	Cond (mS/cm)	TDS (mg/ℓ)	Na (mg/ℓ)	COD (mg/ℓ)	TOC (mg/ℓ)	OA (mg/ℓ)	ADMI colour
Min	6,0	185	240	37	180	39	18	75
Max	9,5	2 400	3 400	495	719	520	55	987
Mean	7,3	1 330	990	206	330	134	36	453

The cross-flow microfilter gave fluxes in the region of 30 to 200 ℓ/m^2h depending on the feed constituents, the recycle ratio and the degree of fouling. The flux was restored periodically by soaking the filter tube in sulphuric acid solution at pH 2.

Species rejections achieved by cross-flow microfiltration are summarised in Table 4.73.

TABLE 4.73
SUMMARY OF SPECIES REJECTIONS ACHIEVED BY CFMF

	Rejection %		
	COD	TOC	ADMI colour
Min	-	-	4
Max	68	77	91
Mean	34	44	70

4.11.5.1 <u>Closed Loop Recycle of Cotton/ Synthetic Fibre Dyehouse Effluents</u>

A pilot plant for the treatment of cotton/synthetic fibre dyehouse effluents was designed **(Appendix 4.37)**. The plant consisted of a cross-flow microfilter and a two-stage hyperfiltration unit.

The specific tasks of the project were to :-

(a) determine the technical feasibility of closed loop recycle systems for dyehouse effluents containing :-

  (i) cotton (viscose and/or nylon) dyestuffs,

  (ii) polyester dyestuffs,

  (iii) mixed effluent containing both cotton and, synthetic fibre dyestuffs,

(b) determine the cost effectiveness,

(c) estimate the reduction in water usage and waste production and the impact of the treatment system on the final effluent of cotton/synthetic textile dyehouse,

(d) develop estimates of the net savings in water, chemical reuse, energy and waste treatment,

(e) evaluate cross-flow microfiltration using woven fabric tubes in conjunction with alum coagulation for removing suspended solids and dispensed dyes,

(f) to evaluate the various membranes for flux decline and rejection in the hyperfiltration stage,

(g) estimate impurity build up in the closed loop system,

(h) develop a process design for a treatment/recycle system on a continuous basis for full scale textile mill operation.

The cross-flow unit had the following specifications :-

Operating mode	:	Feed and bleed with water recoveries of 85 % to 95 %
Chemical addition	:	(a) Alum coagulation at 500 to 800 mg/ℓ (b) pH correction to 5,5
Precoating	:	Precoat the tubes with alum, pH adjusted to 5,5
Tube dimensions	:	25 mm x 4,5 m
Tube configuration	:	8 modules in series with 25 parallel tubes per module tube length of 4,5 m
Module configuration	:	Leader pipe assessment
Tube velocity	:	2,5 m/s
Minimum flux	:	70 ℓ/m²h
Design flux	:	50 ℓ/m²h
Product rate needed	:	100 m³/d
Pressure drop in tube at 2,5 m/s	:	12 kPa/m

Pilot plant trials were completed in phases as experience in operating procedure was gained **(Appendices 4.43 and 4.44)**.

Phase 1

The cross-flow microfilter gave an initial flux of 906 ℓ/m²h on mains water at an inlet pressure of 195 kPa with a 90 kPa pressure drop across the unit.

The flux resulting from the treatment of the mixed factory effluent, containing wastewaters from dyeing, printing and scouring was poor. The flux dropped from 533 ℓ/m²h at the start to 180 ℓ/m²h after the run on the first day. On start up on the second day the flux was 20 ℓ/m²h, and this dropped to 5 ℓ/m²h after 5 days continuous running. After an acid clean, the flux dropped from 30 ℓ/m²h to 5 ℓ/m²h over 1 day.

Examination of the tubes indicated that the fouling was due to printing pastes, lint and fine sand.

Phase 2

In order to overcome the tube fouling, several plant modifications were made :-

(i) the effluent source was changed to the yarn dyehouse pipeline, and to a fabric dyeing machine,

(ii) diatomaceous earth, polyelectrolytes and the alum were added to the feed as filter aids,

(iii) a wedge wire screen was installed prior to the flocculation tank,

(iv) to avoid cavitation, the pipe manifolding from the pump suction was changed. The tube velocities were then increased from 1,6 m/s to 2,5 m/s.

The effects of these changes improved the flux performance. The flux dropped from 525 ℓ/m^2h to 160 ℓ/m^2h after 5 days of continuous running.

After a new set of tubes were fitted onto tank 2 the flux declined from 260 ℓ/m^2h to 90 ℓ/m^2h after 6 days of continuous running.

Phase 3

The second bank of filter tubes were replaced with new ones and the velocity in the tubes for both banks was increased by reducing the number of tubes in parallel from 25 to 15.

The flux performance improved substantially, with fluxes of 380 ℓ/m^2h dropping to 40 ℓ/m^2h. However, on average the fluxes obtained were maintained at 100 to 160 ℓ/m^2h for 1 day and 3 days respectively.

Control of the flux decline was possible by allowing the tubes to dry out and with periodic acid washes.

The rejection performance is summarised in Table 4.74.

TABLE 4.74
SPECIES REJECTION ACHIEVED BY PILOT PLANT CFMF

Parameter		Feed	Permeate	% Rejection
COD	(mg/ℓ)	715	293	59
TC	(mg/ℓ)	238	79	67
ADMI Colour		752	128	83

Table 4.75 is a summary of the performance of the pilot plant cross-flow microfilter from July 1981 to September 1982.

TABLE 4.75
PERFORMANCE SUMMARY OF PILOT PLANT CROSS-FLOW MICROFILTER

		July-Dec 1981	Jan-June 1982	July-Sep 1982	Total
Running time	(h)	2 460	2 523	1 559	6 542
Feed volume	(m^3)	2 143	1 408	1 367	4 918
Product volume	(m^3)	1 822	1 112	1 300	4 234

Table 4.76 gives a summary of the feed and permeate compositions over the same time period.

TABLE 4.76
SUMMARY OF FEED AND PERMEATE COMPOSITION
(JUL 1981 TO SEPT 1982)

		pH	Cond (mS/cm)	TS (g/ℓ)	Na (mg/ℓ)	COD (mg/ℓ)	TC (mg/ℓ)	ADMI Colour
Dyehouse Effluent	Mean	7,91	0,65	0,61	152	757	175	1 368
	Min	5,50	0,11	0,13	45	16	75	170
	Max	12,24	7,89	5,68	495	5 461	415	6 504
CFMF Permeate	Mean	6,00	1,79	1,56	422	224	61	219
	Min	4,12	0,40	0,14	45	16	21	19
	Max	9,08	10,00	12,38	900	693	153	2 025

The design flux for operating periods between January to September 1982 was achieved for 100 to 150 hours depending on the character of the feed.

High tube velocities improved the initial performance and the steady state flux.

These results indicate that cumulative product fluxes after a week of 100 ℓ/m^2h may be achieved under the pressure conditions of high outlet pressure and high tube velocity.

4.12 CROSS-FLOW MICROFILTRATION OF EFFLUENT FROM THE FOOD AND CARAMEL INDUSTRIES

4.12.1 Introduction

An investigation was undertaken at Robertsons Spices (Pty) Ltd. to evaluate the feasibility of treating effluents from their food and caramel factories with cross-flow microfiltration in order to reduce effluent discharge costs.

The food factory produces dry powders and pasty products. Raw materials are mainly starch, fats, salt, monosodium glutamate, dehydrated vegetables and small quantities of sugar and caramel. No processing aids are used. In addition, there is a kitchen where whole chickens are cooked in an autoclave, and the fat removed in a basket centrifuge.

4.12.2 Laboratory Investigations into Treatment Methods

Laboratory tests on both food and caramel factory effluents were undertaken **(Appendix 4.44 (Part 1))**. Analyses of these effluents is given in Table 4.77 and

4.78. The food effluent was often high in suspended solids causing sludge formation in the sumps. Over a five month period, 14,4 m^3 of sludge, mainly settled fat and starch was collected.

TABLE 4.77
ANALYSIS OF FOOD EFFLUENT TAKEN AFTER WEIR
(Daily Food Composites from 9/4 - 11/4/85)

Parameter		Minimum value	Average value	Maximum value
pH		5,01	7,28	11,9
TS	(g/ℓ)	4,208	8,900	14,570
TDS	(g/ℓ)	3,176	5,270	8,019
SS	(g/ℓ)	1,032	3,630	6,551
TC	(mg/ℓ)	760	1 356	2 387
IC	(mg/ℓ)	72	163	300
TOC	(mg/ℓ)	869	1 435	2 315
OA	(mg/ℓ)	102	238	524
COD	(mg/ℓ)	2 281	4 215	6 194
BOD 5	(mg/ℓ)	2 800	2 900	3 000
Cond	(mS/cm)	3,07	4,65	7,80
Ash	(g/ℓ)	1,987	6,241	7,904
Na^+	(mg/ℓ)	198	970	1 790
K^+	(mg/ℓ)	24	24	24
Ca^{+2}	(mg/ℓ)	15	20,5	30,5
Mg^{+2}	(mg/ℓ)	4,9	8,9	12,1
Cl^-	(mg/ℓ)	410	810	1 028
SO_4^{-2}	(mg/ℓ)	50	50	50
H_2S		0	0	0
Folin protein	(mg/ℓ)	312	537	76
HPLC sugar		0	0	0
ADMI colour	(mg/ℓ)	442	731	1 020
Oil and fats	(mg/ℓ)	-	400	-

TABLE 4.78
ANALYSIS OF CARAMEL EFFLUENT
(Daily Food Composites from 11/4 - 8/5/85)

Parameter		Minimum value	Average value	Maximum value
pH		5,63	6,50	7,48
TS	(g/ℓ)	31,47	51,8	77,52
TDS	(g/ℓ)	46,99	49,86	52,73
Suspended solids	(g/ℓ)	1	1,94	-
TC	(mg/ℓ)	648	10 155	22 500
IC	(mg/ℓ)	180	522	864
TOC	(mg/ℓ)	12 672	17 496	22 320
OA	(mg/ℓ)	287	33 617	112 000
COD	(mg/ℓ)	40 868	45 004	49 139
BOD 5	(mg/ℓ)	580	890	1 200
Cond	(mS/cm)	1,3	23,1	44,6
Ash	(g/ℓ)	22,04	27,32	32,59
Na^+	(mg/ℓ)	88	6 549	15 000
K^+	(mg/ℓ)	5,6	5,6	5,6
Ca^{+2}	(mg/ℓ)	9,0	19,0	30,7
Mg^{+2}	(mg/ℓ)	3,5	6,1	12,4
Cl^-	(mg/ℓ)	16	99	319
SO_4^{-2}	(mg/ℓ)	9 275	9 275	9 275
Glucose and zylose		6,09	6,09	6,09
Redox	(mV)	25,0	85	145,0

Settling tests showed that concentrations of TS, SS, TOC and OA in the food factory effluent could be reduced, (Table 4.79) but that the concentration of dissolved inorganic salts was unaffected.

TABLE 4.79
CONCENTRATION REDUCTIONS ACHIEVED BY SETTLING OF THE FOOD FACTORY EFFLUENT

TS (%)	TDS (%)	Suspended solids (%)	TOC (%)	OA (%)	Cond
35,4	1,9	80	8 to 36	8 to 26	0

Coagulation tests were undertaken at different pH values, but in general were not effective and gave variable results.

Filtration through a 0,22 μ filter reduced the TS and OA concentrations of the food effluent by 33 % and 24 % respectively and the TC of the carmel effluent by 31 %. A reduction of 89 % in the TC concentration of caramel effluent was obtained by filtering the effluent through diatomaceous earth after adding polyelectrolyte.

4.12.3 Cross-flow Microfiltration Pilot Plant Investigations

A semi-technical scale pilot plant was installed at the factory to treat effluent from the food factory **(Appendix 4.45, Part 2)**. The cross-flow microfilter had the following specifications :-

Pump	:	Mono pump
Pump delivery	:	3,8 m^3/h
Flow velocity	:	1 to 2 m/s
Inlet pressure	:	100 to 250 kPa
Tube diameter	:	25 mm
Tube type	:	polyester
Filter aid	:	(1) diatomaceous earth (2) metal hydroxide

Effluent was collected in a feed holding tank and pumped to a clarifier. Overflow from the clarifier was used as feed to the cross-flow microfilter.

Tests were conducted using diatomaceous earth as a precoat. Fluxes obtained were low, 10 to 20ℓ/m^2h, over a 28 hour period at a pressure of 120 kPa. Using alum as a precoat, a premeate flux of 20ℓ/m^2h was obtained over a 7 hour period at the same pressure.

The permeate was free from suspended solids and a significant degree of colour removal was obtained.

OA rejections of up to 50 % were obtained depending on the precoat used and nature of the effluent.

4.13 CROSS-FLOW MICROFILTRATION OF SAPREF OIL REFINERY EFFLUENTS

At SAPREF refinery four effluent streams are generated from the various processing units. These are :-

(i) the CDU II stream which arises from the crude distillation unit,

(ii) the Road 8 stream from the catalytic cracking unit,

(iii) the Road 6 stream from the No.1 crude oil distillation column tank,

(iv) the Luboil stream from the production of lubricating oil.

All these streams report to a mixing tank where they are combined before being discharged to the sewer.

An investigation into the treatment of SAPREF effluents by reverse osmosis was undertaken. The aim was to recover water of suitable quality for reuse either as cooling tower make-up or boiler feed water.

The SAPREF effluents contains high molecular weight organics, small oil particles and various salts. Treatment of these effluents by reverse osmosis, required the development of a pre-treatment sequence to remove potential membrane foulants such as oil, adsorbable organics and colloidal and suspended material.

A pretreatment sequence involving flocculation, dissolved air flotation and cross-flow microfiltration was evaluated.

As the CDU II effluent stream was the most voluminous, laboratory tests were conducted on this effluent which is made up of the liquors from the crude distillation unit with the periodic addition of demineraliser regeneration chemicals, the desalter wash water and sour water liquors. Analysis of this effluent is given in Table 4.13.1

TABLE 4.80
CDU II EFFLUENT STREAM ANALYSIS

Parameters		Typical	Discharge of demineraliser chemicals	
			Anion	Cation
pH		8,39	11,0	6,45
Cond	(mS/cm)	3,42	7,13	13,01
TS	(g/ℓ)	1,84	4,36	7,51
TDS	(g/ℓ)	1,8	3,92	7,48
TC	(mg/ℓ)	198	122	126
IC	(mg/ℓ)	25	10	36
TOC	(mg/ℓ)	172	112	89
Cl	(mg/ℓ)	939	2712	4260
Na	(mg/ℓ)	326	1462	2965
Ca	(mg/ℓ)	22	4,7	76
Mg	(mg/ℓ)	32	0,8	54
SO_4	(mg/ℓ)	280	120	280
Oil	(mg/ℓ)	25	30	33
OA	(mg/ℓ)	26	38	39
Si	(mg/ℓ)	12	13	15

The use of in-line flocculation and cross-flow microfiltration to remove oil and colloidal matter was investigated.

The effluent was flocculated with 100 mg/ℓ of aluminium as alum and the pH corrected to between pH 4,5 to 5,0 by the addition of sodium hydroxide. The flocculated effluent was then cross-flow microfiltered for 24 hours under total recycle conditions. Flux and membrane rejections were monitored. Analyses of the

flocculated effluent, cross-flow microfiltration permeate and the species rejections obtained are given in Table 4.81. Cross-flow microfilter performance data is given in Table 4.82.

TABLE 4.81
ANALYSIS OF FLOCCULATED EFFLUENT, CROSS-FLOW MICROFILTRATION PERMEATE AND SPECIES REJECTION

		Feed	Perm	Rejection (%)	Feed	Perm	Rejection (%)
Time (h)		0,5			24		
pH		4,61	4,74		4,67	455	
Cond	(mS/cm)	4,59	4,46		4,56	4,57	
TS	(g/ℓ)	4,2	3,34	20	3,90	3,39	13
Cl	(g/ℓ)	1,01	1,01		1,04	1,06	
TC	(mg/ℓ)	82	66	20	80	60	25
COD	(mg/ℓ)	584	423	27	581	453	22
Na	(mg/ℓ)	949	960		960	966	
Oil	(mg/ℓ)	130	ND	100	-	ND	100

TABLE 4.82
CROSS-FLOW MICROFILTRATION PERFORMANCE DATA

Time (h)	Flux (ℓ/m²h)	Pressure (kPa)	Temperature (°C)
½	61	300	Ambient
1	57	300	
2	61	300	
3	61	300	
3	64	300	
24	43	300	

The flux dropped rapidly to 61 ℓ/m²h within half an hour probably due to the presence of the oil in the effluent. The permeate quality was good, with total oil removal and COD rejection above 20 %.

Because of this low flux, it was considered necessary to remove the oil by dissolved air flotation prior to cross-flow microfiltration (**Appendix 4.46**). The underflow from the flotation cell was flocculated with 50 mg/ℓ of iron as ferric chloride and the supernatant used as feed to the cross-flow microfilter.

Cross-flow microfiltert performance was significantly improved with a flux of 360 ℓ/m²h recorded aftetr 24 hours operation (pressure, 150 kPa; temperature, 24 °C; membrane area 0,2 m²) compared to 43 ℓ/m²h on the original effluent.

From the laboratory scale investigations, a pretreatment sequence system of flocculation and dissolved air flotation (DAF) followed by cross-flow microfiltration was established. In order to confirm laboratory results and to determine operating conditions a semi-technical scale investigation was undertaken.

A new batch of effluent was received from SAPREF but as this was less concentrated than the first batch received,the DAF underflow was concentrated up to approximately 90 % using the cross-flow microfilter at an inlet pressure of 150 kPa and a temperature of 19 °C.

The effluent was preflocculated with 15 mg/ℓ of iron as ferric chloride.

The cross-flow microfiltration of the DAF underflow gave a permeate of quality suitable for use as feed to a reverse osmosis unit, having an SDI value of 4,5. Permeate fluxes ranged from 430 to 570 ℓ/m²h over the concentration range.

Following laboratory and semi-technical scale investigations an on-site pilot plant consisting of a DAF unit, a cross-flow microfiltration unit and reverse osmosis unit was installed at the refinery to provide the necessary design basis for full-scale costing and economic evaluation.

The cross-flow microfiltration unit consisted of a chemical dosage system, a feed pump, a tubular microfilter and associated control equipment.

The installed cross-flow microfiltration area was capable of being varied from 8 to 24 m². On a total tube area of 12,6 m², the pretreated CDU II effluent gave fluxes of between 300 to 400 ℓ/m²h,and produced a permeate of high quality with an SDI value of 3, 9 **(Appendix 4.47)**.

Due to unforeseen problems in the delivery line from the CDU II sump to the mixing tank, it became necessary to switch the pilot plant over to other effluent streams.

4.13.1 Cross-flow Microfiltration of Lube Oil Effluent

The lube oil effluent was similar in character to the effluents originating in the crude distillation unit and catalytic cracker, except that it contains greater amounts of various solvents such as methyl-ethyl-ketone and furfurol. An analysis of the raw lube oil effluent is given in Table 4.83.

TABLE 4.83
LUBE OIL EFFLUENT ANALYSIS

pH		7,7
Cond	(mS/cm)	2,7
TDS	(mg/ℓ)	1 420
TS	(mg/ℓ)	1 650
Na	(mg/ℓ)	196
Ca	(mg/ℓ)	8
Mg	(mg/ℓ)	40
K	(mg/ℓ)	10
Cl	(mg/ℓ)	655
SO_4	(mg/ℓ)	300
TC	(mg/ℓ)	57
IC	(mg/ℓ)	27
TOC	(mg/ℓ)	30
COD	(mg/ℓ)	393
Oil on filtered sample		3,5
Oil on unfiltered sample		15

The flux decline was pronounced, falling from 93 ℓ/m²h to 35 ℓ/m²h during the first 15 hours of total recycle operation. 30 to 40 % removal of organic carbon was achieved and the turbidity of the effluent was greatly reduced **(Appendix 4.48)**.

Tests were carried out on the mixed effluent which consisted of the four process streams.

TABLE 4.84
MIXED EFFLUENT

Parameter		
pH		7,78
Cond	(mS/cm)	2,72
TS	(g/ℓ)	2,12
TDS	(g/ℓ)	2,106
TC	(mg/ℓ)	131
IC	(mg/ℓ)	15
TOC	(mg/ℓ)	116
Ca	(mg/ℓ)	11
Mg	(mg/ℓ)	36
Na	(mg/ℓ)	652
Cl	(mg/ℓ)	1 065
SO_4	(mg/ℓ)	362
OA	(mg/ℓ)	66
Oil	(mg/ℓ)	35
COD	(mg/ℓ)	516

Cross-flow microfilter performance data is given in Table 4.85.

TABLE 4.85
CROSS-FLOW MICROFILTER PERFORMANCE OF MIXED EFFLUENT

pH of feed		6,5	6,5	6,5	6,5
Feed flow	(m^3/h)	4,2	4,2	4,1	4,1
Reject flow	(m^3/h)	0,1	0,1	0,1	0,1
Pressure	(kPa)	120	120	135	135
Permeate flow	(m^3/h)	4,1	4,1	4,0	4,0
Water recovery	(%)	98	98	98	98
Area of tubes	(m^2)	6,3	6,3	6,3	6,3
Flux	(ℓ/m^2h)	650	650	635	635
Specific flux	($\ell/m^2h.kPa$)	5,42	5,42	4,7	4,70

Permeate quality as estimated by the SDI values obtained was good. Typical SDI values of the DAF underflow and cross-flow permeate are given in Table 4.86.

TABLE 4.86
MICROFILTRATION PERMEATE MIXED EFFLUENT

SDI of Underflow	SDI of Microfiltrate
7,6	4,2
7,9	4,5
8,2	4,8
7,9	5,6
8,5	3,5

Table 4.87 is a summary of the cross-flow microfiltration data obtained on the various SAPREF effluents during operation of the pilot plant.

Treatment of the DAF underflow by cross-flow microfiltation gave water of a quality suitable for reverse osmosis treatment. Fluxes were good and water recoveries high. Little fouling of the microfilter was evidenced during the period of operation **(Appendix 4.49)**.

Occasionally a sour water stream, high in dissolved H_2S and sulphides is added to the CDU II effluent, resulting in a fine metal sulphide precipitate. This precipitate was difficult to remove in the cross-flow microfilter and it is recommended that for full-scale operation the sour water stream be kept separate from all the other effluents.

The addition of demineraliser regeneration chemicals to the CDU II stream had little adverse effect on the performance of the cross-flow microfilter.

The presence of solvents from the lube oil manufacturing plant (furfural and methyl-ethyl-ketone) did not have an adverse effect on the microfilter.

TABLE 4.87
SUMMARY OF THE CROSS-FLOW MICROFILTRATION DATA

Effluent type		Time	Flux	P_{in}	TS (mg/ℓ)		SDI
		(h)	(ℓ/m²h)	kPa	Feed	Perm	Perm
CDU 2 (i)	a	6,0	283	120	0,73	0,63	4,15
	b	15,25	393	195	6,51	6,46	4,90
	c	10,40	327	158	2,35	2,19	4,49
ROAD 8 + CDU 2 (i)	a	8,67	291	170	1,63	1,61	4,01
	b	15,0	307	170	2,99	3,46	4,91
	c	12,62	301	144	2,32	2,52	4,54
CDU 2 (ii)	a	6,83	507	120	0,70	1,67	-
	b	9,0	571	200	2,03	2,87	-
	c	7,94	544	157	1,57	2,27	4,40
Mixing Tank (ii)	a	5,17	510	100	0,79	0,82	3,50
	b	23,6	722	180	3,76	4,0	5,60
	c	14,6	596	143	1,56	1,80	4,54

CFMF plant area key :
(i) 12,7 m²
(ii) 6,7 m²

5 THE DEWATERING OF SLUDGES BY TUBULAR FILTER PRESS

The potential of using a cross-flow microfilter in a tubular filter press mode, for dewatering sludges was investigated. Dewatering a sludge produces a spadable cake which can be disposed of more readily compared to a sludge. Thus the tubular filter press offers an alternative method for the disposal of water works, industrial and sewage sludges.

5.1 THE DEWATERING OF WATER WORKS SLUDGES

Water works produce sludges which range in concentration from 2 to 50 g/ℓ depending on the treatment and chemicals used. Most common are alum, lime and polyelectrolyte/bentonite sludges.

5.1.1 Dewatering of Alum Sludge

At Durban Heights Water Treatment Works, alum sludge is produced. A pilot plant was installed to investigate the effectiveness of the tubular filter press in dewatering the alum sludge and to determine the specific cake resistance of the sludge.

The tubular filter press had the following specifications :-

Tube type	:	Woven nylon
Tube dimensions	:	25 mm x 5 m
Filter area	:	0,40 m^2
Run time	:	0,33 to 8,20 hours
Feed pressure	:	200 to 520 kPa

The total solids concentration obtained by the tubular filter press varied between 24% m/m after 0,3 hours of pressing at 200 kPa, to 31,8% m/m after 8,2 hours of pressing at 400 to 520 kPa **(Appendix 5.1)**.

A summary of the tubular filter press results are given in Table 5.1.

TABLE 5.1
SUMMARY OF TUBULAR FILTER PRESS RESULTS

Specific cake resistance (m/kg)	Equivalent cake volume (m^3)	Feed TS (g/ℓ)	Equivalent cake mass (g/m^2)
$3{,}68 \times 10^{13}$	0,022	3,9	215
$2{,}43 \times 10^{13}$	0,058	2,1	308
$2{,}52 \times 10^{13}$	0,022	10,2	556

5.1.2 Dewatering of Lime Sludge

A semi-technical scale sludge dewatering pilot plant was installed at the Rand Water Board's Vereeniging Pump Station.

The pilot plant which consisted of a cross-flow microfilter unit and a tubular filter press unit was used to dewater lime sludge produced from the treatment of Vaal River water.

The cross-flow microfilter thickened the lime slurry to 30 to 70 g/ℓ total solids concentration.

The tubular filter press was operated as a dead end filter by closing the outlet valve and pumping sludge into the tubes where it was dewatered to a cake consistency. The cake was removed from inside the tubes by means of a roller device.

The tubular filter press had the following specifications :-

Tube type	:	Woven polyester curtain
Tube dimensions	:	25 mm x 5 m x 4 tubes
Area	:	1,5 m^2
Tube configuration	:	4 tubes connected in parallel
Fluid velocity	:	0,0 m/s
Feed pressure	:	300 to 600 kPa

The aim of this semi-technical scale study was to evaluate the potential feasibility of the unit, sizes and running costs. Comparison with alternative processes were undertaken.

Tubular filter press performance and dewatering data are given in Tables 5.2 and 5.3 **(Appendix 5.2).**

TABLE 5.2
THE TUBULAR FILTER PRESS CAKE DRYNESS AND PERCENTAGE SOLIDS CAPTURE

Feed sludge (g/ℓ)	Total filtrate volume (ℓ)	Captured cake mass (g)	Cake dry solids % (m/m)	Cake capture (%)
38	81	-	38	-
35	76	7 000	35	92
65	47	8 130	39	100

TABLE 5.3
SPECIFIC CAKE RESISTANCE

Pressure (kPa)	Specific cake resistance (m/kg)	Cake resistance (m^{-1})
400	$2{,}08 \times 10^{13}$	$7{,}17 \times 10^{12}$
300	$1{,}29 \times 10^{13}$	$4{,}44 \times 10^{12}$
300	$2{,}97 \times 10^{13}$	$4{,}49 \times 10^{12}$

A comparison between a tubular filter press and a chamber filter press treating 0,5 Mℓ/d of a 12 % m/v sludge indicates that at an operating pressure of 800 kPa, the tubular press area required is 218 m^2 while the chamber press requires 707 m^2. Thus the cost of the tubular press per unit area will be very much less than the chamber press. However the cake dryness of a tubular press (40 %) will not be as good as that obtained from a chamber press (65 to 70 %).

This preliminary feasibility study indicated that scale up is conceivable.

It is recommended that :-

(i) large scale tubular press pilot plants be constructed and tested at both Rand Water Board's sludge stations.

(ii) Future test work should examine the :-

(a) Daily and seasonal variations in sludge filterability.

(b) Design features required and operating methods necessary to accommodate variations in sludge quality and quantity.

(c) Optimum cleaning cycle over an extended period of time.

(d) Relative merits of both the spray and roller cleaning methods.

(e) Filter tube life and the selection of optimum fibre type for this particular application.

5.1.3 The Dewatering of Polyelectrolyte/Bentonite Sludge

A pilot plant consisting of a cross-flow microfilter, operated as a sludge thickener, and a tubular filter press was operated at the Umgeni Water Board's D.V. Harris Treatment Plant, to determine the suitability of the units in treating the polyelectrolyte/bentonite sludge produced by coagulation and flocculation of water from Midmar Dam.

The tubular filter press had the following specifications :-

Tube type	:	EPOC (Pty) Ltd, woven filter tube
Tube dimensions	:	2,4 m x 25 mm
Tube area	:	0,178 m^2
Tube pressure	:	100 to 600 kPa

Five tubular filter press runs were carried out using polyelectrolyte/bentonite sludge. An average cake solids of 25% m/v was obtained. Tube cleaning and cake capture techniques were developed. Sufficient sludge filterability data was obtained to enable the size of a full scale plant to be estimated.

The data is summarised in Table 5.4 and the estimation of the specific cake resistances are given in Table 5.5 **(Appendix 5.3).**

TABLE 5.4
TUBULAR FILTER PRESS SLUDGE FILTERABILITY, OPERATING CONDITIONS AND RESULTS

Feed TS (g/ℓ)	19		33		27		31,5	
Filter area (m^2)	0,183		0,183		0,183		0,183	
Pressure (kPa)	400		400		400		400	
	Filtrate volume V (m^3)	Filtration rate dt/dv (s/m^3)	Filtrate volume V (m^3)	Filtration rate dt/dv (s/m^3)	Filtrate volume V (m^3)	Filtration rate dt/dv (s/m^3)	Filtrate volume V (m^3)	Filtration rate dt/dv (s/m^3)
	0,0045	$1,99 \times 10^5$	0,0028	$2,81 \times 10^5$	0,0030	$2,73 \times 10^5$	0,0028	$2,96 \times 10^5$
	0,0060	$2,26 \times 10^5$	0,0043	$4,68 \times 10^5$	0,0044	$4,47 \times 10^5$	0,0044	$4,37 \times 10^5$
	0,0073	$3,07 \times 10^5$	0,0063	$6,35 \times 10^5$	0,0054	$5,46 \times 10^5$	0,0064	$6,35 \times 10^5$
	0,0090	$4,37 \times 10^5$	0,0081	$7,29 \times 10^5$	0,0072	$7,57 \times 10^5$	0,0075	$6,35 \times 10^5$
	0,019	$5,62 \times 10^5$	0,0095	$8,20 \times 10^5$	0,0083	$8,55 \times 10^5$	0,0084	$6,78 \times 10^5$
	0,0127	$6,56 \times 10^5$			0,0090	$8,55 \times 10^5$	0,0096	$9,39 \times 10^5$
	0,0145	$7,87 \times 10^5$						

TABLE 5.5
ESTIMATION OF SPECIFIC CAKE RESISTANCES OF POLYELECTROLYTE/BENTONITE SLUDGE

Specific cake resistance
$3,52 \times 10^{13}$
$3,20 \times 10^{13}$
$5,30 \times 10^{13}$
$4,10 \times 10^{13}$

The data indicates that, assuming a feed sludge flow of 20 kℓ/day and a sludge total solids concentration of 60 g/ℓ, a full-scale 80 Mℓ capacity plant should have the following specifications :-

Curtain length		:	10 m
Number of curtains		:	1
Total filtration area		:	16 m^2
Parallel tubes per curtain		:	20
Cycle time		:	18 minutes
Pump size	Press filling	:	70 m^3/h
	Pressure	:	0,8 m^3/h
Operating pressure		:	500 kPa
Power usage		:	3,2 kWh/T

It is recommended that these units be considered for large scale testing and evaluation.

5.1.4 Dewatering of Polyelectrolyte Sludge

At the H.D. Hill Water Treatment Plant in Pietermaritzburg, the turbidity of the surface water ranges from 3,5 to 74,0 NTU with an average of 12,0. A polyelectrolyte with the occasional addition of bentonite (usually in the winter months of low rainfall and low turbidity) is used as the coagulant in the treatment of raw water. The concentration and flow rate of the resulting sludge are approximately 20 g/ℓ and 50 kℓ/day respectively with an average of 22 g/ℓ of suspended solids and a total solids concentration varying from 4 to 40 g/ℓ **(Appendix 5.4)**.

A prototype tubular filter press unit was constructed and its performance tested on polyelectrolyte sludge. Different filter tube fabrics were compared.

The tubular filter press pilot plant had the following specifications :-

Pressure pump	:	Helical rotor pump
Cleaning/flushing pump	:	Centrifugal pump
Tube array	:	Filter tube curtain
Present operation	:	25 mm x 10 curtains consisting of up to 20 parallel tubes. Provision has been made for the installation of up to 6 of these filter curtains.
Cake thickness	:	Maximum - 20 % of the tube diameter.

The configuration of the various tubes used is given below :-

(i)	Tube type	:	Triple seam - Gelvenor Textiles
	Tube dimension	:	25 mm x 10 m
	Tube configuration	:	20 tubes set in parallel flow
	Tube seam sealing	:	Shoepatch
	Total operating time	:	1 000 hours
	Operating time	:	400 kPa average

		:	550 kPa maximum
	Comments	:	1) Tube blockages - however these were overcome. 2) Tube stretching - not excessive.
(ii)	Tube type	:	SPX - Gelvenor Textiles
	Tube dimensions	:	25 mm x 10 m
	Tube configuration	:	20 tubes set in parallel flow
	Tube seam sealant	:	None
	Total operating time	:	200 h
	Operating pressures	:	500 kPa average
		:	555 kPa maximum
	Comments	:	Tube blockages - very few
(iii)	Tube type	:	SPX - Mark I Gelvenor Textiles
	Tube dimensions	:	43 mm x 10 m
	Tube configuration	:	15 out of 22 woven tubes set in parallel flow
	Tube seam sealant	:	Nil
	Total operating time	:	20 h
	Operating pressures	:	400 kPa
	Bursting pressures	:	560 kPa
	Comments	:	1) Tube blockages - nil. 2) Tube stretch - excessive at pressures above 400 kPa.
(iv)	Tube type	:	SPX - Mark I Second cloth sample
	Operating pressures	:	400 kPa
	Operating pressures	:	450 kPa
	Tube specifications	:	As in (iii) above but there were only 13 operating tubes.
(v)	Tube type	:	SPX - Mark II Gelvenor Textiles
	Tube dimensions	:	40 mm x 10 m
	Tube configuration	:	13 out of 22 woven tubes in use
		:	set in parallel flow
	Tube seam sealant	:	Nil
	Comments	:	1) Tube blockages - nil. 2) Tube stretch -excessive stretching above 300 kPa.

When it was estimated that the desired cake thickness had been achieved (through monitoring the filtration rate), the cake discharge valve was opened, the flushing pump started and the cake dislodged from the inner tube surface by rollers moving along the tube surface. A high pressure water spray system was installed for cleaning the filter curtain whenever necessary.

Each cycle consisted of a cake formation stage (10 to 60 minutes) and a cake removal stage (2 to 3 minutes). Feed sludge was pumped under level control into the feed tank, filtrate was returned under gravity to the head of the works and cake was deposited on a trailer prior to dumping.

Control of the feed sludge concentration was automatically achieved by monitoring the quantity of feed sludge required to deposit a given cake layer.

The entire process was micro-processor controlled and required a minimum of operator attention.

The analytical data is summarised in Table 5.6.

TABLE 5.6
FEED, FILTRATE AND CAKE SUSPENDED SOLIDS CONCENTRATION

	Feed suspended solids (g/ℓ)	Filtrate suspended solids (mg/ℓ)	Cake solids concentration (% m/m)
Mean	22	75	31
Range	2 to 40	0 to 200	23 to 41

The solids treatment capacity is approximately proportional to the feed solids concentration. The feed solids concentration varied from 4 to 40 g/ℓ while the cake concentration remained at 30 %. A feed solids concentration of 30 g/ℓ resulted in a dry solids treatment capacity of 25 to 30 kg/hr. A feed solids concentration of 5 to 10 g/ℓ resulted in a treatment rate of 5 to 10 kg/hr.

The liquid treatment rate was constant at 1 m^3/h and is almost independent of the feed solids concentration.

The filtrate quality is dependent on the feed sludge solids concentration. A feed sludge with a high suspended solids concentration (in excess of 15 g/ℓ) results in the rapid deposition of a cake and a filtrate with 0 to 75 mg/ℓ of suspended solids. Cake build up is slower for a feed with a low suspended solids concentration (less than 10 g/ℓ), and the resultant filtrate has a higher suspended solids concentration (up to 200 mg/ℓ).

The cake moisture content is dependent on the average cake voidage which is governed by the operating pressure.

Tubular filter press operating data is summarised in Table 5.7.

TABLE 5.7
THE EFFECT OF OPERATING PRESSURE ON CAKE MOISTURE CONTENT AND SPECIFIC CAKE RESISTANCE

Pressure (kPa)	Cake solids concentration (% m/m)	Specific cake resistance (m/kg)
200	33,0	$0,75 \times 10^{13}$
400	34,9	$1,35 \times 10^{13}$
600	35,2	$1,95 \times 10^{13}$

Decreasing the cake thickness decreases the resistance to filtration and increases the filtration rate.

The effect of operating pressure on production rate is dependent on the cake compressibility. The production rate is proportional to pressure for an incompressible cake while being insensitive to pressure for a highly compressible cake (**Appendix 5.5**). The polyelectrolyte sludge was found to be compressible (compressibility coefficient of 0,89).

A comparison of the performance of the different filter tubes is given in Table 5.8.

5.2 THE TREATMENT OF INDUSTRIAL PROCESS SLUDGES

The potential of the tubular filter press for dewatering sludges generated in the Johannesburg Consolidated Investment Company's (JCI) mining and mineral process operations was assessed.

Four sludges were used :-

(i) Underground sludge (unlimed) : Raffinate from the clarification of underground mine water using lime and polyelectrolyte.

(ii) Underground sludge (limed) : Lime was added to sample (i) and the pH increased to a value of 11.

(iii) Cyanide sludge : Resulting from ore processing for gold recovery.

(iv) Raffinate sludge: Resulting from ore processing for uranium recovery.

Test work was undertaken to determine the effect of solvents present in the Raffinate sludge, on the filter tube fibre strength.

TABLE 5.8
CLOTH PERFORMANCE SUMMARY

Tube type	Tube blockage	Operating pressure	Perm quality	Cake release	Tube repair	Tube hanging	Manifolding	Tube Stretch	Total score
25 mm 3 Seam	2	3	2	4	2	3	3	2	21
25 mm SPX	2	2	4	4	2	2	2	2	20
40 mm SPX Mark I	4(e)	0	4	4	2	2	2	1	19
40 mm SPX Mark II	4 (e)	2	4	4	2	2	2	1	21 20
25 mm Fire-hose Jacket (g)	2	4(f)	3(d)	1	3(a)	2(b)	3(c)	2(e)	16
25 mm Swiss Silk (g)	2	2	0	4	3(a)	2(b)	3(c)	0	

Notes (a) damaged tubes can be repaired
(b) estimated -no experience
(c) tubes can be manifolded individually
(d) permeate quality is excellent for certain weave qualities, poor for other
(e) estimated -operating experience limited
(f) tubes have been operated at pressures of up to 1000 kPa
(g) test work on single tube

Rating key : 0 - unacceptable
1 - poor
2 - satisfactory
3 - good
4 - excellent

The semi-technical scale pilot plant had the following specifications :-

Filter tube	:	Triple seam sealed - polyester
Tube dimension	:	3m x 25mm
Pressure pump	:	Mono pump C32M
Cleaning pump	:	Alfa Lavel Centrifugal pump GM2

A total of 18 constant pressure batch pressings were undertaken. For each test, the rate of filtration was measured against the accumulated volume filtered.

A summary of analytical results are given in Table 5.9, the calculated specific cake resistance values are given in Table 5.10 and the average specific cake resistance values of the sludge tested is given in Table 5.11 **(Appendix 5.6)**. For comparison H.D. Hill sludge values are also given.

The results indicate that, for the range of sludges generated by JCI, the tubular filter press process can be used successfully for dewatering. To optimise the process careful control of the feed solids concentration is required.

TABLE 5.9
FEED SLUDGE CAKE AND FILTRATE SOLIDS ANALYSIS

Sludge	Feed			Cake		Filtrate
	Susp. solids (g/ℓ)	pH	TDS (g/ℓ)	% (m/m)	% organics	Susp. solids (snap sample) (g/ℓ)
H.D. Hill sludge	23,2	7,5	0,16	29,9	15,0	-
Underground sludge (Unlimed)	96,3	8,1	2,4	45,9	3,7	0,083
Raffinate sludge	46,0	11,6	3,5	29,6	4,7	0,066
Cyanide sludge	17,3	9,7	3,4	22,6	-	0,036

TABLE 5.10
SPECIFIC CAKE RESISTANCE AND CAKE RECOVERY RESULTS

Batch no.	Feed type	Feed conc. (g/ℓ)	Pressure (kPa)	Cake deposition time (mins)	Filtrate flux batch end (ℓ/m^2h)	Specific cake resist. x 10^{12} (m/kg)	Cake recovery (R)	Cake solids mass deposited Md (kg/m^2)
1	H.D. Hill		400	17,5	63	300 x 10^{12}	0,636	0,79
4	U/Ground	23,3	400	11,0	109	2,7 x 10^{12}	0,545	4,12
5	U/Ground	96,9	400	7,0	122	2,9 x 10^{12}	0,565	2,87
6	U/Ground	96,5	400	4,5	190	3,5 x 10^{12}	0,536	2,75
19	U/Ground with lime	92,3 92,5	400	2,5	340	2,1 x 10^{12}	0,480	2,75
8	Raffinate		400	6,8	254	2,1 x 10^{12}	0,240	1,80
9	Raffinate	32,5	400	-	382	1,4 x 10^{12}	-	-
10	Raffinate	32,8	400	2,3	1 021	0,9 x 10^{12}	-	-
16	Cyanide	37,9	400	4,43	218	15,7 x 10^{12}	0,530	0,44
17	Cyanide	14,7	400	6,0	153	19,2 x 10^{12}	0,680	0,56
18	Cyanide	19,8	550	5,5	169	22,4 x 10^{12}	0,940	0,56

TABLE 5.11
SLUDGE SPECIFIC CAKE RESISTANCE AT 400 kPa

Sludge type	Specific cake resistance (m/kg)
1. H.D. Hill sludge	30,0 x 10^{12}
2. Underground sludge	3,0 x 10^{12}
3. Underground sludge with lime	2,1 x 10^{12}
4. Raffinate sludge	1,5 x 10^{12}
5. Cyanide sludge	7,5 x 10^{12}

It is recommended that a pre-production scale pilot plant be constructed for on-site process evaluation. The following features should be incorporated in the pilot plant :-

(i) skid mounting,

(ii) a sludge solids concentrations meter,

(iii) a split feed tank for control of sludge concentration,

(iv) full automation.

5.3 THE TREATMENT OF BIOLOGICAL SLUDGES

5.3.1 Dewatering of Anaerobically Digested Raw and Waste Activated Sludge

An attempt was made to dewater anaerobically digested raw and waste activated sludge using the tubular filter press **(Appendix 5.7).**

The tubular filter press pilot plant had the following specifications :-

Tube type	:	Polyester - single tube cut from a curtain
Tube dimension	:	25 mm x 1,6 m
Feed pressure	:	500 - 550 kPa
Feed velocity	:	0,1 - 0,05 m/s
Feed total solids	:	18 - 19,5 g/ℓ
Precoat	:	a) Limestone
		b) None
Chemical addition	:	a) None
		b) Alum to pH 6
		c) Alum and lime
Pretreatment	:	The feed was concentrated using a cross-flow microfilter

It was found that the permeate flux decreased with increasing permeate volume collected (Figure 5.1), indicating that no significant cake deposition had occurred. When alum or alum and lime was added to the sludge the flux decline was less severe.

In general the tubular filter press process is not suitable for dewatering anaerobically digested raw and waste activated sludge, as no significant cake formation could be achieved, with or without chemical addition.

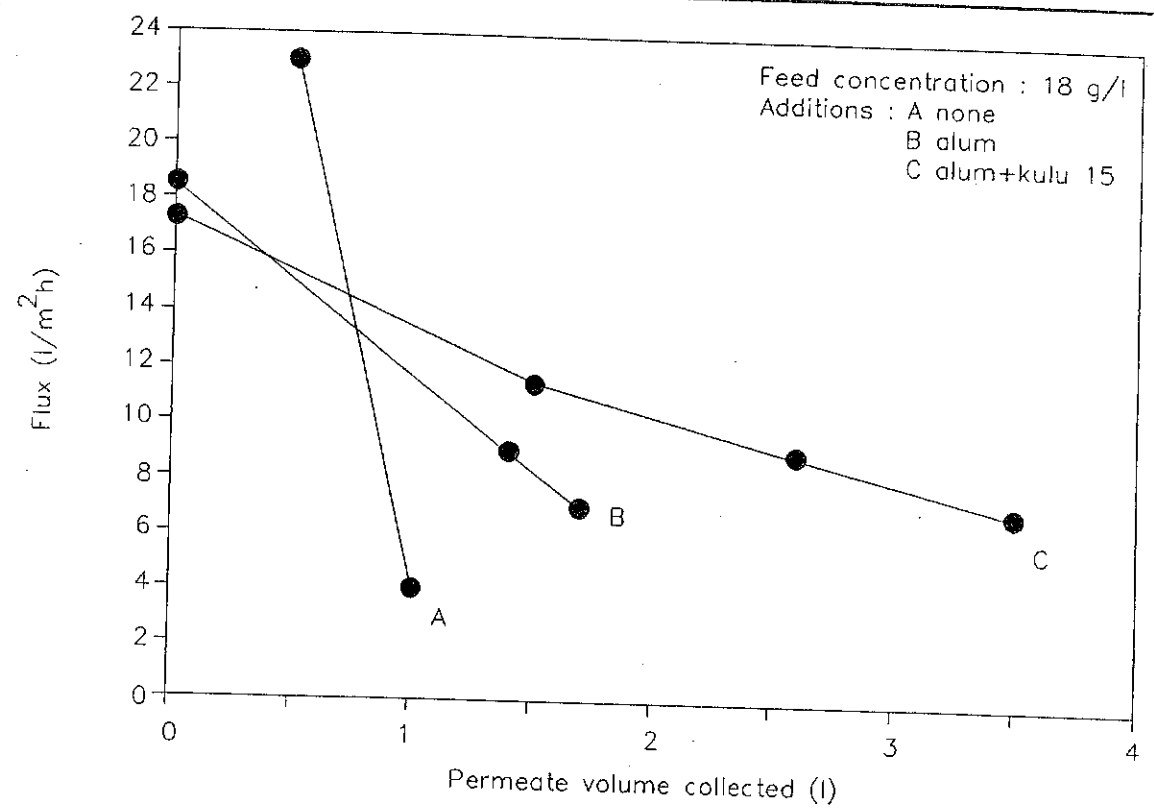

FIGURE 5.1 : VARIATION IN PERMEATE FLUX WITH INCREASING PERMEATE VOLUME

6 DESIGN AND OPERATION OF A CROSS-FLOW MICROFILTER

6.1 INTRODUCTION

Cross-flow microfiltration is a technique for removing colloidal and suspended particles which do not readily flocculate or settle. The use of woven fabric tubes as the filtration surface, with or without the addition of precoating chemicals, expanded the potential of cross-flow microfiltration as an effluent or waste water treatment process. Investigations into the effectiveness of cross-flow microfiltration using fabric tubes, have been reported in Chapters 1 to 4.

In designing cross-flow microfiltration units consideration should be made of variations in the volume of feed due to either seasonal factors or variations in the effluent producing processes, for example seasonal variation in the volume of feed to be processed can be accommodated by increasing or decreasing the filtration area. Variations in feed solids concentration do not usually impose design limitations as the system is self-regulating in that a decrease or increase in solids concentration is balanced by an increase or decrease in permeate flux respectively.

In this chapter, the equipment needed for cross-flow microfiltration and the various modes of operation are described. As the cross-flow microfilter can vary in size from a single tube unit used for laboratory scale testing to pilot plant scale, emphasis is placed on the type of information that should be recorded at each level of testing

6.2 EQUIPMENT FOR CROSS-FLOW MICROFILTRATION

The size and complexity of the equipment required to undertake cross-flow microfiltration will vary with scale of testing, but the basic components remain constant.

These are :-

(i) cross-flow microfilter tubes,

(ii) feed tank/s,

(iii) pressure pump,

(iv) permeate collection facility.

The capacity or size of these components is largely determined by the number of filter tubes (and hence filtration area) used.

Over the years a variety of woven fabric tubes have been tested, ranging from fire hose jacket fabric to specially woven fabric.

For single linear filter tubes, best results have been obtained using polyester fabric woven by SST Thal (Cat. No. 193). The multi-tube arrays currently used are manufactured by Gelvenor Textiles (Pty) Ltd.

A method of supporting the filter tubes is necessary, the complexity of the support system varying with number of filter tubes and their configuration. Various tube configurations have been used. These include :-

(i) linear,

(ii) spiral-flat, horizontal,

(iii) spiral-circular, vertical,

(iv) parallel flow,

(v) series flow,

(vi) shell and heat exchanger arrangement,

(vii) header pipe arrangement,

(viii) series taper.

The choice of tube configuration and support system is dependent on unit size, for example for rapid screening or laboratory scale testing, a linear configuration with the tube suspended over a gutter, is adequate.

Generally a linear configuration is preferred regardless of size, as it facilitates examination, repair and cleaning of the filter tubes.

On a single tube laboratory scale unit, cleaning is achieved by flushing and manual squeezing to dislodge particulate material from the filter tube fabric. For a scientific scale unit jets of water sprayed onto the exterior of the tube during flushing is an acceptable cleaning method. A mechanised spray cleaning-head has been developed to effectively clean multi-tube array curtains on the pilot-plant scale.

Feed tanks, pressure pumps and permeate collection facilities should be of a size appropriate for the scale of the cross-flow microfilter unit.

6.3 MODES OF OPERATION

The mode of operation of the cross-flow microfilter can be varied. Depending on whether the aim is to concentrate the effluent or filter it, an appropriate mode of operation is chosen. The characteristics of the effluent may also effect the way in which the cross-flow microfilter is operated.

6.3.1 Total Recycle

Total recycle is the most simple of the modes of operation. Both permeate and reject streams are recycled to the feed tank, thus maintaining overall bulk composition of the effluent. This method of operation is used largely for initial exploratory testings as it gives an indicator as to whether the effluent is amenable to cross-flow microfiltration treatment. Permeate flux at zero water recovery can be measured and the quality of permeate assessed.

6.3.2 Batch Concentration

In the batch concentration mode permeate is continually withdrawn from the system and the feed thus concentrated until the desired water recovery is achieved. The degree of water recovery can be determined by the difference in tank levels at the start and end of each batch. If a high water recovery is required it is generally necessary to filter several batches of feed to, for example, 50 % water recovery. The concentrates from each batch are combined and can be concentrated further. If the desired product is the concentrated effluent, then extra concentrate storage tanks are required. Where the desired product is the filtrate, a holding tank may be necessary, until a volume, sufficient for further use/treatment, has accumulated.

6.3.3 Serial Batch Concentration

Serial batch concentration is similar to batch concentration, except that the concentrate is not removed at the end of each batch, but fresh feed is added to the tank and filtration continued. In this way the overall water recovery level is increased continuously but in an oscillating step-like manner.

6.3.4 Continuous Feed and Bleed

This mode of operation is used when, having achieved the desired level of water recovery (by batch concentration), a constant total solids concentration is required to be maintained in the concentrate. Only one feed tank is necessary and feed is added continuously, to compensate for permeate production and concentrate removal. The operating method is shown schematically in Figure 6.1.

6.3.5 Series-taper

The configuration of a three stage series-taper cross-flow microfiltration unit is shown schematically in Figure 6.2. The number of stages can vary from 2 to 5.

This operating method is used where a large volume of permeate is required at a high water recovery. The system achieves the highest permeate flux at the lowest energy consumption and is confined to large plants.

Because of the overall pressure drop (from feed inlet pressure to final stage outlet pressure), inter-stage pumps are normally required. The size of these pumps can decrease progressively, as the residual pressure from each stage is available for use by the succeeding stage and the feed volumetric flow decreases.

Where low water recovery is experienced from "down-line" stages, concentrate can be recycled to the feed tank or to inter-stage feed tanks for reprocessing, or the number of filtration tubes can be increased at each successive stage.

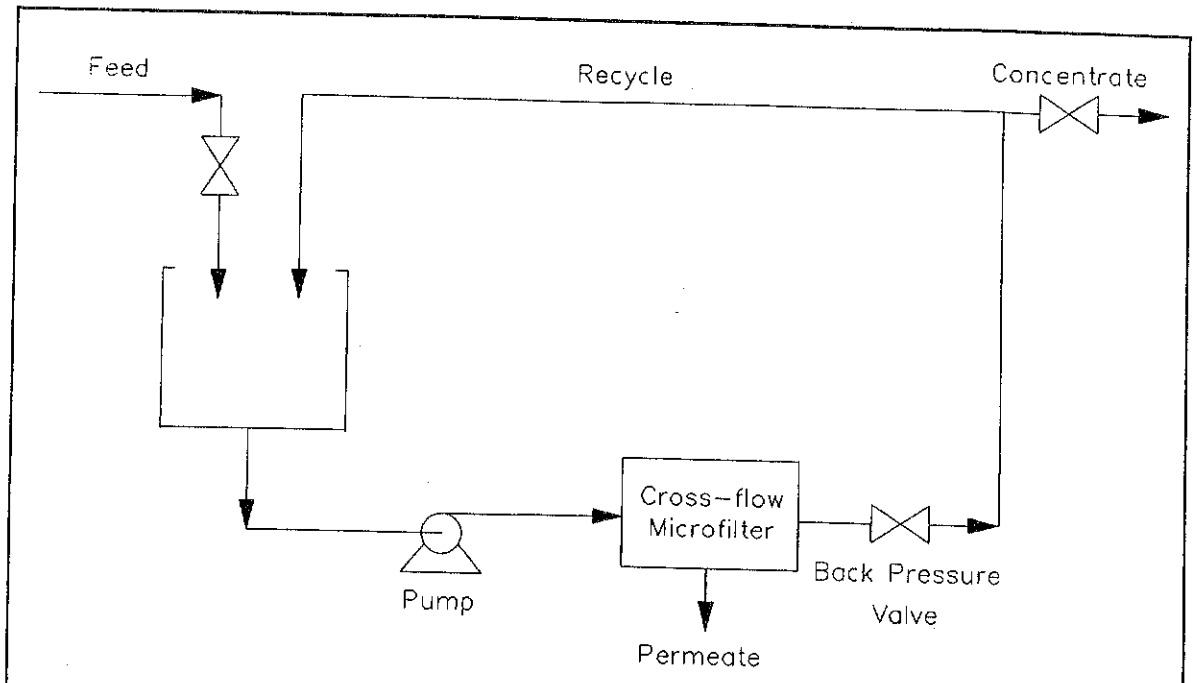

FIGURE 6.1 : SCHEMATIC OF CROSS-FLOW MICROFILTER UNIT IN CONTINUOUS FEED AND BLEED MODE

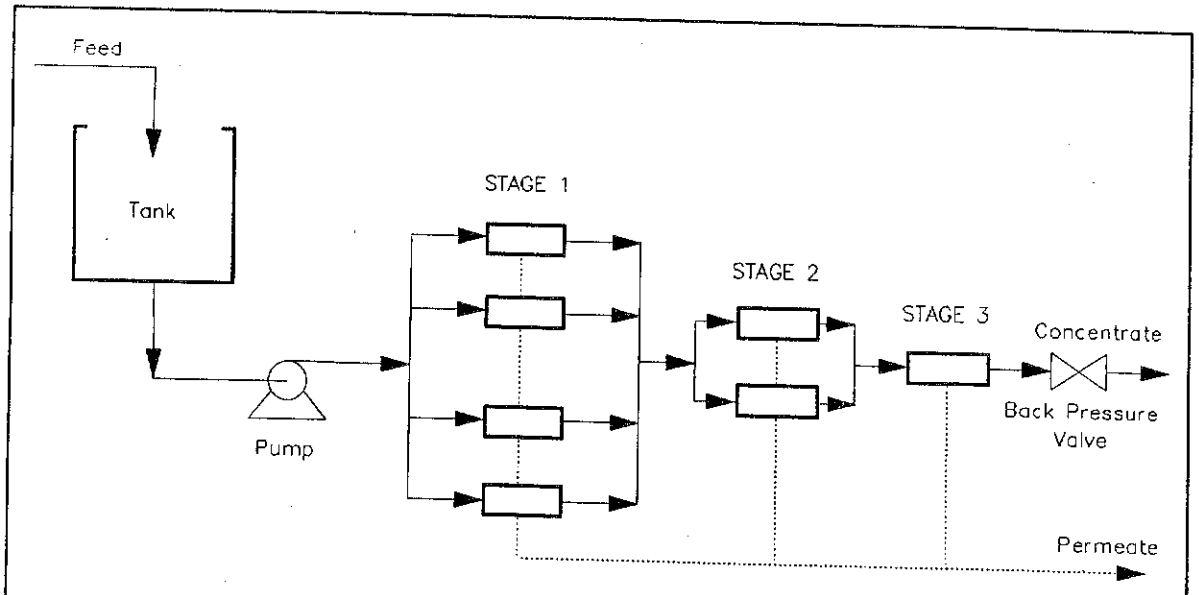

FIGURE 6.2 : SCHEMATIC OF CROSS-FLOW MICROFILTER UNIT IN SERIES-TAPER MODE

A variation on the series-taper configuration is the once-through method of operation where there is no inter-stage recycling. Flow velocity is maintained by decreasing the number of parallel tubes in successive stages, with overall operating pressure being maintained by inter-stage pumps.

6.4 LEVELS OF TESTING

A series of tests of increasing experimental and scientific rigour should be undertaken to assess the effectiveness of cross-flow microfiltration in treating a particular effluent. Depending on the results at any given stage, a decision to proceed to the next level of testing can be made. The various levels of testing and the type of information obtained at each stage are described below.

6.4.1 Rapid Screening Tests

The lowest level of testing is the rapid screening test. This comprises filtering the effluent, under vacuum pressure, through a 0,45 μm filter, using standard vacuum filtration apparatus.

By examining the filtrate, an indication is obtained of permeate quality. The filtration rate can also be measured. If a high filtration rate is obtained, but the filtrate is turbid, the test can be repeated using various filtration aids such as diatomaceous earth or limestone. The most satisfactory combination of filtration rate and type of filter aid is noted. If more than visual comparison is required, the feed and filtrate can be analysed for appropriate species and species rejection values calculated.

6.4.2 Laboratory Scale Cross-flow Microfiltration

The laboratory scale cross-flow microfiltration unit is illustrated in Figure 6.3 and consists of a single microfiltration tube, together with a feed tank, pump and permeate collection gutter. If the filter tubes are to be precoated a separate precoat slurry tank streamlines operation of the unit.

The laboratory scale unit is first operated in total recycle mode to obtain flux values at zero water recovery. At this stage, any pinholing of the filter tubes, and turbidity in the permeate are noted and if necessary a precoat can be deposited on the filter tubes to improve microfiltration.

When the system has stabilised, which depending on the nature of the effluent, may take a few minutes to a few hours, flux measurements can be taken. Flow velocity and operating pressure are varied systematically to find the optimum operating conditions. The total recycle test can be repeated using tubes of different diameter.

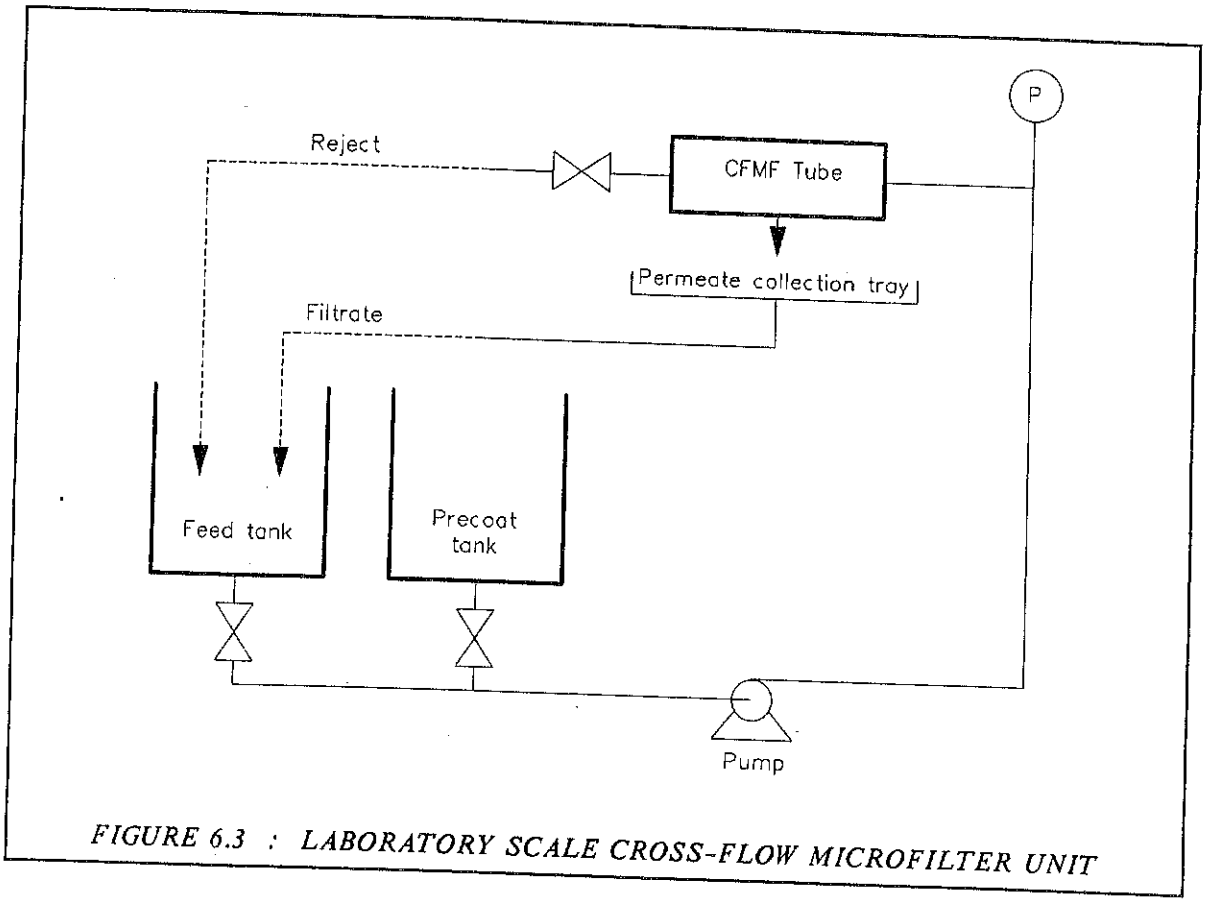

FIGURE 6.3 : LABORATORY SCALE CROSS-FLOW MICROFILTER UNIT

If, for a given set of operating conditions, flux values are constant for a reasonable period of time, a batch concentration can commence. Permeate filtration rates are measured regularly and any flux decline with time noted. If flux values become unacceptably low or the volume in the feed tank drops rapidly (due to high filtration rates), more feed can be added and the system operated in serial batch concentration mode.

Flux data obtained on the laboratory scale unit are not indicative of values that would be obtained on a larger unit. Rather they distinguish between an easily filterable effluent and a more difficult one.

Regular collection of feed and permeate sample pairs can be analysed to provide confirmation of removal of solids from the permeate and their retention by the concentrate. Concurrent rejection of other species e.g. total organic carbon and conductivity, can be checked.

6.4.3 Scientific Scale Cross-flow Microfiltration

Tests conducted using the scientific scale cross-flow microfilter are important as it is from this scale of microfilter unit that accurate measurements are obtained which can

be used for predicting behaviour on a larger scale. Consequently considerable data concerning the relationships between operating variables should be collected. Different filter tube diameters can also be evaluated.

The scientific scale cross-flow microfilter contains one filter tube which is cleaned manually.

Additional items of equipment include :-

(i) temperature control,

(ii) variable flow pump with a magnetic induction flow transducer and controller,

(iii) pressure tranducer and controller,

(iv) linear orifice back pressure controller,

(v) covers to minimise evaporation.

A typical scientific cross-flow microfiltration unit is illustrated in Figure 6.4 and details of operating instructions are given in **Appendix 6.1**.

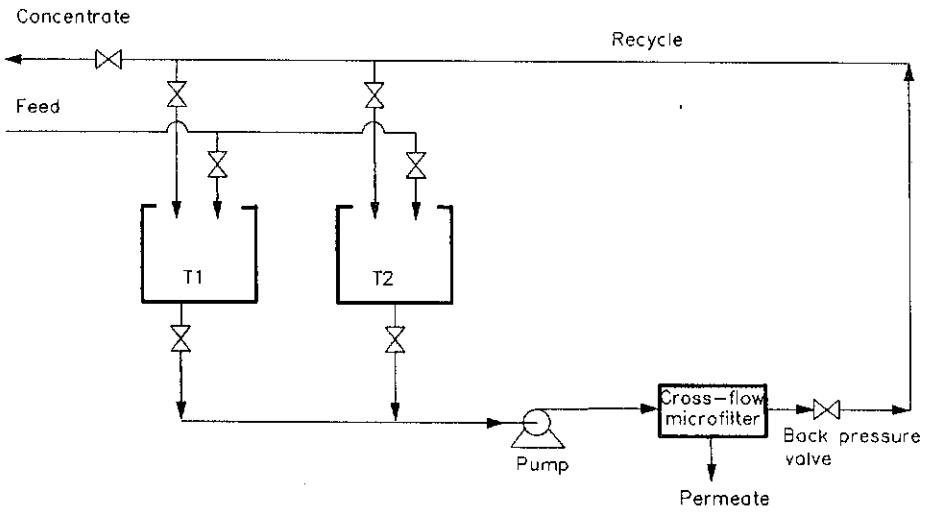

FIGURE 6.4 : SCIENTIFIC SCALE CROSS-FLOW MICROFILTER UNIT

The data collected will depend on the ultimate objective and area of interest, but in all cases the following data should be collected :-

(i) accurate flux measurements,

(ii) the effect of pressure on flux at various solids concentrations,

(iii) the effect of flow velocity on flux at various solids concentrations.

Where the concentrate is of prime interest, the relationship between viscosity and concentration should be studied as the rheological properties of the concentrate change with increasing concentration and could determine the upper limit to thickening.

The operation of a laboratory scale cross-flow microfilter unit requires a person in attendance always. Data is collected at 10 to 15 minute intervals and experimental runs are a maximum of 12 hours duration.

Data obtained should be evaluated carefully. If areas of uncertainty remain, further tests should be undertaken. The aim at the end of scientific scale testing should be to have available, not only sufficient data to enable scale-up to pilot-plant or full scale but to have gained an insight and *feel* for the behaviour of the effluent and to have quantified the relationship between operating variables.

6.4.4 Pilot Plant Cross-flow Microfiltration

Testing on the pilot-plant scale enables engineering data and experience to be obtained and allows the potential user to gain experience in operation of the equipment. Large volumes of permeate and concentrate are produced which can be assessed for use in other down-stream processes.

A typical pilot plant scale cross-flow microfilter unit is shown schematically in Figure 6.5.

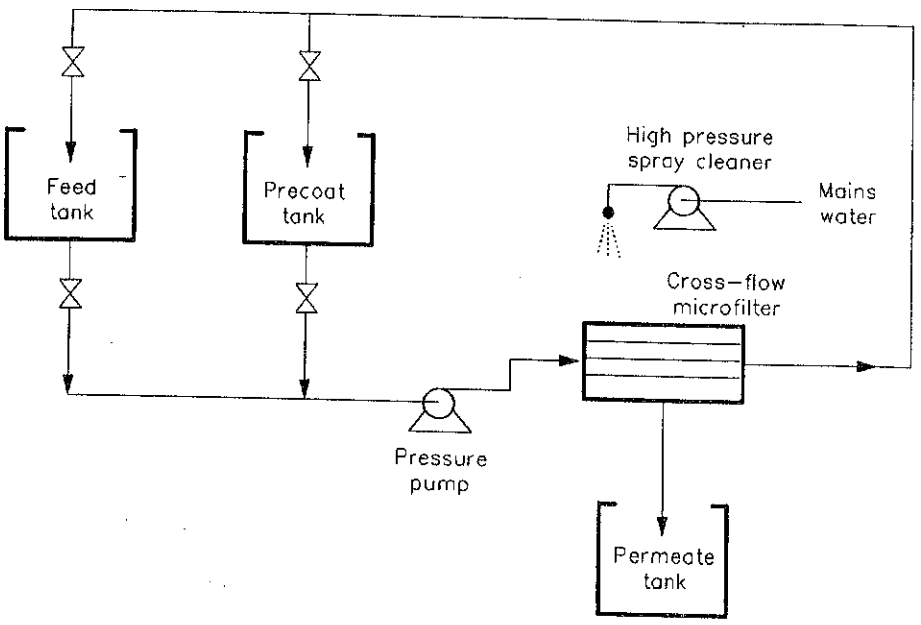

FIGURE 6.5 : TYPICAL PILOT PLANT SCALE CROSS-FLOW MICROFILTER UNIT

In addition to the microfilter unit and associated tanks and pumps, additional components such as a pH controller, a cleaning unit, an in-line dosing system, electrical connections, storage facilities for both feed and product may be required.

Each pilot plant should be designed to accommodate on-site circumstances, for example, although the ideal pilot-plant should be completely automatic and capable of unattended operation such a design is superfluous if the process producing the effluent is of a batch nature. Any variability in the nature and/or composition of the effluent may have to be accommodated by making provision for occasional dosing of flocculants. Provided the behavioural relationships of the effluent have been fully determined at the scientific stage of testing, such on-site variables can be accommodated by engineering principles. The data acquired during pilot-plant operation is mainly qualitive on operation and quantitive on chemical analyses.

6.5 CHEMICAL NATURE OF THE FEED

The chemical nature of the feed must be well understood in order that possible physio-chemical changes can be taken into account.

Aspects to be considered include:-

(i) the effect of temperature on solubility,

(ii) oxidation or reduction reactions (eg. post precipitation of ferric hydroxide from ferrous salts),

(iii) adsorption of carbon dioxide from the atmosphere leading to post precipitation of calcium carbonate in limed effluent,

(iv) ageing of precipitates leading to thermodynamically very stable aluminates and silicates which cannot be removed from the fabric,

(v) presence of charged organic bodies (surfactants, flocculants, polyelectrolytes) which could bond to the fabric leading to enhanced or diminished flux values,

(vi) presence of nutrients leading to biological growth in the permeate,

(vii) the stability of fresh effluent.

6.6 PHYSICAL NATURE OF THE FEED

The permeate flux is dependent on the flow of fluid through the filter cake. The porosity of the filter cake is dependent on the physical characteristics of the particles in the feed. Any change in their size, shape and distribution wil lead to variations in the permeate flux. For example, the loss of fine particles will lead to enhanced permeate fluxes while the breakdown of floc particles due to shear in pumps and valves will reduce the permeate flux. For rigid spheres, a reduction in particle diameter by a half will reduce the permeate flux from 160 to 10 ℓ/m^2h.

7 DESIGN AND OPERATION OF A TUBULAR FILTER PRESS

7.1 INTRODUCTION

A tubular configured sludge dewatering process has been developed (**Appendix 7.1**) by the Pollution Research Group, University of Natal, in terms of a Water Research Commission project.

A prototype unit was constructed (**Appendix 7.2**) at Umgeni Water's HD Hill Water Treatment Works and commissioned in January 1987. The process has operated successfully according to design for a two year period. The water works sludge has been dewatered from a concentration of approximately 15 g/ℓ to form a cake at approximately 30 % m/m.

Following the successful operation of the HD Hill unit two units have been constructed in the United Kingdom and one in the United States of America. In addition laboratory scale test work has been undertaken on numerous types of sludge. The process has been licenced internationally and is marketed under the name EXXPRESS.

In order to provide users and potential users of this technology with some indication of the process performance and methods of process optimisation, the process design equations are provided together with test results on a wide range of sludges.

7.2 EQUIPMENT FOR A TUBULAR FILTER PRESS

The process schematic is shown in Figure 7.1. The unit consists of a sludge balancing sump, a feed tank, a filtrate collection tray, a pressure pump (helical rotor pump), a tube flushing or cleaning pump (centrifugal), the filter tube array and cleaning rollers and carriage.

The tube array of the dewatering unit is made up of filter tube curtains. Each tube curtain consists of a number of filter tubes manifolded, in parallel, between an inlet and a reject manifold. The tubes are flexible and are constructed from woven polyester fabric. The selection of the number of curtains and their length for a particular application is dependent upon the slurry characteristics and the quantity of the sludge to be treated. Each tube curtain is fitted with its own set of cleaning rollers.

The sludge pump supplies sludge on demand from the balancing sump to the feed tank. The sludge is pumped into the tube array by the pressure pump. When the cake discharge valve is closed the pressure increases in the tube array and the liquid portion of the slurry permeates through the woven tube wall. The slurry solids are simultaneously deposited as a cake on the inner wall of the tube (Figure 7.2) and as the thickness of the cake increases the filtrate flow rate decreases. The cake thickness

can be monitored through the filtration rate. The cake thickness is limited to a maximum of about 15 % of the tube diameter (i.e. 2 to 4 mm for a 25 mm diameter tube).

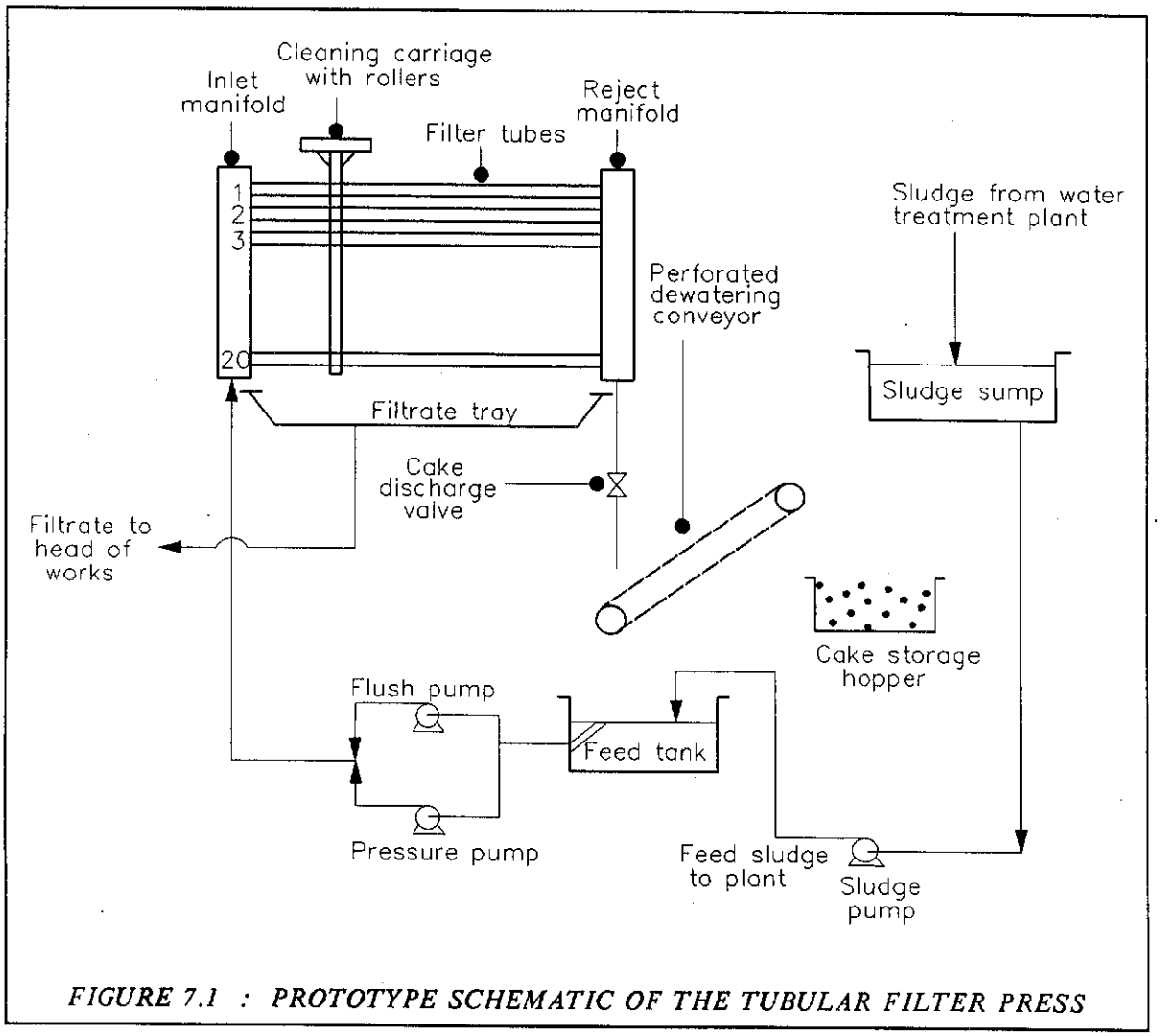

FIGURE 7.1 : PROTOTYPE SCHEMATIC OF THE TUBULAR FILTER PRESS

When it is estimated that the desired cake thickness has been achieved, the cake discharge valve is opened, the flushing pump started and the cake dislodged from the inner tube surface by the action of the rollers moving along the tube surface (Figure 7.3). The rollers create a restriction in the tubes; the high flow velocity, reduced pressure and turbulence created at the point of restriction is sufficient in dislodging the cake from the tube surface. The cake is simultaneously hydraulically conveyed out of the tubes and is separated from the bulk fluid on a perforated conveyor belt. A high pressure water spray system is used to clean the filter curtain periodically.

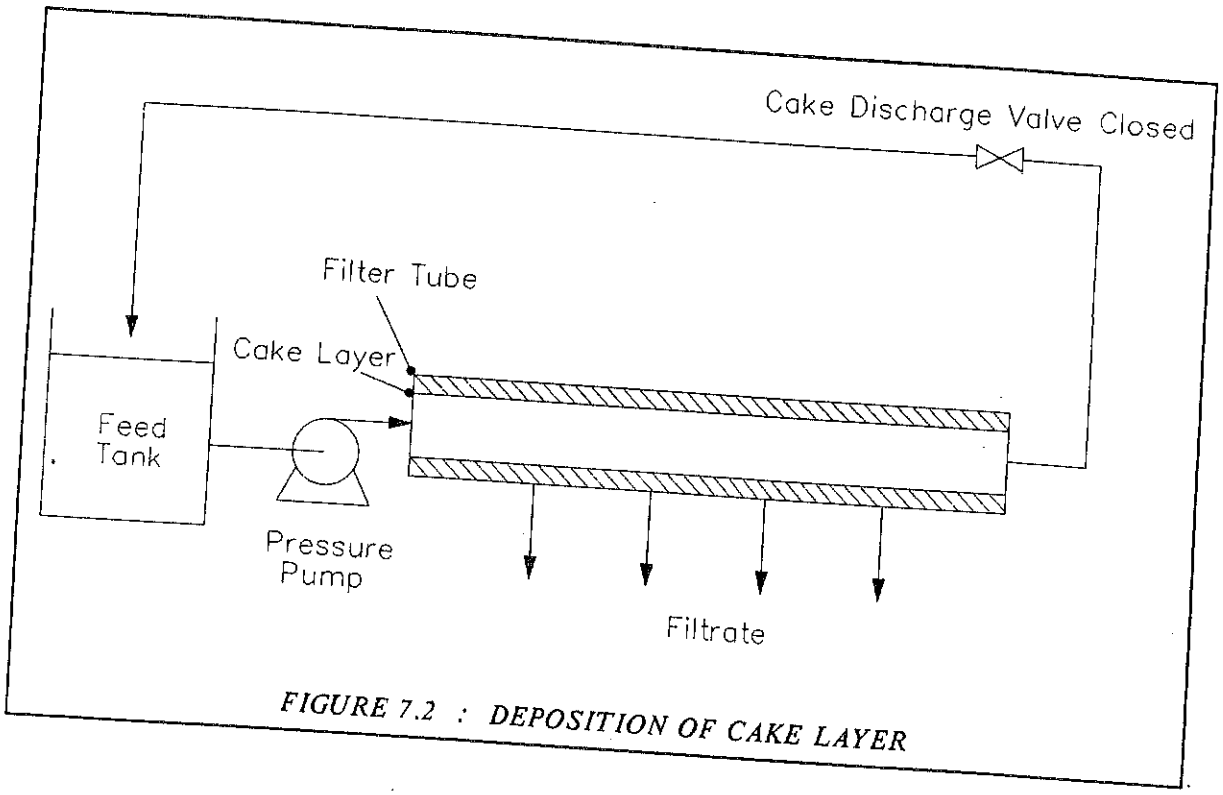

FIGURE 7.2 : DEPOSITION OF CAKE LAYER

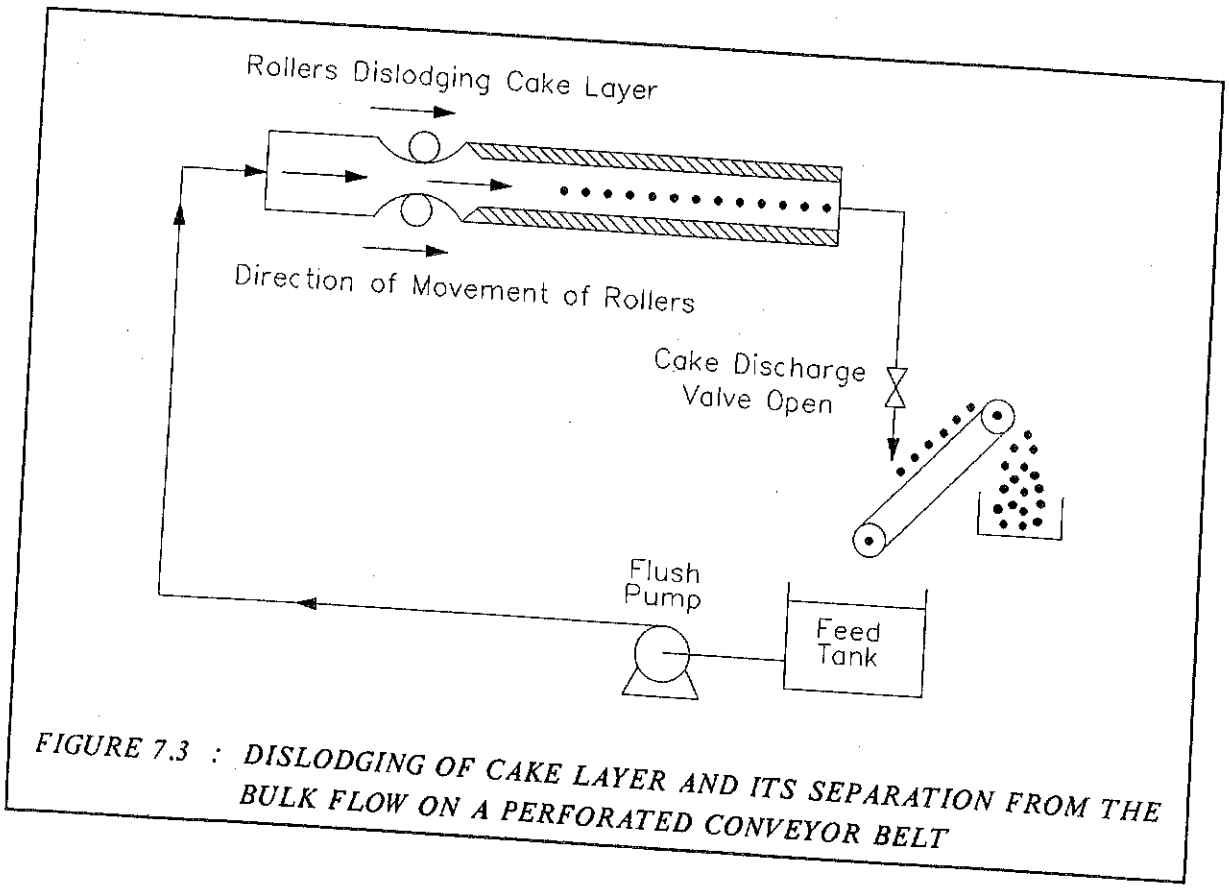

FIGURE 7.3 : DISLODGING OF CAKE LAYER AND ITS SEPARATION FROM THE BULK FLOW ON A PERFORATED CONVEYOR BELT

The process operation is cyclic; each cycle consists of a cake deposition stage (typically lasting 10 to 60 min depending on the feed sludge concentration) and a cake removal stage (typically 2 to 3 min). Feed sludge is pumped under level control into the feed tank, filtrate is returned under gravity to the head of the works and the cake is deposited in a trailer prior to dumping.

The entire process is micro-processor controlled and requires a minimum of operator attention.

7.3 DESIGN OF A TUBULAR FILTER PRESS

7.3.1 Design Equations for Cake Formation

(i) *Definition and Estimation of Specific Cake Resistance*

From the Carman-Kozeny equation for flow through packed beds an expression for the flow rate of filtrate through a filter cake may be determined :-

$$\frac{dt}{dV} = \frac{\mu \alpha w}{A^2 P}(V + Ve) \qquad (1)$$

where t = filtration time, s.
V = filtrate volume, m^3.
μ = filtrate viscosity, Pa.s.
α = specific cake resistance, m/kg.
w = feed slurry suspended solids concentration, kg/m^3
A = filter area, m^2.
P = filtration pressure, Pa.
Ve = equivalent filtrate volume, m^3
(i.e. the volume of filtrate that will deposit a cake of the same resistance as the filter cloth).

Assuming that the cloth resistance is very much lower than the cake resistance, Ve may be ignored. Equation (1) then reduces to :-

$$\frac{dt}{dV} = \frac{\mu \alpha w}{A^2 P}.V \qquad (2)$$

The specific cake resistance may be determined from the slope of a plot of $\frac{dt}{dV}$ against V using the results from a constant pressure filtration experiment.

The effect of pressure on specific cake resistance is given by equation (3) :-

$$\alpha = \alpha_o P^s \qquad (3)$$

where α_o = specific cake resistance at unit pressure.
s = compressibility coefficient.

(ii) *Estimation of Filtration Time*

The time to filter any volume V may be determined by integrating equation (2) to give :-

$$t = \frac{\mu \alpha w}{2A^2 P} . V^2 \qquad (4)$$

(iii) *Estimation of Cake Deposition Time*

If :-

M_d = Mass of dry filter cake solids deposited per unit filtration area, kg/m².

t_d = Time to deposit a mass, M_d, of filter cake, s.

and

$$M_d = \frac{Vw}{A} \qquad (5)$$

Then after substituting equation (5) in equation (4) :-

$$t_d = \frac{\mu \alpha}{2P} . \frac{M_d^2}{w} \qquad (6)$$

From equation (6) the time to deposit any cake mass, M_d, from a feed slurry with solids concentration, w, may be determined.

(iv) *Estimation of Cake Production Rate*

As a result of the cake removal and recovery process a fraction of the cake layer is reslurried. The fraction reslurried is dependent on the degree of cohesion of the cake solids and the degree of agitation in the recovery process.

If :-

M_r = Mass of dry filter cake solids recovered per unit filtration area, kg/m².

R = Fraction of the cake layer recovered from the tubes.

Then

$$R = \frac{M_r}{M_d} \qquad (7)$$

The steady-state concentration of solids fed to the filter is greater than the concentration of solids in the feed to the plant as a result of the partial re-slurrying of the cake. Assuming the volume of filtrate in the cake is negligible the steady-state solids concentration of the feed tank increases such that :-

$$w = \frac{w_i}{R} \tag{8}$$

where w_i = solids concentration in the feed to the plant, kg/m^3.

The cake production rate, J_s, may now be determined :-

$$J_s = \frac{M_d . R . 3600}{(t_d + t_c)} \tag{9}$$

where J_s = mass dry solids produced per unit filtration area and per unit time, kg/m^{2}h.

t_c = time to clean tubes, s.

The liquid treatment rate may similarly be determined :-

$$J = \frac{M_d . 3,6 \times 10^6}{w(t_c + t_d)} \tag{10}$$

where J = average filtrate flux, ℓ/m^{2}h.

(v) *Process Optimisation*

The cake production rate (J_s) may be optimised with respect to the cake mass deposited by differentiating equation (9) with respect to t_d. The mass deposited (M_d) in equation (9) is written in terms of t_d using equation (6). At the maximum cake production rate :-

$$\frac{dJ_s}{dt_d} = 0$$

At this point for constant specific cake resistance, viscosity, concentration and pressure it may be shown that :-

$$t_d = t_c \tag{11}$$

The maximum theoretical production rate may therefore be estimated from equation (9) for any given values of P, w, α, μ, R and t_c by adjusting M_d until equation (11) is satisfied.

The effect of M_d on J_s is plotted in Figure 7.4 showing the maximum occurs when equation (11) is satisfied.

Note:

1. It has been found that the value of R is fixed for any given cake type and operating pressure provided the cake thickness is in excess of approximately 1 mm.

$$w = \frac{w_i}{R} \tag{8}$$

where w_i = solids concentration in the feed to the plant, kg/m^3.

The cake production rate, J_s, may now be determined :-

$$J_s = \frac{M_d . R . 3600}{(t_d + t_c)} \tag{9}$$

where J_s = mass dry solids produced per unit filtration area and per unit time, kg/m^{2}h.

t_c = time to clean tubes, s.

The liquid treatment rate may similarly be determined :-

$$J = \frac{M_d . 3,6 \times 10^6}{w(t_c + t_d)} \tag{10}$$

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$$t_d = t_c \tag{11}$$

The maximum theoretical production rate may therefore be estimated from equation (9) for any given values of P, w, α, μ, R and t_c by adjusting M_d until equation (11) is satisfied.

The effect of M_d on J_s is plotted in Figure 7.4 showing the maximum occurs when equation (11) is satisfied.

Note:

1. It has been found that the value of R is fixed for any given cake type and operating pressure provided the cake thickness is in excess of approximately 1 mm.

2. The maximum value of M_d is limited to a cake mass which will not block the filter tube. The maximum value is a function of the wet cake solids density and the tube diameter and can be increased by increasing the tube diameter.

3. The minimum value of M_d is governed by the degree of cohesion of the cake. An excessively thin cake layer (less than 1 mm) will result in a high degree of cake re-slurrying and a low cake recovery (R).

4. The value of t_c is timed by the maximum rate at which solids can be conveyed out of the tubes without causing a blockage.

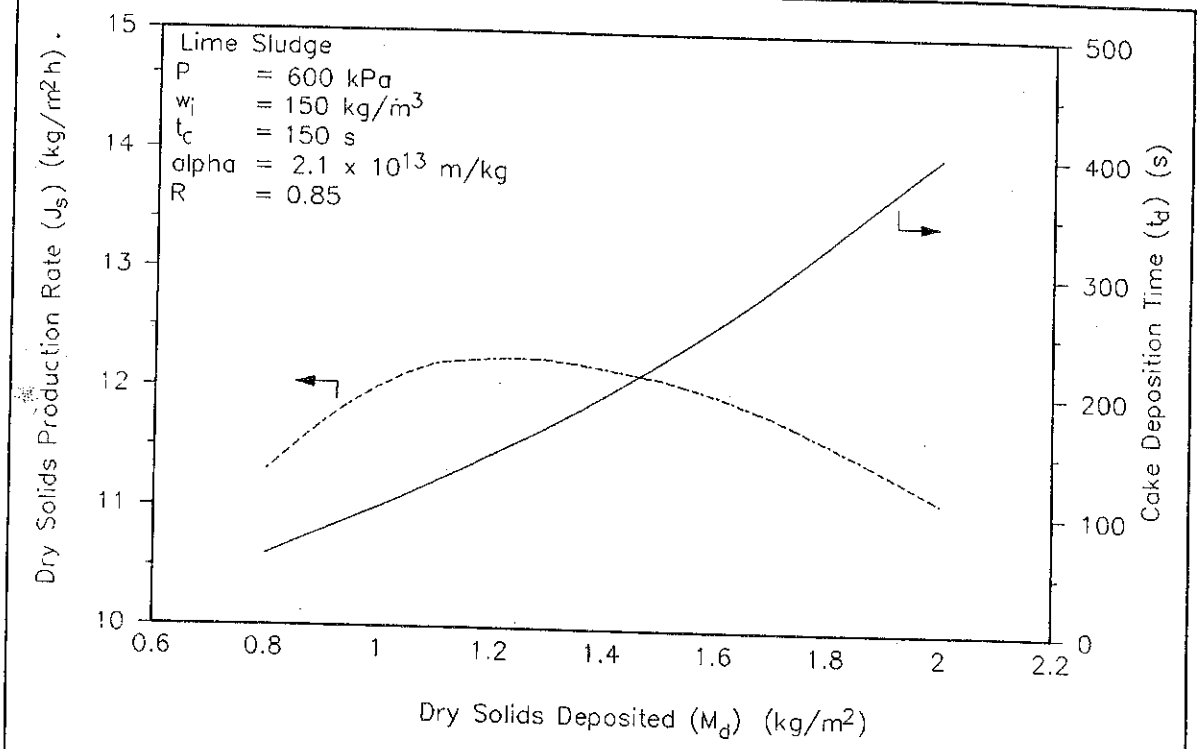

FIGURE 7.4 : DETERMINATION OF THE OPTIMUM CAKE MASS

(vi) *Estimation of Power Requirements for Cake Formation*

The power required to form a cake is dependent on the filtration pressure, the feed solids concentration and the pump efficiency and may be shown to be as follows :-

$$Power\ for\ cake\ formation = \frac{P}{w_i . 3600 . Efficiency} kWh/ton \qquad (12)$$

7.3.2 Design Equation for Cake Removal

(i) *Pressure Velocity Relationship*

The cake is removed from the surface of the filter tubes, in the low pressure area between the rollers, by the shearing action of the slurry as it passes through the roller gap. The actual velocity and pressure required to dislodge the cake is dependent on the degree of adhesion of the cake to the cloth and must be determined experimentally. The pressure and velocity relationship at the roller throat may be derived using Bernoulli's equation adapted for the tubular filter press process.

$$P_1 = P_2 + \frac{\rho u_2^2}{2} - \frac{\rho u_1^2}{2} \qquad (13)$$

$$P_2 = P_0 + 2 f_d (L - x) u_0 \qquad (14)$$

$$u_2 = \left(\frac{Q_c - J_c . \pi . x}{3,6 . 10^6} \right) . \frac{4}{\pi . d^2} \qquad (15)$$

where P_0 = system back pressure, Pa.
P_1 = pressure at roller throat, Pa.
P_2 = pressure upstream of rollers, Pa.
u_0 = velocity at tube outlet, m/s.
u_1 = velocity at roller throat, m/s.
u_2 = velocity upstream of rollers, m/s.
ρ = slurry density, kg/m^3.
L = total tube length, m.
x = cleaned tube length, m.
f_d = friction factor downstream of rollers.
J_c = flux on cleaned tube, ℓ/m^{2}h.
Q_c = flow rate into tube, m^3/s.
d = tube diameter, mm.

Equations (13), (14) and (15) may be used to determine the pressure profile at the roller gap as the rollers pass down the length of the tubes for a given roller gap setting, fluid flow, fluid viscosity and system back pressure. An example of this pressure profile is given in Table 7.1 for the following condition :-

Roller gap	=	2,5 mm.
Tube diameter	=	25 mm.
Velocity of tube inlet	=	1,8 m/s.
Filtrate flux on clean tube	=	200 ℓ/m^{2}h.
Slurry viscosity	=	0,003 Pa.s.
Cake thickness	=	3 mm.
Outlet pressure	=	10 kPa.

(ii) *Estimation of Power Required for Cake Removal*

The power required to remove a cake is dependent on :-

a) the carriage speed,
b) the tube inlet pressure,
c) fluid flow rate,
d) pump efficiency

and may be shown to be as follows :-

$$Power\ for\ cake\ removal = \frac{Q_c . P_c . 1000}{v . \pi . d . M_r . Efficiency}\ kW/h/ton \qquad (16)$$

where Q_c = flow rate per tube during cleaning, m^3/s.
P_c = cleaning pump pressure, Pa.
v = carriage speed, m/h.

TABLE 7.1
THE ESTIMATED PRESSURE AT THE ROLLER THROAT AT VARIOUS POSITIONS DOWN THE TUBE LENGTH

Distance along tube m	Velocity in throat m/s	Pressure gauge in throat kPa
1	12,73	10,5
2	12,66	1,7
3	12,59	-6,9
4	12,52	-15,4
5	12,45	-23,6
6	12,38	-31,6
7	12,31	-39,5
8	12,24	-47,2
9	12,17	-54,7
10	12,10	-62,0

7.3.3 Unit Sizing and Process Optimisation

For each set of operating conditions there will be a maximum value of cake mass, M_d, determined from equations (11) and (6). The allowable minimum and maximum values of M_d must be determined experimentally for a given sludge. As a guideline, based on the experimental data, Table 7.2 gives the minimum and maximum values of M_d for various types of sludge for 25 mm diameter tube (estimated data for 40 mm tubes is also included).

TABLE 7.2
MINIMUM AND MAXIMUM VALUES OF CAKE MASS DEPOSITED FOR VARIOUS TYPES OF SLUDGE AND TWO TUBE DIAMETERS

	Sludge type	Tube diameter 25 mm		Tube diameter 40 mm	
		M_d min	M_d max	M_d min	M_d max
1	Water works Alum and ferric sludges Low organic waters	0,50	1,00	0,50	2,00
2	Water works Alum and ferric sludges High organic and coloured waters	0,25	0,50	0,25	1,00
3	Water works and industrial Lime sludges	1,00	2,00	1,00	4,00
4	Mineral processing Scrubber sludges	1,00	2,00	1,00	4,00
5	Mining operation sludges	1,25	2,50	1,25	5,00

The effect of each of the operating variables (pressure, feed concentration, specific cake resistance and cake recovery) on the filter cake production rate is presented in Figures 7.5 to 7.8. The individual production rates have been maximised with respect to cake mass using equations (11), (6) and (9), subject to the constraint that the cake mass has been kept between the limits given in Table 7.2.

These figures show that the production rate is most significantly effected by the feed concentration and the specific cake resistance. Pressure (for a compressible cake), cake mass and cake recovery (within normal limits) do not have a significant effect on process performance and can be selected to suit the most economic selection of equipment.

7.4 OPERATION OF A TUBULAR FILTER PRESS

Operating instructions for a semi-technical pilot plant are given in **Appendix 7.3** and **7.4**. Laboratory studies have been undertaken on a variety of municipal and industrial sludges **(Appendices 5.1, 5.2, 5.3 and 5.6)**. The results of the test work and the process design constants for each sludge are presented in Table 7.3.

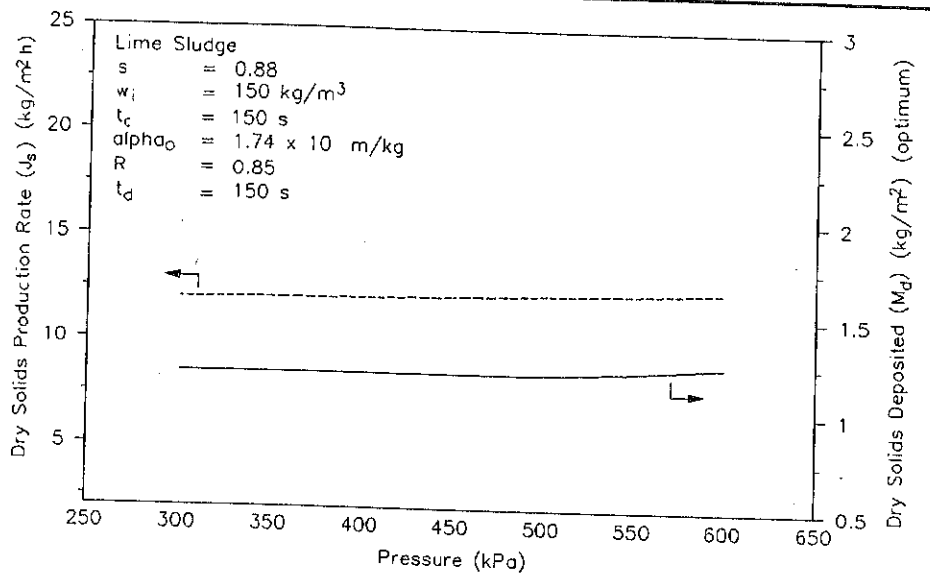

FIGURE 7.5 : THE EFFECT OF PRESSURE ON CAKE PRODUCTION RATE

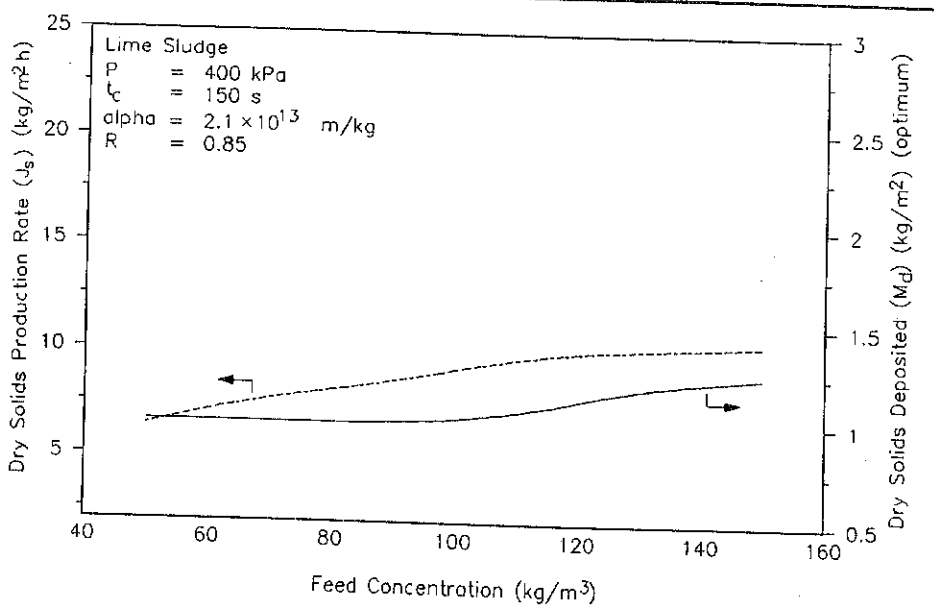

FIGURE 7.6 : THE EFFECT OF SLUDGE CONCENTRATION ON CAKE PRODUCTION RATE

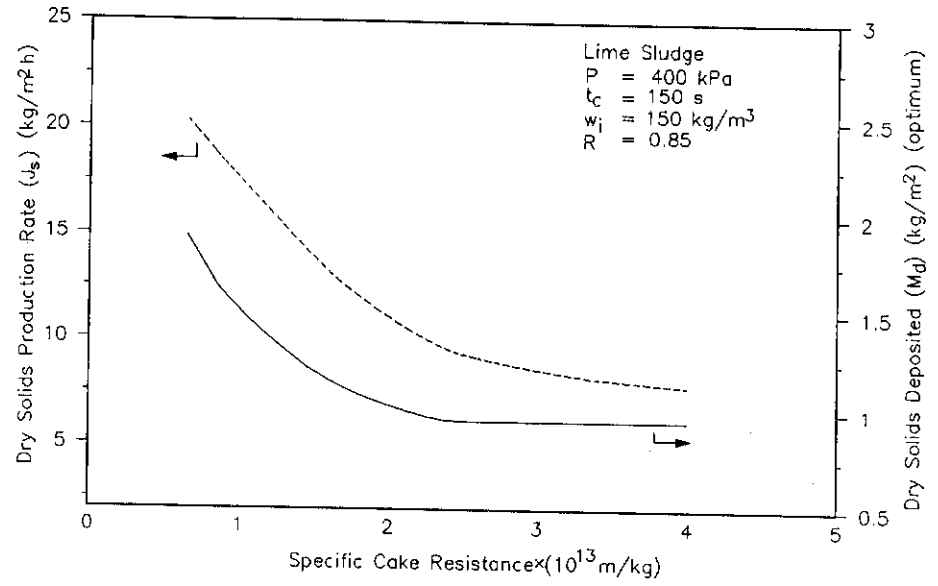

FIGURE 7.7 : THE EFFECT OF SPECIFIC CAKE RESISTANCE ON CAKE PRODUCTION RATE

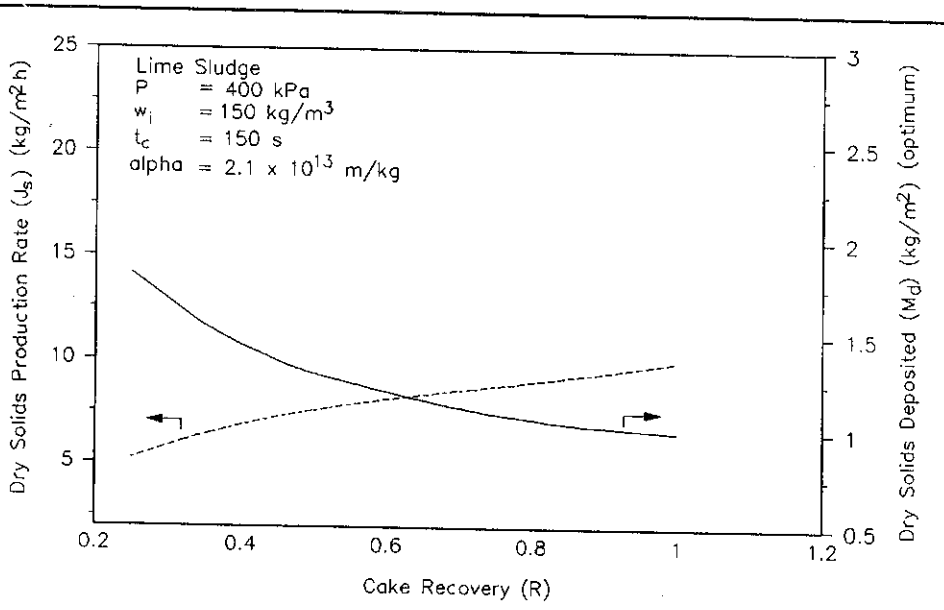

FIGURE 7.8 : THE EFFECT OF CAKE RECOVERY ON CAKE PRODUCTION RATE

TABLE 7.3

TUBULAR FILTER PRESS LABORATORY TEST RESULTS AND PROCESS DESIGN PARAMETERS FOR MUNICIPAL AND INDUSTRIAL SLUDGES

Sludge source	Sludge type	Spec cake resist α m/kg	Initial feed conc. w_i kg/m^3	Cake solids conc. % (m/m)	Cake recovery R -	Cake mass recover M_r kg/m^2	Cake mass deposit M_d kg/m^2	Feed conc. w kg/m^3	Cake form time t_d min	Cake prodn rate J_s kg/m^{2}h	Liquid filtn rate J l/m^{2}h
Iron scrubber	Iron ore	$4{,}9 \times 10^{11}$	15	53	0,20	0,32	2,00	75	0,5	7,88	132
Quarry	Quartz	$1{,}2 \times 10^{12}$	20	76	0,10	0,40	4,00	200	2,0	5,41	270
Mineral process	Uranium recovery	$1{,}5 \times 10^{12}$	40	29	0,60	0,80	1,33	67	0,8	14,40	360
Scrubber	Gold process	$1{,}7 \times 10^{12}$	200	60	0,90	1,80	2,00	222	0,6	34,60	173
Mine	Underground	$2{,}1 \times 10^{12}$	100	43	0,60	1,40	2,33	167	1,4	21,38	214
Scrubber	Titanium process	$2{,}3 \times 10^{12}$	190	59	0,95	1,60	1,68	200	0,7	30,19	159
Mine	Underground	$3{,}0 \times 10^{12}$	100	45	0,60	1,70	2,83	167	3,0	18,51	185
Mineral process	Gold recovery	$1{,}8 \times 10^{13}$	20	19	0,65	0,50	0,77	31	7,0	3,15	157
Power station	Lime	$1{,}9 \times 10^{13}$	42	42	0,80	1,50	1,88	53	27,0	3,10	74
Water works	Lime	$2{,}1 \times 10^{13}$	90	40	0,85	1,50	1,76	106	12,9	5,83	65
Water works	Poly-alum chloride	$2{,}8 \times 10^{13}$	52	32	0,68	0,75	1,10	76	9,0	3,32	74
Water works	Poly-electrolyte	$3{,}0 \times 10^{13}$	15	30	0,75	0,65	0,87	20	23,5	1,50	100
Water works	Poly-electrolyte bentonite	$4{,}1 \times 10^{13}$	30	24	0,70	0,70	1,00	43	20,0	1,86	47
Water works	Ferric hydroxide	$4{,}5 \times 10^{13}$	30	32	0,77	0,73	0,95	39	21,0	1,82	61
Water works	Alum	$4{,}9 \times 10^{13}$	42	36	0,83	0,60	0,72	51	10,5	2,79	66
Water works	Ferric hydroxide algae	$5{,}4 \times 10^{13}$	5	17	0,67	0,32	0,48	8	32,0	0,56	103
Water works	Alum coloured water	$8{,}9 \times 10^{13}$	35	20	0,87	0,35	0,40	40	7,5	2,11	60
Water works	Alum coloured water	$1{,}6 \times 10^{14}$	15	12	0,90	0,30	0,33	17	21,7	0,74	50
Water works	Alum coloured water	$1{,}7 \times 10^{14}$	6	12	0,92	0,22	0,24	7	30,3	0,40	67

Operating pressure : 400 kPa for all tests ; Cleaning time : 2,5 min for all tests

Two of the nineteen sludges tested (the quarry sludge and the iron reduction scrubber sludge) produced cakes with a low cohesive strength, resulting in a low cake recovery and a correspondingly high degree of concentration in the feed tank.

The remaining sludges produced a cohesive cake at a solids concentration comparable with other sludge dewatering processes. The production rates given in Table 7.3 were determined in the laboratory for a particular set of operating conditions and are not necessarily the optimum.

7.5 CONCLUSIONS

The wide range of laboratory test work undertaken indicates that the tubular filter press process has wide application in the water treatment and general process industry. The theory of the process has been developed to the extent that a full scale unit may be sized and optimised from a simple set of laboratory experiments.

The specific cake resistance of the sludges investigated ranged from 4,9 x 10^{11} m/kg to 1,6 x 10^{14} m/kg. The cake solids concentration ranged from 12 % to 75 %. The highest specific cake resistance sludges produced the lowest solids content cakes. The cake production rates (dry solids basis) varied from 0,56 kg/m^{2}h for a very dilute algal water dosed with ferric hydroxide to 34,6 kg/m^{2}h for scrubber sludge from a gold recovery process.

A lime sludge resulting from the treatment of raw water was used as an example to illustrate the effect of changes in the operating conditions of the tubular filter press. The operating pressure was seen to have a small effect on filter cake production rate. Increases in the feed solids concentration has almost a linear effect on the filter cake production rate. The specific cake resistance has a strong inverse effect on the filter cake production rate. Reducing the fraction of cake recovered has the obvious effect of reducing the filter cake production rate.

7.6 NOMENCLATURE

d = Tube diameter, mm.
f_d = Friction factor downstream of rollers.
J_c = Flux on cleaned tube, ℓ/m^{2}h.
L = Total tube length, m.
M_d = Mass of dry filter cake solids deposited per unit filtration area, kg/m^2.
M_r = Mass of dry filter cake solids recovered per unit filtration area, kg/m^2.
P = Pressure of filtration, Pa.
P_0 = System back pressure, Pa.
P_1 = Pressure at roller throat, Pa.
P_2 = Pressure upstream of rollers, Pa.
P_c = Cleaning pump pressure, Pa.
Q_c = Flow rate into tube, m^3/s.

R = Fraction of the cake layer recovered from the tubes.
S = Compressibility coefficient.
t = Filtration time, s.
t_c = Time to clean tubes, s.
t_d = Time to deposit a mass, M_d, of filter cake, s.
u_0 = Velocity at tube outlet, m/s.
u_1 = Velocity at roller throat, m/s.
u_2 = Velocity upstream of rollers, m/s.
v = Carriage speed, m/h.
V = Filtrate volume, m^3.
Ve = Equivalent filtrate volume, m^3
(i.e. volume of filtrate which will deposit a cake with the same resistance as the filter cloth).
w = Feed slurry solids concentration to filter tubes, kg/m^3.
w_i = Solids concentration in the feed to the plant, kg/m^3.
x = Cleaned tube length.

α = Specific cake resistance, m/kg.
α_o = Specific cake resistance at unit pressure, m/kg.
μ = Filtrate viscosity, Pa.s.
ρ = Slurry density, kg/m^3.

8 LIST OF PUBLICATIONS

During the course of these two projects a total number of 9 publications and 13 conference proceedings have arisen. A patent 87/0553 has been issued and is lodged with the Water Research Commission.

8.1 PUBLICATIONS

1. GROVES, G.R. BUCKLEY, C.A., SIMPSON, M.P., BINDOFF, A.L., TREFFRY-GOATLEY, K., ORBIN, A., NEYTZELL-DE WILDE, F.G. and DAVIES, C.J., 'Microfiltration Applications in the Treatment of Industrial Effluents', Proc. Symposium on Forest Products Research International - Achievements and the Future, CSIR, Pretoria, South Africa, April 1985. ISBN 0 7988 3375 0.

2. TREFFRY-GOATLEY, K., BINDOFF, A.M. and BUCKLEY, C.A., 'The Potential of Cross-flow Microfiltration for Improving Anaerobic Digester Performance', Proc. Anaerobic Digestion Symposium, University of Orange Free State, Bloemfontein, South Africa, 22nd-24th September 1986. ISBN 0 86886 276 2.

3. TREFFRY-GOATLEY, K., BUCHAN, M.I., RENCKEN, G.E., VOORTMAN, W.J. and BUCKLEY, C.A., 'The Dewatering of Sludges Using a Tubular Filter Press', Desalination, 67, pp. 467-479, 1987.

4. TREFFRY-GOATLEY, K., BUIJS, K.R., BINDOFF, A.M. and BUCKLEY, C.A., 'The Cross-flow Microfiltration of Problematic Surface and River Waters to Produce Potable Water', Desalination, 67, pp. 439-453, 1987.

5. HUNT, J.W., BROUCKAERT, C.J., RAAL, J.D., TREFFRY-GOATLEY, K., and BUCKLEY, C.A., 'The Unsteady-State Modelling of Cross-flow Microfiltration', Desalination, 64, pp. 431-442, 1987.

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7. TREFFRY-GOATLEY, K., BUCHAN, M.I., RENCKEN, G.E. and BUCKLEY, C.A., 'The Application of a Newly Developed Tubular Filter Press to the Dewatering of a Waterworks Sludge', Journal of the Institution of Water and Environmental Management, 2(4), pp. 376-382, August 1988.

8. BINDOFF, A.M., TREFFRY-GOATLEY, K., FORTMANN, N.E., HUNT, J.W. and BUCKLEY, C.A., 'The Application of Cross-flow Microfiltration Technology to the Concentration of Sewage Works Sludge Streams', Journal of the Institution of Water and Environmental Management, 2(5), pp. 513-522, October 1988.

9. TREFFRY-GOATLEY, K., RENCKEN, G.E. and BUCKLEY, C.A., 'Sizing and Optimisation of the Tubular Filter Press Process for Dewatering Municipal and Industrial Sludges', Water Institute of Southern Africa, 1st Biennial Conference, Cape Town, March 1989.

8.2 CONFERENCE PROCEEDINGS

1. COX, J.M. and GROVES, G.R., 'Cross-flow Filtration of Polyester - Dyeing Effluents', IAWPR Conference, Cape Town, 1982.

2. GROVES, G.R., BUCKLEY, C.A., SIMPSON, M.P.J., BINDOFF, A.L., TREFFRY-GOATLEY, K., ORBIN, A., NEYTZELL-DE WILDE, F.G. and DAVIES, C.J., 'Microfiltration Applications in the Treatment of Industrial Effluents', Symposium on Forest Products Research International - Achievements and the Future, CSIR, Pretoria, South Africa, April 1985.

3. TREFFRY-GOATLEY, K., GROVES, G.R. and BUCKLEY, C.A., 'The Application of a Cross-flow Microfiltration Unit to the Thickening of Water Works Alum Sludge, and Sewage Works Waste Activated Sludge', Institute of Water Pollution Control, Biennial Conference, Durban, South Africa, 27th-30th May 1985.

4. K. TREFFRY-GOATLEY, K., BUIJS, K.R. and BUCKLEY, C.A., 'Cross-flow Microfiltration for Drinking Water', Seminar on Technology Transfer in Water Supply and Sanitation in Developing Areas - Bophuthatswana International Water Supply Association/CSIR-S265) Mafeking, Bophuthatswana, June 1986.

5. TREFFRY-GOATLEY, K., BUIJS, K.R. and BUCKLEY, C.A., 'Surface Water Purification Using a Cross-flow Microfilter', Seminar on Technology Transfer in Water Supply and Sanitation in Developing Areas - Bophuthatswana International Water Supply Association/CSIR - S265) Mafeking, Bophuthatswana, June 1986.

6. TREFFRY-GOATLEY, K., BINDOFF, A.M. and BUCKLEY, C.A., 'The Potential of Cross-flow Microfiltration for Improving Anaerobic Digester Performance', Anaerobic Digestion Symposium, University of Orange Free State, Bloemfontein, South Africa, 22nd-24th September 1986.

7. TREFFRY-GOATLEY, K., BINDOFF, A.M., HUNT, J.W. and BUCKLEY, C.A., 'The Application of Cross-flow Microfiltration Technology to the Concentration of Sewage Works Sludge Streams', Institute of Water Pollution Control Biennial Conference, Port Elizabeth, South Africa, 12th-15th May 1987.

8. TREFFRY-GOATLEY, K., RICHARDS, G.W.*, RENCKEN, G.E.* and BUCKLEY, C.A., 'The Tubular Filter Press Process for Dewatering Water Works Sludges. Description and Results of a Prototype Unit', Institute of Water Pollution Control Biennial Conference, Port Elizabeth, South Africa, 12th-15th May 1987.

9. TREFFRY-GOATLEY, K., BUCHAN, M.I., RENCKEN, G.E., VOORTMAN, W.J. and BUCKLEY, C.A., 'The Dewatering of Sludges Using a Tubular Filter Press', 3rd World Congress on Desalination and Water Reuse, Cannes, France, 14th-17th September 1987.

10. TREFFRY-GOATLEY, K., BUIJS, K.R., BINDOFF, A.M. and BUCKLEY, C.A., 'The Cross-flow Microfiltration of Problematic Surface and River Waters to Produce Potable Water', 3rd World Congress on Desalination and Water Reuse, Cannes, France, 14th-17th September 1987.

11. HUNT, J.W., BROUCKAERT, C.J., RAAL, J.D., TREFFRY-GOATLEY, K., and BUCKLEY, C.A., 'The Unsteady-State Modelling of Cross-flow Microfiltration', 3rd World Congress on Desalination and Water Reuse, Cannes, France, 14th-17th September 1987.

12. TREFFRY-GOATLEY, K., BUCHAN, M.I., RENCKEN, G.E., and BUCKLEY, C.A., 'The Tubular Filter Press. A Locally Developed Alternative for Sludge Dewatering', 5th National Meeting of SAIChE, Pretoria, August 1988.

13. BINDOFF, A.M., TREFFRY-GOATLEY, K., FORTMANN*, N.E. and BUCKLEY, C.A., 'Upgrading of Municipal Anaerobic Digesters and Activated Sludge Processes through the Use of Cross-flow Microfiltration', CSIR/WISA/WRC/DWA Symposium on Sludge Handling, Pretoria, November 1988.

8.3 THESIS

1. HUNT, J.W., 'Mathematical Modelling of Cross-flow Microfiltration', Thesis M.Sc. Eng., 1987.

8.4 PATENTS

DEWATERING SLURRIES			
Country	Application No.	Filing Date	Status
South Africa	87/0553	26-1-87	Granted - in force
Argentina	306647	30-1-87	Pending
Australia	589 736	28-1-87	Granted - awaiting issue
Brazil	PI8700441	30-1-87	Pending
Canada	528,510.1	29-1-87	Pending
Europe	87300819.7	30-1-87	Pending
India	68/DEL/87	29-1-87	Granted
Japan	62-18811	30-1-87	Pending
Germany	P3702507.4	28-1-87	Pending
Mexico	5100	30-1-87	Pending
UK	2 185 906	30-1-87	Granted - 18 April 1990
USA	4770793	28-1-87	Granted

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