



ELSEVIER

Desalination 204 (2007) 241–254

DESALINATION

www.elsevier.com/locate/desal

Integrated membrane solutions for green textile industries

N.M.H. ElDefrawy*, H.F. Shaalan*

Chemical Engineering and Pilot Plant Department, National Research Centre, Egypt
Tel. +20 (2) 3371433; Fax +20 (2) 3370931; email: nihaldefrawy@yahoo.com, hayam64@hotmail.com

Received 7 February 2006; accepted 15 March 2006

Abstract

Textile industry utilizes thousands of tons of various chemicals for wet and dry processing. Effluents from wet processing, for instance, are characterized by the presence of coloring, hazardous and toxic pollutants. Numerous studies indicated several opportunities for membrane based interventions for reuse/recovery of water and chemicals. This work is concerned with the proposal of a hybrid treatment–recycling approach for decision making in the textile industry. This approach comprises the segregation of wastewater streams and the selection of the treatment–recycling scheme on the basis of reported performance data and updated cost indicators using a program tailored for this purpose. The program is validated for several scenarios representing typical actual scenarios from the textile industry. Results indicate that the use of membrane systems within the treatment–recycling scheme reduces the wastewater treatment cost through the recovery of chemicals and water. Further, the developed program proved to be sound software for decision making in the textile industry.

Keywords: Textile industry; Membrane separation; Techno economics; Hazardous chemicals

1. Introduction

Textile industry is characterized by the intensive use of water and wide spectrum of processing chemicals. Consequently, textile industrial effluents are characterized by high chemical oxygen

demand (COD) and the presence of non biodegradable components such as dyes, pigments and some types of newly introduced sizing polymers or chemicals. The presence of heavy metals may be also encountered in numerous situations. Physicochemical treatment [1–4], anaerobic [5,6] or aerobic [1,4,7] biological treatment has been in use for management of end- of pipe- effluent. The

*Corresponding authors.

Presented at EuroMed 2006 conference on Desalination Strategies in South Mediterranean Countries: Cooperation between Mediterranean Countries of Europe and the Southern Rim of the Mediterranean. Sponsored by the European Desalination Society and the University of Montpellier II, Montpellier, France, 21–25 May 2006.

presence of non biodegradable components led to the development of numerous oxidation techniques [8–12] for partial or total destruction of dyes and pigments. Also, reliance on modern adsorption systems [7,13] and metal chelating compounds has been suggested [1].

The rapid advancement of membrane separation schemes enabled numerous functions to be achieved within the total integrated management system of textile industrial wastewater. Microfiltration (MF) and ultrafiltration (UF) [14–16] permit significant volume reduction and also separation and recycling of useful chemicals such as synthetic sizing agents and some types of intermediate chemicals and dyestuff. The application of nanofiltration (NF) [13,17] and reverse osmosis (RO) [18,19] enables also size reduction, water and chemicals recycling in addition to waste minimization.

The availability of numerous commercially established technologies for the treatment and reuse avails a comprehensive choice matrix for the planner, designer and environmental experts. Further, the wide variability of manufacturing and operational practices within the textile manufacturing sector complicates the decision making and also the rapid costing of the numerous possible alternatives.

Two approaches are generally followed for the management of textile wastewater. The first approach capitalizes on the fulfillment of the requirements of the stringent environmental legislations. The second adopts reliance on maximum recycling and reuse with maximum savings to approach minimum possible discharge and consequently minimum cost directed to end- of the pipe-treatment. While those approaches are possible in some situations, the real life practice dictates merging of the two approaches taking into consideration the techno-economic profile of the textile industry sector in developing countries.

This paper presents a hybrid approach for the combined treatment and reuse for the appropriate management of textile industry effluent.

2. Current wastewater management practices in the textile sector

2.1. Treatment interventions

Effluents from textile industry are of complex composition and usually require more than a single treatment technology to achieve and maintain compliance with currently enforced environmental legislations. Current treatment interventions comprise physical treatment, physicochemical technologies and biological ones. Numerous treatment interventions include but not limited to the following

- Chemically enhanced primary treatment comprising coagulation, flocculation and sedimentation is used to treat organic dyes, pigments and insoluble dyes (sulfur, disperse and vat) [1–4].
- Degradation of refractory compounds using several oxidation/reduction technologies
 - Oxidizing agents such as calcium hypochlorite, hydrogen peroxide and ozone achieve high degree of decolorization by breaking down the dyestuff. Although this is not accompanied by significant reduction in COD, it increases wastewater biodegradability for biological treatment [11]. On the other hand, Fenton reagent is a powerful oxidizing agent resulting in rapid decolorization as well as COD reduction [1,12]. Further, electrochemical technology treats various classes of dyestuff to achieve biological oxygen demand (BOD), COD and color reduction as high as 90% [13,20].
 - Chemical reduction of azo dyes cause breakdown of the azo bond generating aromatic amines that are more amenable to aerobic biological treatment and activated carbon adsorption than the parent structure [13].
- Biological treatment
 - Aerobic
Textile effluents are moderately biodegradable; about 40–50 % color removal can

be expected due to biodegradation and adsorption of dyes on the flocculated sludge. Also COD removal is expected to reach 70%. A combination of physical-chemical and biological processes would be expected to remove more than 85% COD [7].

- Anaerobic
Although anaerobic treatment results in up to 90% decolorization of azo dyes through the cleavage of azo bond, dye metabolites cause reactor instability and deterioration in settlement [5,6].
- Adsorption
Activated carbon is used as a polishing step for the removal of color and COD. High removal rates (about 90%) occur for cationic, mordant and acid dyes and about 40% for sulfur, dispersed and reactive dyes [7].
- PACT treatment
Powdered activated carbon is added to the activated sludge process achieving high BOD, COD and color removal efficiencies depending on powdered activated carbon dose [13].

2.2. Membrane schemes

Membrane separation systems comprise MF, UF, NF, and RO. These systems may be operated individually or in hybrid form permitting efficient separation and recycling. Some significant previous endeavors are summarized below:

- UF systems are established for the recovery of polyvinyl alcohol (PVA) [14] (sizing agent), indigo dyes [15] and the purification of dilute caustic soda prior to evaporation [16].
- NF systems have been recently introduced to commercial practices for the removal of numerous pollutants such as COD, color and non biodegradable contaminants. The permeate stream is recycled to the appropriate point of use [17]. Also, the concentrate would be treated by a convenient method; for example wet air oxidation [13].
- RO systems find numerous applications in the recovery of both dyes and hot water in con-

tinuous dyeing [13] and as a polishing step for UF/NF permeate.

3. The proposed hybrid treatment–recycling approach

This work is concerned with the proposal of a hybrid treatment–recycling approach for decision making in the textile industry. It resolves the difficulties, at the planning level, arising from the wide variation of the current setting in different mills. It also enables identification of the basic capital required to enable the textile sector to qualify with requirements of applicable legislations. This approach comprises the segregation of wastewater streams and the selection of the treatment–recycling scheme on the basis of reported performance data and updated cost indicators using a program tailored for this purpose. The program is validated for several scenarios representing typical actual scenarios from the textile industry.

3.1. Elements of the proposed approach

3.1.1. Segregation of streams

The plant effluents are conceived as three principal separable streams as follows:

- a The preparation stream. This includes desizing, scouring, bleaching and mercerizing wastewater. The desizing stream is characterized by the presence of the chemicals generated through desizing process and accounts for more than 50% of pollution load.
- b The dyestuff loaded stream. This stream accommodates all the chemicals and dyes generated from the dye house operations; dyeing, rinsing and finishing streams.
- c The main carrier stream (other plant effluents). This stream accommodates principally effluents from service units such as water softening, boilers, condensate resulting from air humidification necessary for the spinning processes as well as municipal discharges.

3.1.2. Optimal treatment schemes

The proposed technology mix comprises treatment–recycling modules for the management of the three identified segregated streams as shown in Table 1.

The proposed hybrid treatment–recycling diagram is shown in Fig. 1.

3.1.3. Performance indicators for the proposed module

The main performance indicators as expressed by the percentage removal of the main pollutants for the selected treatment–recycling modules as well as their permissible discharge limits are shown in Table 2.

3.1.4. Updated cost indicators

The capital and operating cost indicators for the selected modules and recyclables are shown in Table 3. These are based on updated published cost norms and local Egyptian market prices.

3.1.5. The developed TEXPERT program

To come up with the main cost indicators pertinent to the proposed hybrid treatment–recycling scheme, a textile expert program (TEXPERT) has been developed on Excel spread sheet. This program enables the selection of the appropriate modules according to technical criteria involving wastewater characteristics, capacities, removal efficiencies and limiting quality criteria. The prog-

Table 1

The treatment and recycling technologies proposed for the three separate streams

Treatment	Stream		
	(F1) Preparation	(F2) Dye house	(F3) Other plant effluents
Reuse/recycle	Ultrafiltration	Nanofiltration	
In situ treatment		Partial oxidation	
Treatment	Biological treatment	Biological treatment	Biological treatment
	Dual media filtration	Dual media filtration	Dual media filtration
	Reverse osmosis	Reverse osmosis	Reverse osmosis
	Evaporation pond	Evaporation pond	Evaporation pond

Table 2

Typical performance indicators of the selected treatment modules and the permissible discharge limits [4,7,13,21–27]

Process	Removal efficiency (%)							Discharge limits		
	Biological treatment			Dual media filtration		Partial oxidation	Membrane system			
	Primary enhanced sedimentation	Aeration	Total	Typical	Default value		UF	NF	RO	
Item										
COD, mg/l	60	70	88	7–>47	30	20	98	90	90	100
BOD, mg/l	60	75	90	17–>54	30	+10		90	100	60
TSS*, mg/l	70	80	94	46–>98	90	+10	100	100	100	60
TDS**, mg/l	—	—	—	—	—	—	0	70	86–89	2000
Heavy metal, mg/l	30	15	40	80	80	20		100	100	1
Color, m ⁻¹	80	40	88	90	90	40		100	100	0
Recovery rate, %			99.9	100	100	100	90	70	80	—

*TSS = total suspended solids; **TDS = total dissolved solids

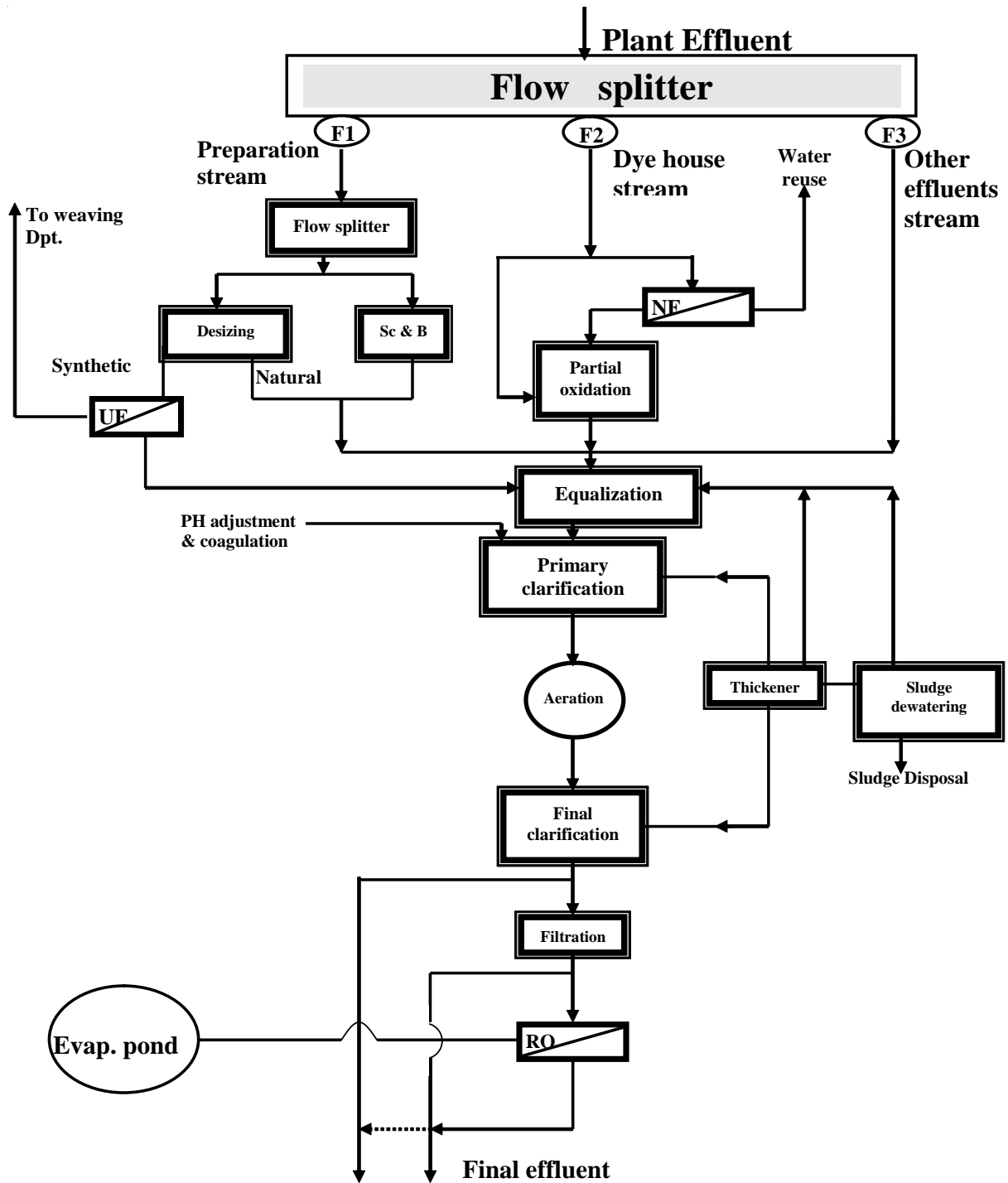


Fig. 1. Hybrid treatment–recycle diagram.

Table 3
Basis of cost estimates for the adopted treatment/ recovery scheme

Item/process	Cost US \$ ^a	Reference
1. Capital costs		
Biological treatment	$C = 15000 Q^{0.62}$	19
Dual media filtration	$C = 44.54 Q$	26, 27
Partial oxidation	$C = 211 Q^{0.67}$	Estimated
Evaporation pond	$C = 380 Q$	Estimated from current Egyptian market prices **
Ultrafiltration	$C = 5159 Q^{0.62}$	27, 28
Nanofiltration	$C = 405 Q^{1.0014}$	Estimated***
Reverse osmosis	$C = 477 Q^{1.0014}$	27, 28
2. O&M costs, US\$		
Biological treatment	0.25/m ³	19
Dual media filtration	0.01/m ³	26
Partial oxidation	0.08–0.2/m ³	Current Egyptian market price
Ultrafiltration	0.04–0.2/m ³	26
Nanofiltration	0.1/m ³	26, 28
Reverse osmosis	0.16–0.3/m ³	27, 28
Evaporation pond	0.02/m ³	Estimated
3. Depreciation		
Wastewater treatment (combined civil and electromechanical)	Years	
UF, NF, RO	40	
Dual media filtration	15	Excluding membrane replacement cost
Partial oxidation	20	
Evaporation pond	20	
4. Other costs, US\$		
PVA, kg	1.5	Current Egyptian market price
NF permeate water	0.2/m ³	Current Egyptian market price

Q : capacity (m³/d); C : US\$

^aCosts updated using Marshall & Swift index for year 2003 and updated using a yearly inflation rate 3% to year 2006

**This item varies considerably according to country, land site and labor cost

***85% of RO capital cost

ram further estimates the capital and operating costs and revenues for the selected integrated scheme. The logical approach of this program is shown in Fig. 2.

3.2. Validation of the developed program

The program have been validated for typical scenarios under varying conditions of wastewater characteristics.

4. Results and discussion

4.1. Input data of TEXPert program

The input data of TEXPert program are shown in Table 4. These include capacity, sizing material and wastewater characteristics for the proposed scenarios covering typical cases from the textile industry.

4.2. Testing and results of the TEXPert program

TEXPERT program has been tested for the following scenarios:

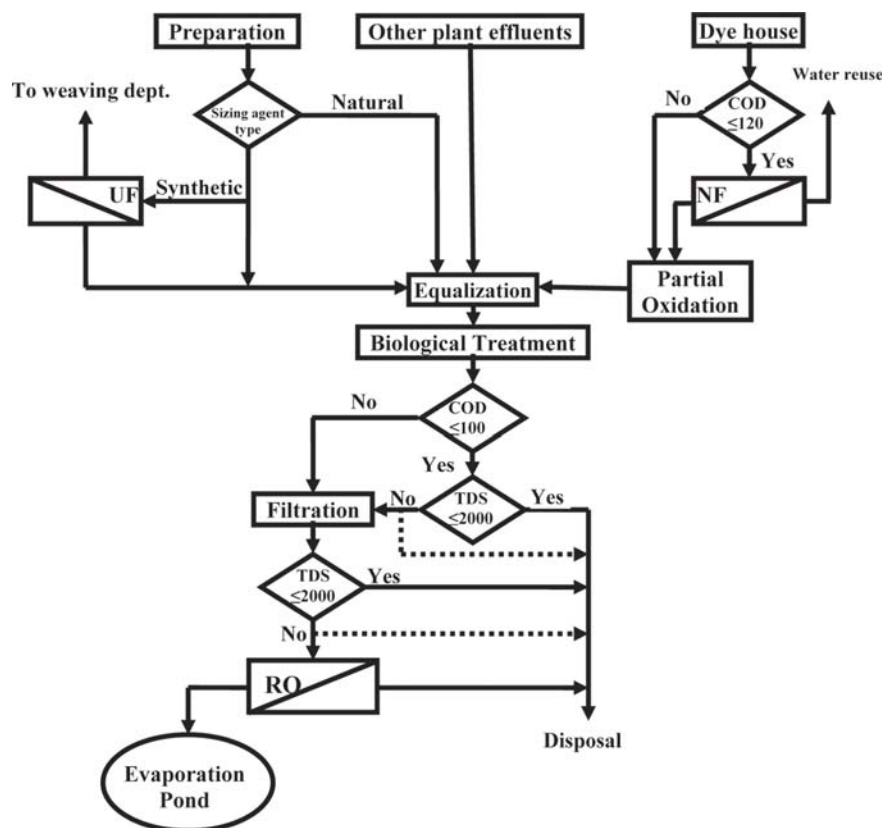


Fig. 2. The proposed logic diagram for the hybrid treatment–recycling approach.

Table 4
Wastewater characteristics of separate streams*

Item	Scenario I			Scenario II	Scenario III ^b		Scenario IV ^c	Scenario V ^c
	F1	F2	F3 ^a	F2	F1	Sc&B	F2	F2
Capacity, m ³ /d	8000	10000	15000	10000	450	7550	10000	10000
Sizing material: type and concentration, %	Starch 1.25%				PVA 1.25			
COD, mg/l	2500		250			640		
NCOD, ppm		120		900	808.9		900	900
BOD, mg/l	670	70	160	480	0.0	201	480	480
TSS, mg/l	255	120	160	520	4.8	285	520	520
TDS, mg/l	2020	3200	1560	3200	2020	2020	3200	5000
Heavy metal, mg/l	3.5	1.8	1	1.8	0	3.7	1.8	1.8
Color, m ⁻¹	0.0	250	20	1100	0	0	1100	1100

*Vertically integrated Egyptian textile facility with complex processing for cotton, wool, cotton and wool blends and polyesters

a: F3 is constant for all scenarios; b: F2 is similar to scenario I; c: F1 is similar to scenario III

- I Low non biodegradable COD (NCOD) and the presence of biodegradable sizing material (natural).
- II High NCOD, the presence of biodegradable sizing materials(natural) and permissible salinity .This scenario is feasible when dilute caustic soda (mercerization rinse) is reused after its concentration in evaporators
- III Low NCOD and synthetic sizing material (PVA).
- IV High NCOD and synthetic sizing material (PVA).

- V High NCOD, high salinity and synthetic sizing material (PVA).

The corresponding material balance of each scenario is shown in Fig. 3a–e. Cost output data are shown in Table 5 and summary of the outputs is shown in Table 6.

The financial indicators depicted in Table 6 reveal the following:

- The relative high unit wastewater treatment cost as depicted by scenarios I, II (being US\$ 0.322/m³ and US\$ 0.33 respectively). In spite of the elimination of the NF and RO from the

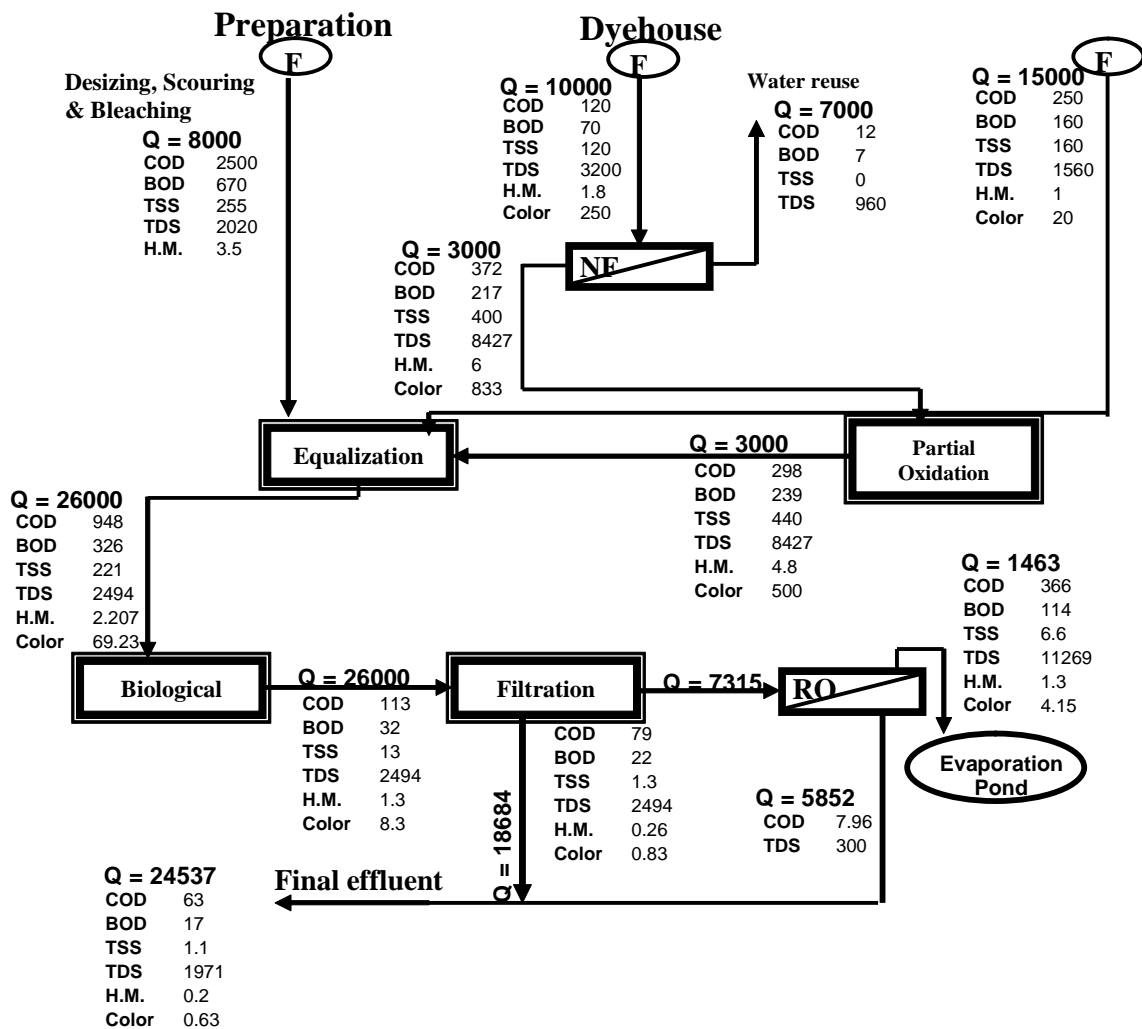


Fig. 3a. Material balance for the proposed treatment–reuse scenario I.

Table 5
Comparative financial indicators pertinent to alternative cases

Scenarios	Treatment module	Capacity (m ³ /d)	Capital cost (US\$ 1000)	O&M (US\$ 1000/y)	Depreciation (US\$ 1000/y)	Total annual* (US\$ 1000/y)	Revenue (US\$1000/y)	Net O&M (US\$1000/y)	Unit cost (US\$/m ³)	
I	Nanofiltration	7,000	2,870	210	200.9	410.91	420			
	Partial oxidation	3,000	45	90	2.254	92.25				
	Biological treatment	26,000	8,192	1,950	272.75	2,222.8				
	Dual media filtration	26,000	1,158	78	57.9	135.9				
	Reverse osmosis	5,853	2,825	526.7	197.8	724.56				
	Evaporation pond	1,463	556	8.78	13.9	22.68				
	Total	33,000	16,134	2,872	745.6	3,609	420	3,539	0.322	
II	Partial oxidation	10,000	100.99	300	5.05	305.05				
	Biological treatment	33,000	9,496.6	2,475	313.4	2,788.4				
	Dual media filtration	33,000	1,469.8	99	73.49	172.5				
		Total	33,000	11,067.5	2,874	391.93	3,266	0.0	3,649	0.33
	III	Ultrafiltration	405	213	24.3	14.94	39.24	2,531		
		Nanofiltration	7,000	2,870	210	200.9	410.9	420		
Partial oxidation		3,000	45	90	2.25	92.25				
Biological treatment		25,955	8,183	1,946	270.04	2,216.7				
Dual media filtration		7,313	326	21.9	16.29	38.22				
Reverse osmosis		5,850	2,824	526.5	197.7	724.24				
	Evaporation pond	1,463	556	8.78	13.89	22.67				
	Total	33,000	15,505	2,828	716	3,544	2,951	593	0.06	
IV	Ultrafiltration	405	213	24	14.94	39.24	2,531			
	Partial oxidation	10,000	101	300	5.05	305.06				
	Biological treatment	32,955	9,489	2,471.6	315.8	2,787.6				
	Dual media filtration	3,719	166	11.16	8.28	19.44				
	Reverse osmosis	2,975	1,435	268	100	368				
	Evaporation pond	744	282.6	4.46	7	11.53				
	Total	33,000	11,686.2	3,079.3	452	3,531	2,531	1000	0.1	
V	Ultrafiltration	405	213	24.3	14.94	39	2,531			
	Partial oxidation	10,000	101	300	5.05	305				
	Biological treatment	32,955	9,489	2,471.6	316	2,788				
	Dual media filtration	12,195	543	36.58	27.2	63.74				
	Reverse osmosis	9,756	4,714	878	329.96	1,208				
	Evaporation pond	2,439	927	14.6	23.17	37.8				
	Total	33,000	15,987	3,725.16	716.3	4,441	2,531	1,910	0.193	

*including depreciation

Table 6
Summary costs for a 33,000 m³/d vertically integrated textile mill

Scenario	Characteristics	Total O&M (US\$1000/y)	Net O&M (US\$1000/y)	Unit cost (US\$/m ³)
I	Low NCOD/natural sizing agent	3,959	3,539	0.357
II	High NCOD/natural sizing agent and permissible salinity	3,649	3,649	0.369
III	Low NCOD/synthetic sizing agent (PVA)	3,879	1,080	0.109
IV	High NCOD/synthetic sizing agent (PVA)	3,897	1,518	0.153
V	High NCO/synthetic sizing agent (PVA) and high salinity	4,844	2,465	0.249

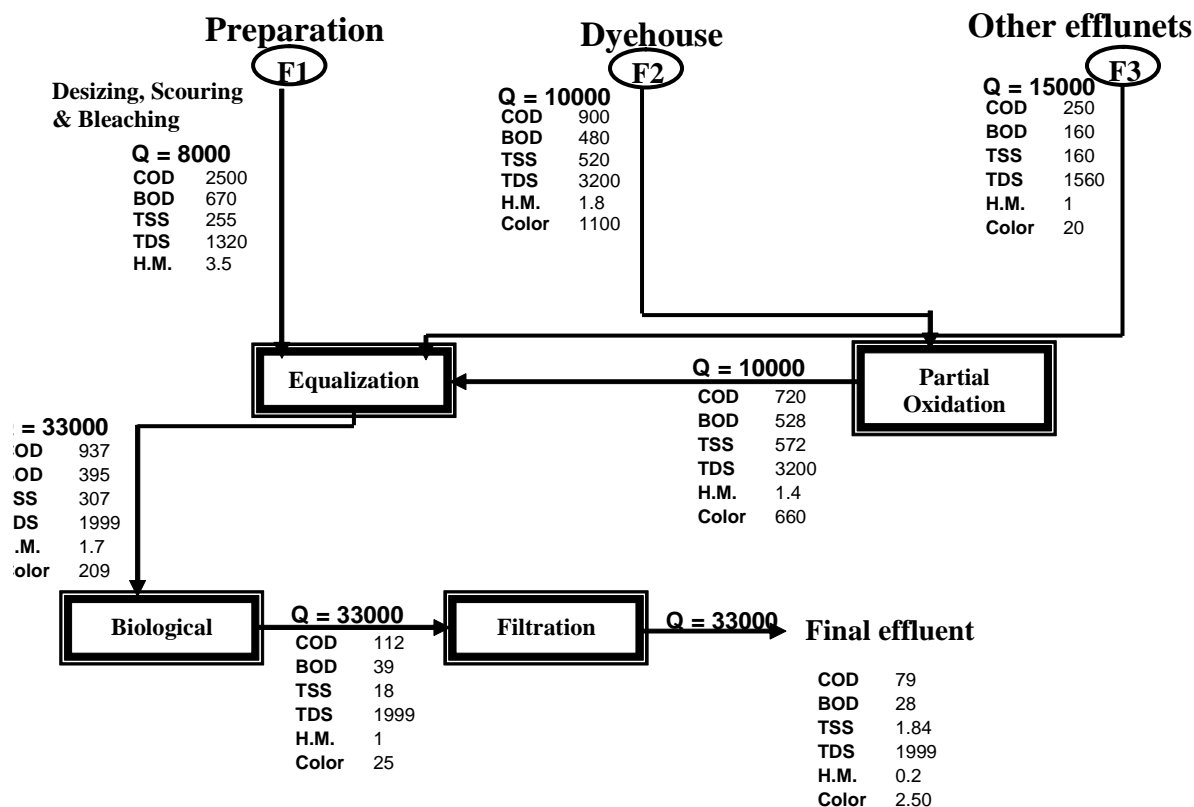


Fig. 3b. Material balance for the proposed treatment–reuse scenario II.

second scenario and consequently the reduction of the capital cost of the latter by about 30%, it's unit cost is higher when compared by the first scenario which is attributed to the presence of annual revenues in scenario I,

about US\$ 420.000/y due to water recycling from the NF stage.

- The third scenario manifests the lowest unit cost (\$ 0.06/m³) in spite of the relatively high capital cost. The significant unit cost reduction

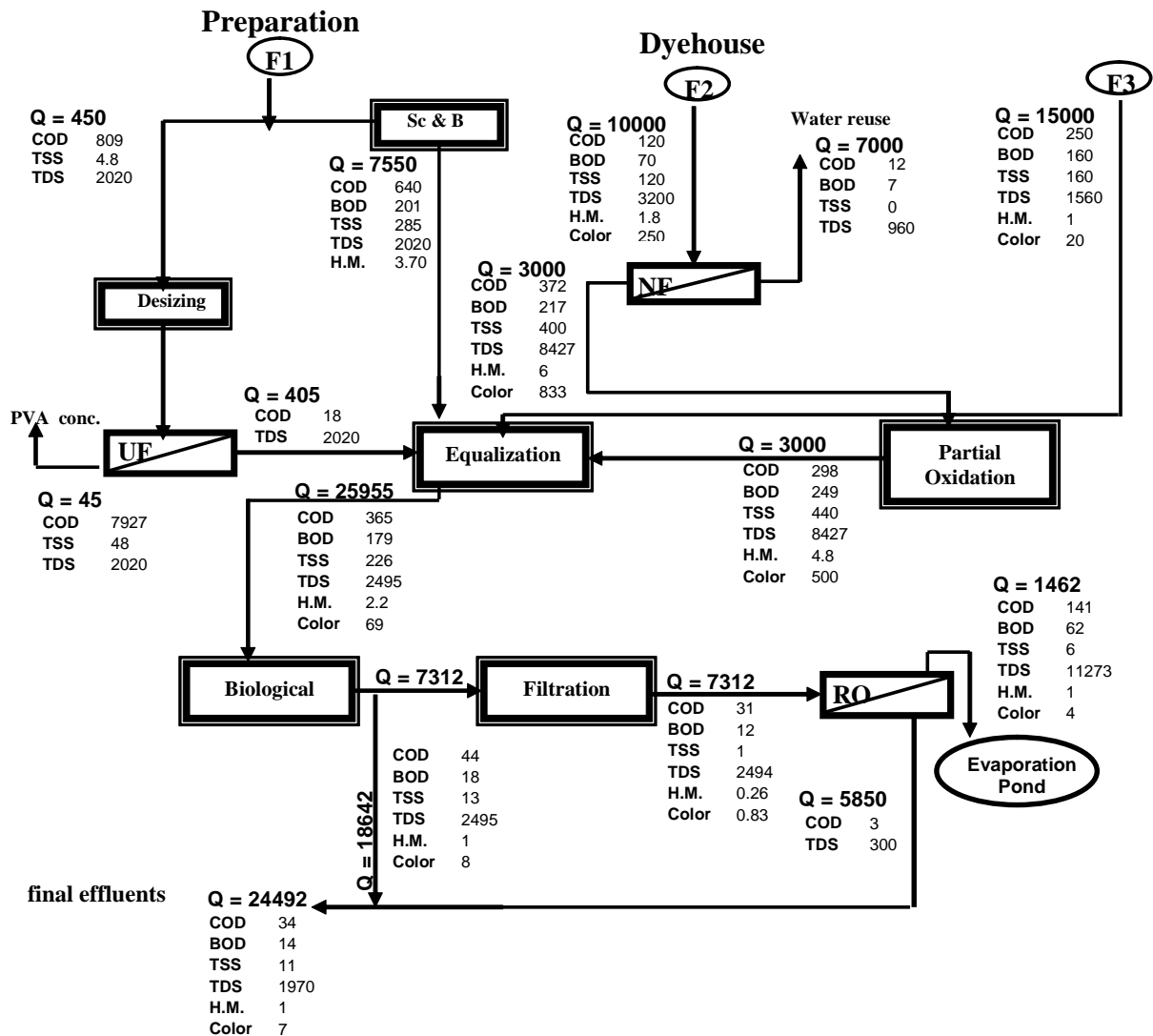


Fig. 3c. Material balance for the proposed treatment–reuse scenario III.

is achieved by the recycling of NF permeate and PVA sizing.

- In the first and third scenarios, the revenues generated by RO permeate are neglected. RO permeate is utilized to adjust salinity to the permissible discharge limits. This also mandates endeavors by the plant manager to improve operational practices to eliminate the need for

RO or enable recycling of RO permeate and thus maximize revenues.

- The unit costs of scenarios IV, V are US\$ 0.1 and US\$ 0.193/m³ respectively. In both scenarios, the NF stage has been eliminated and consequently the revenues of permeate. Further, the fifth scenario is characterized by the increased capital of dual media filtration and RO

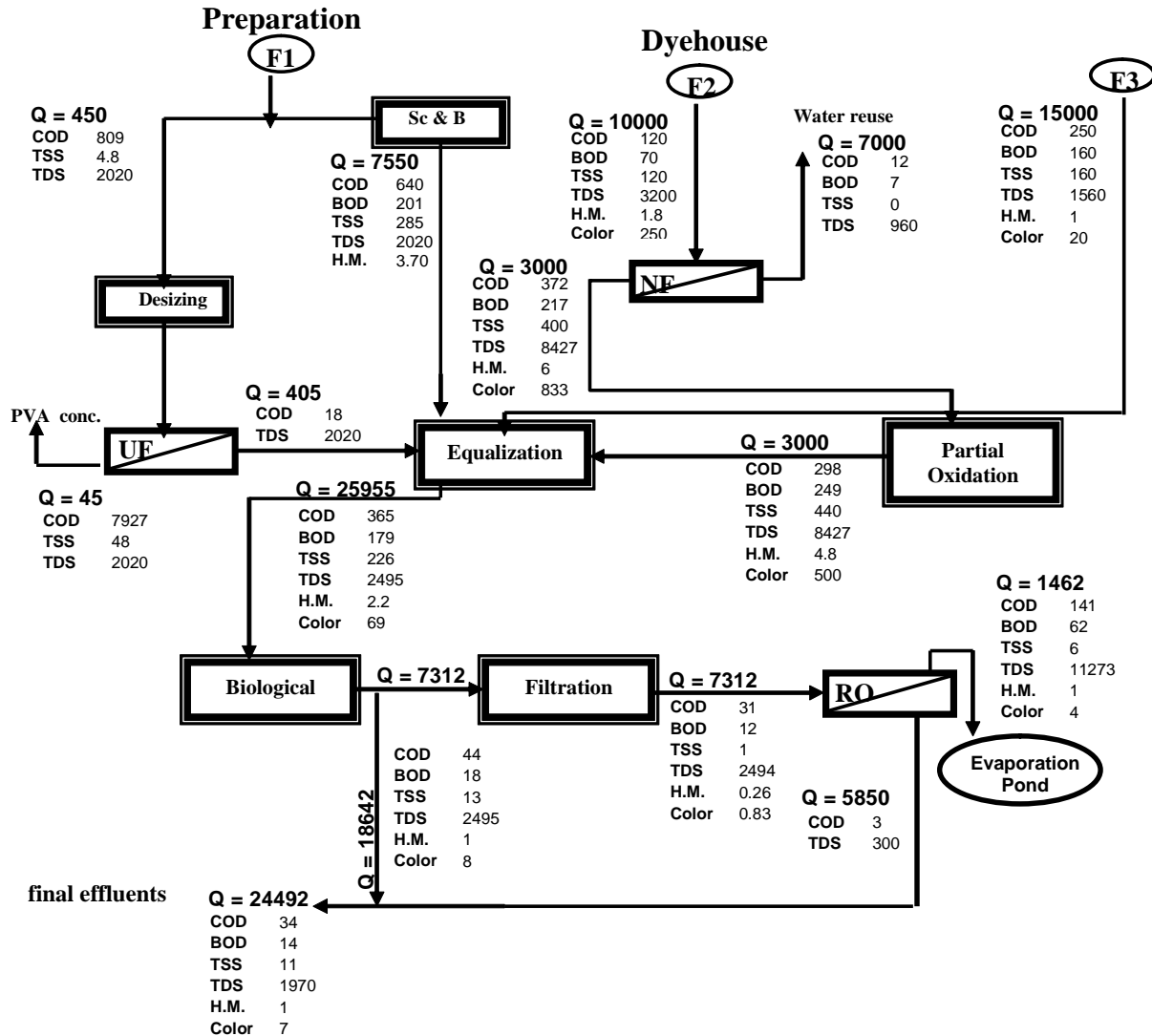


Fig. 3d. Material balance for the proposed treatment–reuse scenario IV.

as compared to the fourth one. Thus, the total O&M cost of the fourth and fifth scenarios are million US\$ 3.531 and 4.441 respectively. Results of unit wastewater treatment cost are within the same order of magnitude for the results obtained by treatment and recycling approach proposed in this work, which confirms the reliability of the proposed logical framework and the developed TEXPERT program [19,29].

- The results of the TEXPERT program manifest the ability to deal with different situations in the textile sector. It enables the selection of the treatment recycling path and consequently capital, O&M, revenues and unit wastewater treatment cost. The program also reveals the importance of integrating membrane recycling systems within the scope of the treatment matrix to achieve permissible discharge limits. The TEXPERT program also enables decision

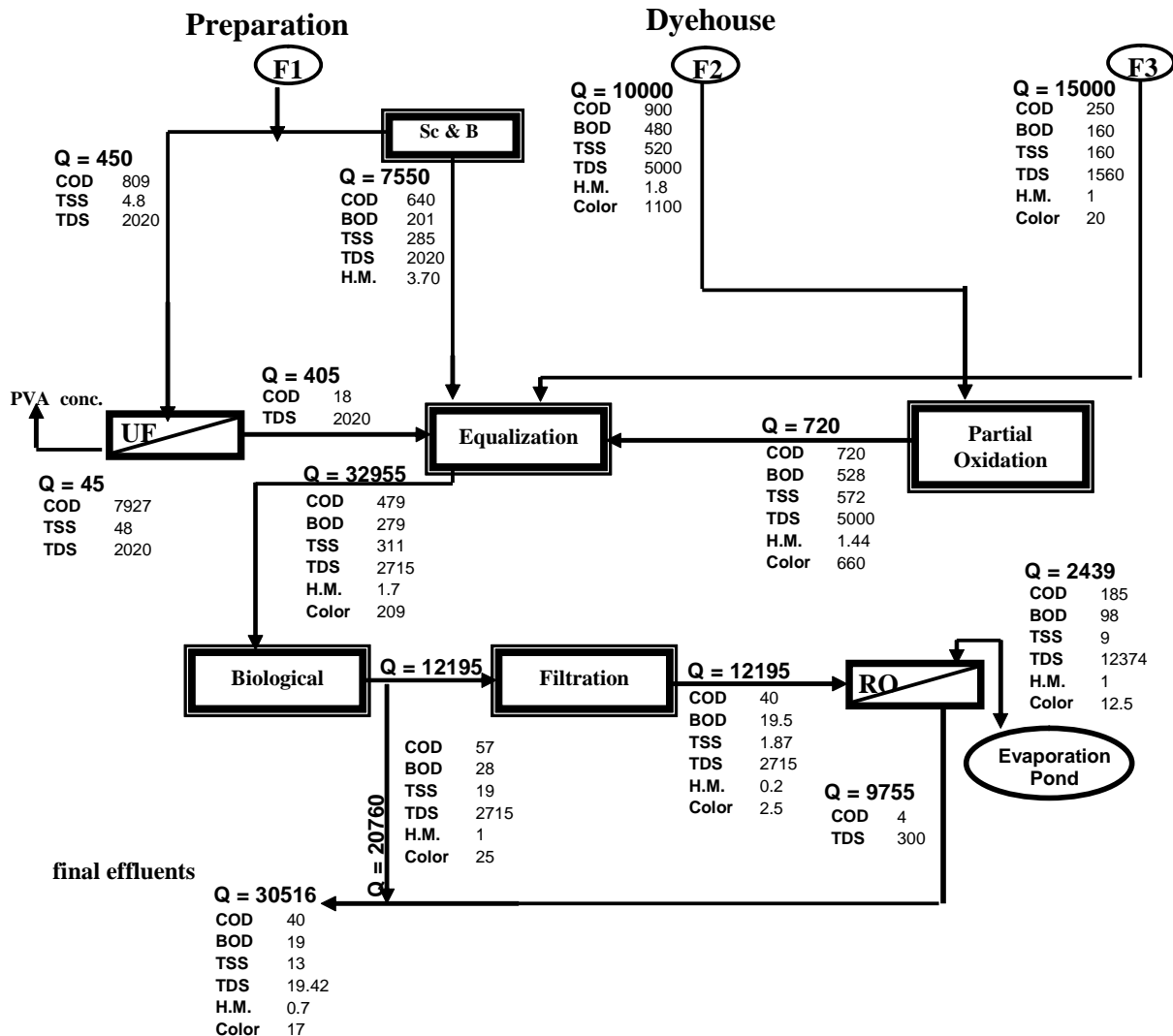


Fig. 3e. Material balance for the proposed treatment–reuse scenario V.

makers at the planning level and financial institutions to decide upon the capital needed on sectoral level.

5. Conclusions

The current diversity of technological setting and operational practices in vertically integrated textile mills creates difficulties for prioritizing and budget allocation in the planning level. Further,

the availability of numerous management interventions (choice mix) complicates decision making at the firm level. Thus, the integrated treatment–recycling wastewater management approach has been proposed and assessed using a TEXTPERT program. Five scenarios reflecting variation of effluents characteristics in textile mills have been analyzed using the developed TEXTPERT program. The financial indicators manifests unit of wastewater treatment cost vary-

ing from US\$ 0.06 to US\$ 0.33. Further, the output results indicate the importance of integrating membrane separation schemes within the conventional treatment matrix to enable the fulfillment of applicable legislations and generate suitable revenues and consequently reducing wastewater treatment unit cost.

References

- [1] S. Barclay and C. Buckley, Waste Minimization Guide for the Textile Industry – A Step Towards Cleaner Production. The Pollution Research Group University of Natal Durban South Africa for the Water Research Commission, vol. 1, 2000.
- [2] O. Can, M. Kobya, E. Demirbas and M. Bayramoglu, Treatment of the textile wastewater by combined electrocoagulation, *Chemosphere*, 62 (2006) 181–187.
- [3] A. Pala, Chemical treatment of textile wastewater: statistical characterization, color and sulfide removal, *Indian J. Environ. Health*, 43(3) (2001) 128–134.
- [4] C. Allegre, P. Moulin, M. Maisseu and F. Charbil, Treatment and reuse of reactive dye effluents, *J. Membr. Sci.*, in press.
- [5] C. Shaw, C. Carliell and A. Wheatley, Anaerobic/aerobic treatment of colored textile effluents using sequencing batch reactors, *Wat. Res.*, 36(8) (2002) 1993–2001.
- [6] J. Bell and C. Buckley, Treatment of a textile dye in the anaerobic baffled reactor, *Water S.A.*, 29(2) (2003) 129–134.
- [7] O. Marmagne and C. Coste, Color removal from textile plant effluents, *Amer. Dyestuff Reporter*, April (1996) 15–27.
- [8] M. Aslam, M. Baig, I. Hassan, I. Qazi, M. Malik and H. Saeed, Textile wastewater characterization and reduction of its COD and BOD by oxidation, *Electronic J. Environ., Agric. Food Chem.*, 2004.
- [9] S. Lin, Treatment of textile waste effluent by ozonation and chemical coagulation, *Wat. Res.*, 27(12) (1993) 1743–1748.
- [10] J. Sarasa, M. Roche, M. Ormad, E. Gimeno, A. Puig and J. Ovelleiro, Treatment of wastewater resulting from dye manufacturing with ozone and chemical coagulation, *Wat. Res.*, 32(9) (1998) 2721–2727.
- [11] J.A. Libra and F. Sosath, Combination of biological and chemical processes for treatment of textile wastewater containing reactive dyes, *J. Chem. Technol. Biotechnol.*, 78(11) (2003) 1149–1156.
- [12] J. Perkowski and L. Kos, Treatment of textile dyeing wastewater by hydrogen peroxide and ferrous ions, *Fibers Textile in East. Eur.*, July/Sep (2002) 68–81.
- [13] A. Reife and H. Feeman, *Environmental Chemistry of Dyes and Pigments*. John Wiley and Sons, 1996.
- [14] J. Porter, Recovery of polyvinyl alcohol from textile wastewater using thermally stable membranes, *J. Membr. Sci.*, 151(1) (1998) 45–53.
- [15] W.N. Rozelle, Parksdale begins massive spinning machinery changeover. (Parksdale Mills), *Textile World*, 144 (1994) 67–68.
- [16] J. Gaddis, H. Spencer and D. Jernigan, Caustic recovery and recycling at a textile dyeing and finishing plant, *Natl. Res. Council. Can., Report NRCC 29895, Adv. Reverse Osmosis and Ultrafiltration*, 1989, pp. 347–355.
- [17] C. Lopes, J. Peturs and H. Riella, Color and COD retention by nanofiltration membranes, *Desalination*, 172 (2005) 77–83.
- [18] C. Brandon, Closed Cycle Dyeing: Full Scale Hyper Filtration Demonstration (Design), U.S. Environmental Protection Agency, EPA-600/2-80-005, March 1980.
- [19] N. El Defrawy, Water management in textile industry: technical and economical aspects, *Intern. J. Environ. Studies*, 59(5) (2002) 573–587.
- [20] S. Lin and C. Pong, Treatment of textile wastewater by electrochemical method, *Wat. Res.*, 28(2) (1994) 277–282.
- [21] C. Fersi, L. Gzara and M. Dhabbi, Treatment of textile effluents by membrane technologies, *Desalination*, 185 (2005) 399–409.
- [22] C. Tang and V. Chen, Nanofiltration of textile wastewater for water reuse, *Desalination*, 143 (2002) 11–20.
- [23] M. Marcucci, G. Nosenzo, G. Capannelli, I. Ciabatti, D. Corrieri and G. Ciardelli, Treatment and reuse of textile effluents based on new ultrafiltration and other membrane technologies, *Desalination*, 138 (2001) 75–82.
- [24] T. Kim, C. Park and S. Kim, Water recycling from desalination and purification process of reactive dye manufacturing industry by combined membrane filtration, *J. Cleaner Production*, 13 (2005) 779–786.
- [25] Metcalf and Eddy, *Waste Water Engineering (Treatment, Disposal and Reuse)*. McGraw Hill, 1991.
- [26] M. Sorour, N. ElDefrawy and H. Shaalan, Treatment of agricultural drainage water via lagoon/reverse osmosis system, *Desalination*, 152 (2002) 359–366.
- [27] N. El Defrawy and H. Shaalan, Techno-economic assessment of biological treatment and water reuse of effluent from the food industries, *Intern. J. Environ. Studies*, 60(2) (2003) 111–122.
- [28] K. Pickering and M. Wiesner, Cost model for low pressure membrane filtration, *J. Environ. Eng.*, 119 (1993) 772–797.