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PILOT SCALE UF AND RO STUDIES ON WATER REUSE IN CORRUGATED BOARD INDUSTRY

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ABSTRACT

The coloured effluents from pulp and paper mill industry are treated anaerobically and/or aerobically by a two stage membrane system with high efficiency. Three different types of membranes (UF and RO (BW and SW)) were used in the experiments. Surface area of each membrane was 2 m^2. The combination of ultrafiltration (UF) and reverse osmosis (RO) treatment achieve a very high removals of COD (98-99%), colour and conductivity. At the end of a single pass with RO using seawater (SW) membrane, the initial COD, colour and conductivity values were reduced to 10-20 mg/l, 0-100 Pt-Co units and 200-300 µs/cm, respectively. The influent, UF permeate, RO permeates for brackish water (BW) and seawater (SW) membranes were 6000-6700 µs/cm, 5500-5900 µs/cm, 1000-1500 µs/cm and 200-300 µs/cm, respectively. Excellent conductivity rejections were obtained in the UF and RO membrane systems. Almost complete colour removals were achieved in the RO experiments with SW membranes. RO studies with BW membranes were also performed with the same permeate from the first stage UF study. The observed flux has declined with time and membranes were cleaned periodically to maintain a constant flux. Applying this advanced membrane treatment technology, it is clear that about 60 percent of the process water can be recycled in the investigated industry. © 1999 IAWQ Published by Elsevier Science Ltd. All rights reserved

KEYWORDS

Colour removal; pulp and paper mill industry effluents; RO; two stage membrane system; UF; water reuse.

INTRODUCTION

Reuse of industrial effluents became more and more important in recent years. Discharging of industrial effluents to receiving waters causes unacceptable environmental conditions even if conventional waste treatment technologies are applied. Water reuse can be practised for various industries applying advanced treatment technologies. Membrane technology has been considered as a promising treatment method for the problematic industries.

The pulp and paper mill production industry is an industry consuming large amounts of water, with estimates of around 200 m^3 per tonne of cellulose produced and 100-1000 l per tonne of paper (depending on the type of manufacturing process) in addition to cooling water. The water is used to prepare the solvent for the pulping process and for the bleaching process and is also used for washing, transport of fibres and purification. Consequently high volumes of effluent water are produced which is virtually non-biodegradable due to the presence of the dissolved wood components. In addition to this, effluents are hot and highly coloured with significant fluctuations of pH (Scott, 1995).

Membrane processes have potential applications with rinsing waters and effluents from pulp and paper mill industry in various areas; including concentration of highly dilute sulphite liquors (wash water), separation of lignins, desalination of bleach effluents from alkali extraction stage and treatment of paper machine effluents to assist the internal water recirculation systems. Ultrafiltration (UF), nanofiltration (NF) and reverse osmosis(RO) have been tested on a laboratory and pilot plant scale on several liquors and waters in the pulp and paper mill industry including; UF and RO of black liquor, UF and RO of bleaching effluents and UF of paper machine wash waters (Afonso *et al.*, 1991), (Ekengren *et al.*,1991), (Scott, 1995). Membrane filtration combined with different biological treatment for the purification of bleaching effluents (Boman *et al.*, 1991), (Frostell *et al.*, 1994), (Hall *et al.*, 1995) and potential uses of UF and NF in the kraft pulp and paper industry were tested in the laboratory (Zaidi *et al.*, 1992). Application of these processes in the pulp and paper mill industry are mostly used for removal of dissolved solids, colour and organics from wastewater. The use of RO to obtain reuse water from pulp and paper mill effluents, has demonstrated that rejects are treated up to 90 to 95% for colour, TDS, organics and inorganics; COD and BOD were obtained for RO feeds consisting of permeate from UF membranes (Chakravorty *et al.*, 1987). Two full-scale UF plants with membrane areas of 500-1500 m^2 have been installed in Japan to clean up bleached effluents. The following performances are achieved for the UF separation; permeate rate 88%, COD reduction 82%, colour reduction 94% and TSS reduction 100% (Zaidi *et al.*, 1992), (Scott, 1995).

Application of membrane technology has been first considered for water pollution control in the 1970s, but minor progress has been achieved till then due to certain constraints. The most important restraining factors were high capital and operating costs. In the late 1980s, the application of membrane technology had become more widespread with the introduction of a variety of membrane materials offering the following advantages: High water flux rates, high salt rejection, high tolerance to chlorine and other oxidants, resistance to biological attack, relatively low costs, high mechanical strength, chemical stability and resistance to high temperatures (Ujang *et al.*, 1996).

The purpose of this study is to investigate the colour removal of high strength pulp and paper mill industry effluents from an existing full scale anaerobic-aerobic treatment plant by using membrane technology. Two-stage membrane technology, ultrafiltration (UF) and brackish water (BW) or sea water (SW) reverse osmosis (RO) membranes were used in series throughout the experimental studies to find out the effect of UF on the fluxes by using RO membranes as a second step.

The investigated industry

The investigated industry is a corrugated board production factory located in province Tekirdag in Turkey. The factory produces annually 90000 ton corrugated board with SAICA processes by using straw and old paper as raw materials. This factory has a 10% share of the whole corrugated board production in Turkey.

Total water consumption of industry is about 2500 m^3, including cooling water. Wastewater quantities and characteristics of the industry for a period of one year (22.11.1993-20.11.1994) are given in Table 1. Specific water consumption and pollution loads are also given in Table 2. Changes of COD and SS in the raw effluent are presented in Figure 1 and 2 (Ozturk *et al.*, 1996).

Table 1. Wastewater quantities and characteristics of the investigated industry

Parameter	White Liquor	Black Liquor	Average
Flow rate (m^3/day)	1400	100	1500
COD (mg/l)	8765	61400	12275
SS (mg/l)	2610	8940	3030
Temperature (°C)	40-50	25-30	37
pH	7.26	6.66	7.18

Table 2. Specific water consumption and pollution load of the industry

Parameter	White Liquor	Black Liquor	Average
Flow rate (m^3/tonne paper)	8	1	9
COD (kg / tonne paper)	50-80	50-80	150
SS (kg/tonne paper)	15-30	10	30

The industry has a two-stage biological treatment plant (Figure 3.). It consists of an anaerobic contact reactor (ANAMET process) and in particular an extended aeration activated sludge system. The main problems of the biologically treated effluents are dark brown colour and high residual COD.

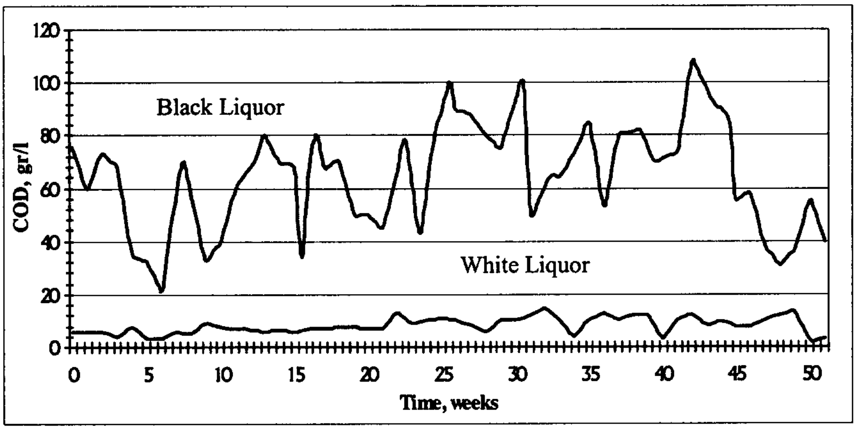


Figure 1. COD versus time graph for the raw industrial effluents.

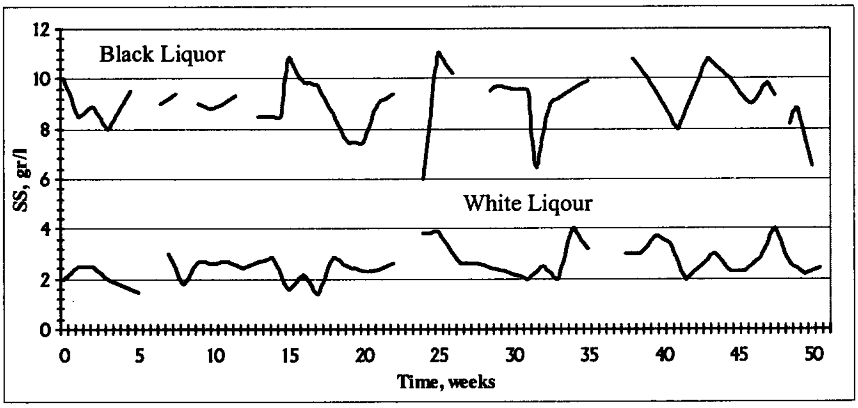
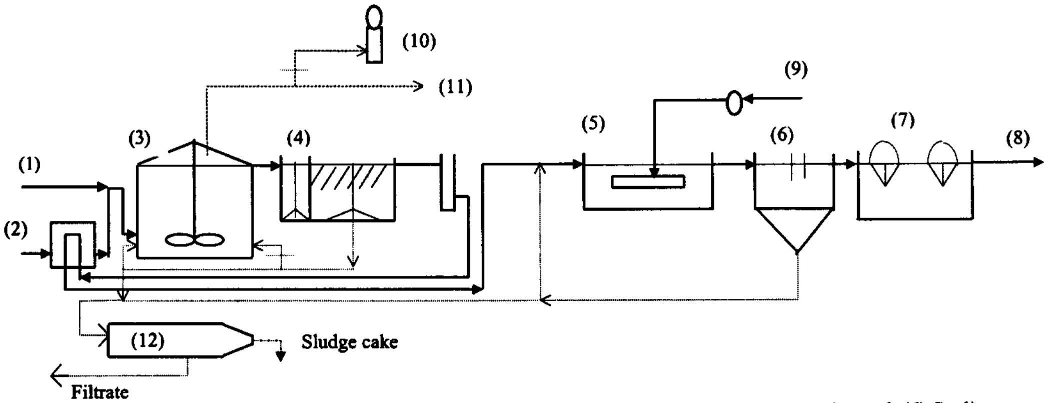


Figure 2. SS versus time graph for the raw industrial effluents



(1) Black liquor (2) White liquor (3) Anaerobic reactor (4) Lammella separator (5) Aeration tank (6) Settling tank (7) Aerated lagoon (8) Discharge to river (9) Air (10) Flare (11) Biogas to boiler house (12) Centrifuges

Figure 3. The flow diagram of the existing wastewater treatment plant in the investigated industry.

MATERIALS AND METHODS

Three different types of membranes (UF and RO (BW and SW)) were used in the experiments. Surface area of each membrane was 2 m^2. Technical characteristic of the membranes used in laboratory scale pilot plant are given in Table 3. All membranes were cleaned with alkaline detergent solution (Ultrasil) following each run. The flow diagram of the pilot plant is shown in Figure 4.

Table 3. Technical characteristics of the membranes used in this study

Operating Limits	Ultrafiltration (UF)	Reverse Osmosis (BW)	Reverse Osmosis (SW)
Membrane Manufacturer	Desalination System Inc.	Filmtech Corp.	Filmtech Corp.
Membrane Type	Thin film Composite	Thin film Composite	Thin film Composite
Max. Operating Pressure (bar)	4	40	70
Max. Operating Temperature (°C)	50	45	45
Max. Feed Turbidity (NTU)	-	1	1
Free Chlorine Tolerance (ppm)	<0.1	< 0.1	< 0.1
pH Range	2-11	2-11	2-11
Max. Feed Flow (l/min.)	-	23	23
Max. SDI	5	5	5
Salt Rejection (%)	98	98	99.1
Single Recovery (%)	-	15	10

pH was measured using an ORION SA 720 type pH meter. AGB-10001 Laboratory Data Logging system was used to measure temperature, conductivity and TDS. COD was determined according to Standard Methods (APHA, 1989) and colour was measured with a Hach model colourometer as Pt-Co unit.

The experiments were conducted using anaerobically and aerobically pretreated wastewater. The effluents from the aerobic treatment stage with the following characteristics were used in the study : COD = 2500 - 3500 mg/l, pH = 6.0-7.0, conductivity = 6000 - 6700 μs/cm and colour = 3000 - 3500 Pt.Co. unit.

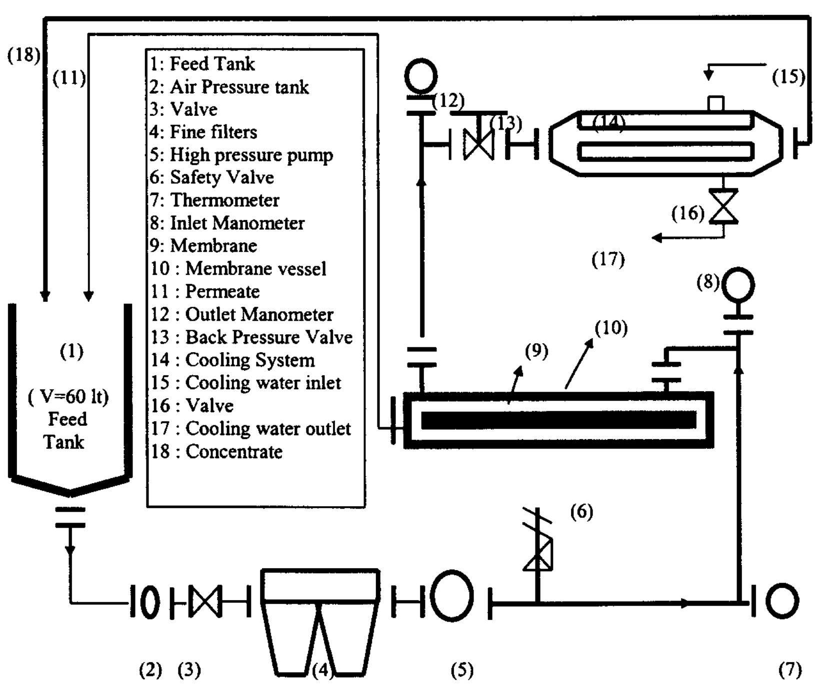


Figure 4. The flow diagram of the membrane pilot plant.

A pilot-scale membrane reactor system in our laboratory was used for this purpose. Since, the pilot membrane reactor was operated at a totally closed cycle mode both for UF and RO experiments, the brine and permeate flows were recycled to the feed tank. Effluent from the first stage UF system was used as a feed to the subsequent RO experiment for all runs. The applied pressures were 25 bar for BW membrane and 55 bar for the SW membrane. Temperature was about 30°C.

The removal efficiency is calculated using the following equation:

$$E(\%) = \frac{C_f - C_p}{C_f} x100$$

in which, C_f, is concentration in feed water (mg/l) and C_p is concentration in permeate (mg/l).

RESULTS AND DISCUSSION

Treated water quality

The removal efficiencies of tests for the COD, colour and conductivity parameters were given in Figures 5 and 6 for the BW and SW membranes, separately.

The UF experiments at 4 bar pressure indicate that COD, colour and conductivity removals may be achievable up to 83-90 %, 80-90 % and 10-20 %, respectively. The initial COD and colour values were reduced to 450-500 mg/l and 700-780 Pt-Co units following a single pass. COD and colour removals of 85-90 % and 80-95 % (Zaidi *et al.*, 1992), COD removal of 60-80 % (Ekengren *et al.*, 1991) and colour removal of 60-70 % (Afonso *et al.*, 1991) were reported with UF membranes. The findings of this study are comparable to the related studies.

Following the first stage UF treatment, the permeate was further treated with SW in the RO operation mode at 55 bar pressure. In these experiments, COD, colour and conductivity removals of 98, 95 and 95 % were achieved in turn. At the end of a single pass the initial COD and colour values were reduced to 10-20 mg/l and 0-100 Pt-Co units, respectively. Almost complete colour removals were achieved in the RO experiments with SW membranes. RO studies with BW membranes were also performed with the same permeate. In these experiments, COD, colour and conductivity removals of more than 85, 90 and 80 % were obtained, respectively. Ekengren *et al.* (1991) have reported COD removals of 85-95 % supporting the findings of the study.

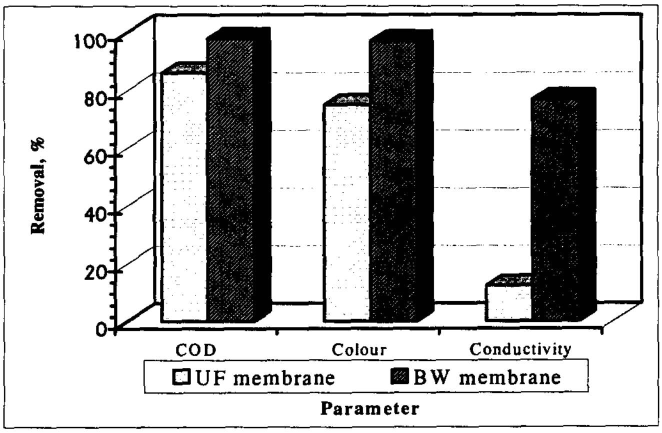


Figure 5. The removal efficiencies of tests for the COD, colour and conductivity parameters for UF and BW membranes

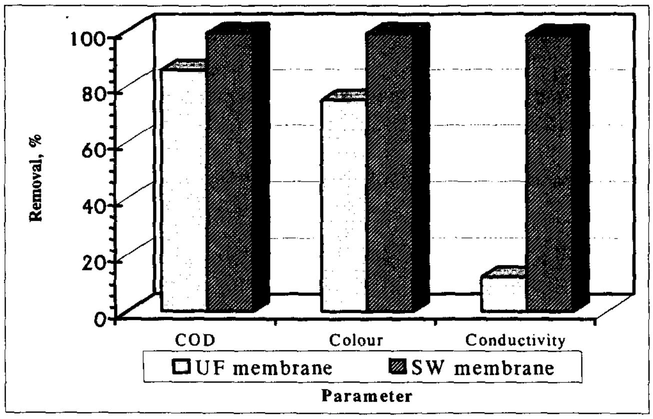


Figure 6. The removal efficiencies of tests for the COD, colour and conductivity parameters for UF and SW membranes.

The combination of UF and RO treatment achieves very high removals of COD, colour and conductivity (higher than 98-99 %). COD removals of 98.8-99.9 % were reported by Ekengren *et al.* (1991) for a similar study.

Conductivity values of the influent, UF permeate, BW permeate and SW permeate are given in Figure 7. The influent, UF permeate, BW permeate and SW permeate conductivities were 6000-6700 μs/cm, 5500-5900 μs/cm, 1000-1500 μs/cm and 200-300 μs/cm, respectively. Excellent conductivity rejections were obtained. It is obvious that a good quality permeate was obtained with SW permeate considering the current effluent discharge standards of the Aquatic Products Cominique in Turkey.

Membrane fouling

Membrane fouling has been monitored by permeate fluxes. Flux is the volume of product water flowing through a unit membrane area per unit time and is expressed as l/m^2.day. The initial permeate flux of UF was about 60 l/m^2.h but at the end of each run it was reduced to a constant value (about 50 l/m^2.h) (Figure 8). Ekengren *et al.* (1991) reported 40 l/m^2.h in their studies. Water flux of BW membrane also decreased with time. The initial permeate flux of BW membranes was 35 l/m^2.h (Figure 9). Following a sharp decline, it decreased to the constant value of 20 l/m^2.h. The initial, SW flux was 50 l/m^2.h. At the end of the experiments, SW flux was decreased to 30 l/m^2.h (Figure 10). This value was reported as 35 l/m^2.h (40°C, 40 bar) by Ekengren *et al.* (1991).

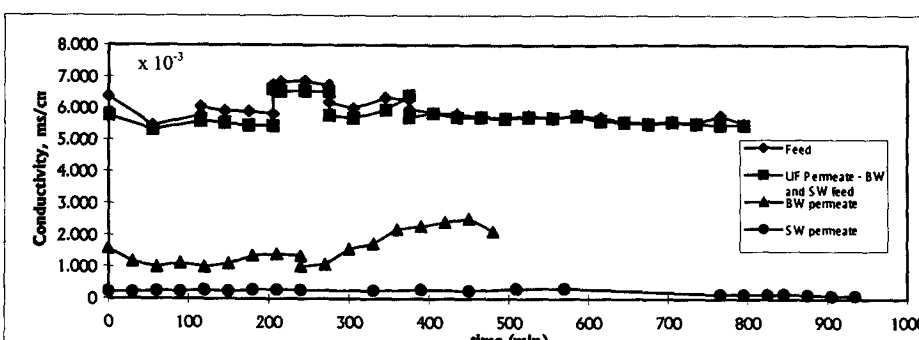


Figure 7. Conductivity values of the raw effluent, UF permeate, BW permeate and SW permeate.

Figure 8, 9 and 10 show typical runs with UF, BW and SW membranes. The observed fluxes declined with time and membranes were cleaned periodically to maintain a constant flow.

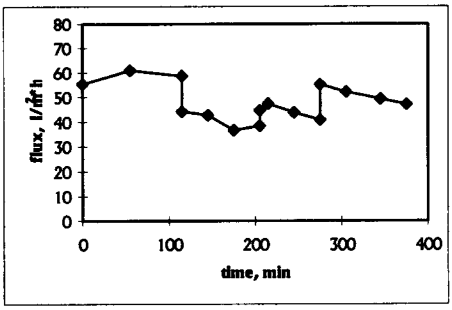


Figure 8. Flux versus time graph for UF membrane.

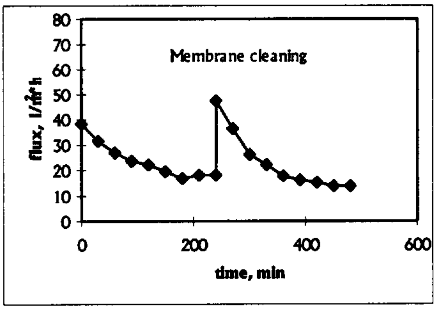


Figure 9. Flux versus time graph for BW membrane.

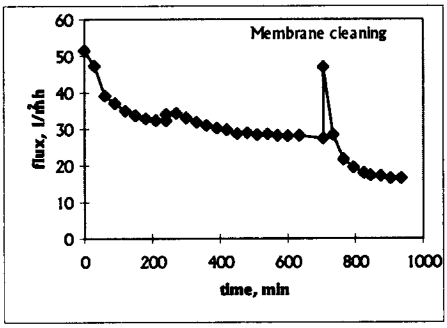


Figure 10. Flux versus time graph for SW membrane.

Optimization of the system

The cartridge filters had to be used and replaced quite frequently. In this way, membrane life can be extended. To increase the treatment efficiency of UF and RO membranes, chemical treatment can be applied after aerobic biological treatment.

Applying this advanced membrane treatment technology, about 60 percent of the process water can be recycled and the problems resulting from the unacceptable colour can be solved.

From these experiments, it can be observed that the combination of UF with RO results in higher removal efficiencies. It may be interesting to conduct some experiments with low-pressure RO membranes (nanofiltration) to reach a more cost effective solution.

CONCLUSIONS

The study has indicated that the permeate from the two-stage membrane reactor system (UF+RO) is of high quality and can be used as a process water for the investigated industry. Using this system about 60 percent of the process water can be recycled as process water for the industry.

The combination of UF and RO treatment results in a very high removals of COD, colour and conductivity (more than 98-99%). Considering the current discharge standards, it is clear that a good quality permeate was obtained with SW permeate. The observed flux indicated a decline with time emphasizing the significance of periodic cleaning to maintain a constant flux.

Anaerobic treatment can be applied to treat the rejects of the system. Further investigations are recommended including the treatment of the brine and cost estimation of the system. The combination of UF and RO has to be studied for longer periods and on much larger scales. It is well known that the findings of scaling-up will lead to quite different values. More effective combinations including NF should also be investigated.

ACKNOWLEDGEMENTS

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