TREATMENT OF A CONCENTRATED OILY WASTES USING THE *SPINTEK* ROTARY ULTRAFILTRATION SYSTEM

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Abstract: The SpinTek rotary ultrafiltration system (ST-II) uses membrane rotation to provide the turbulence required to minimize concentration polarization and flux decline. The ST-II system was effective in concentrating oily wastes from about 5% to as high as 75%. The decoupling of turbulence promotion from feed pressurization/recirculation by rotating the membrane is the primary reason for the improvement in performance over that observed with conventional UF systems. Flux increased by about 45% when the temperature was increased from 110 to 140°F. A larger decrease in waste viscosity, over that predicted for water alone, was the primary reason for the stronger than expected flux-temperature relationship. The flux decreased with decreasing rotational speed (ω) and the gel layer did exhibit some sustainable stability with increases in ω. A ceramic membrane was superior to a polymeric membrane in regards to flux quantity and quality as well as membrane cleaning/durability.

INTRODUCTION

Concentrated (> 5%) oily wastes are produced by various metal-working operations (rolling mills, metal cutting and working). The ability of conventional cross-flow membrane technology to treat a concentrated oily waste directly or the residual from the conventional membrane system is limited because of the low permeate flux observed at high oil concentrations. Conventional cross-flow systems rely on high recirculating velocities ($\approx$ 10 ft/s) to scour or clean the membrane surface so that satisfactory permeate flux is maintained. As the concentration of the feed increases, the maintenance of a high velocity is difficult because of the increase in feed viscosity. The decoupling of the cleaning action from feed recirculation/pressurization can be accomplished by moving the membrane surface. For example, SpinTek (Huntington, CA) has developed a high-shear rotary cross-flow ultrafiltration system in which membrane disks are rotated at high speeds. The rotation of the membrane provides the turbulence required to clean the membrane while the pump is required only to provide transmembrane pressure and a small amount of recirculation. The objective of this research was to assess the efficacy of using the SpinTek high-shear rotary cross-flow ultrafiltration system for the direct treatment of rolling mill coolants/lubricants. Two types of membrane materials, ceramic and polymeric, and two rolling mill coolants/lubricants were investigated.

System performance was measured using the following parameters: 1) permeate flux, 2) permeate quality, 3) membrane cleaning and durability.

BACKGROUND

Ultrafiltration is a pressure driven membrane technique that uses porous membranes for the separation of material in the 1 nm - 10 μm size range or compounds with molecular weights in excess of 5000. Colloidal material, macromolecules and micelles are examples of items that can be fractionated. "Clean" water (permeate) is forced through the porous membrane while the solute is retained by the membrane, concentrating the feed with time. Numerous researchers have reported on UF's effectiveness in treating oil/grease wastewaters.

In all membrane processes, a solute boundary layer will form at the membrane surface due to convective mass transport. This phenomenon is referred to as "concentration polarization" and is one reason why the permeate flux for a waste is lower than the clean water flux (CWF). The buildup of the solute at the membrane surface is reduced by back diffusion of the solute and the reduction in the thickness of the boundary layer through turbulence. A schematic of the SpinTek high-shear rotary cross-flow ultrafiltration system (referred to as ST-II system hereafter) is presented in Figure 1. The ST-II system uses a series of flat, round membrane disks set on a hollow rotating shaft inside a cylindrical housing (only one disk shown). The fluid stream enters the membrane chamber under pressure and is distributed across the membrane surface. Permeate is forced through the membrane and is collected in the hollow shaft and is discharged. The concentrate exits at the edge of the membrane packs. To reduce concentration polarization in conventional UF systems, a large portion (≈98%) of the concentrate is recycled back to the membrane unit producing large liquid velocities near the membrane surface. The large velocities increase turbulence which reduces the thickness of the solute boundary layer. In the ST-II system, the rotation of the membrane disk produces the required turbulence. In addition to the rotational action, turbulence promoters ("wagon wheels") are located on each side of the membrane to prevent rotational flow (vortex formation) from occurring. In conventional UF systems, maximum liquid velocities of about 15 ft/s are possible while with the ST-II system liquid velocities of 60 ft/s are typical. As the feed thickens with treatment time, a conventional UF system is not able to maintain the high cross-flow velocities because of the difficulty in pumping viscous material at high flow rates. Because the ST-II system does not rely on pumping to produce the required liquid velocities, extremely concentrated wastes can be treated.

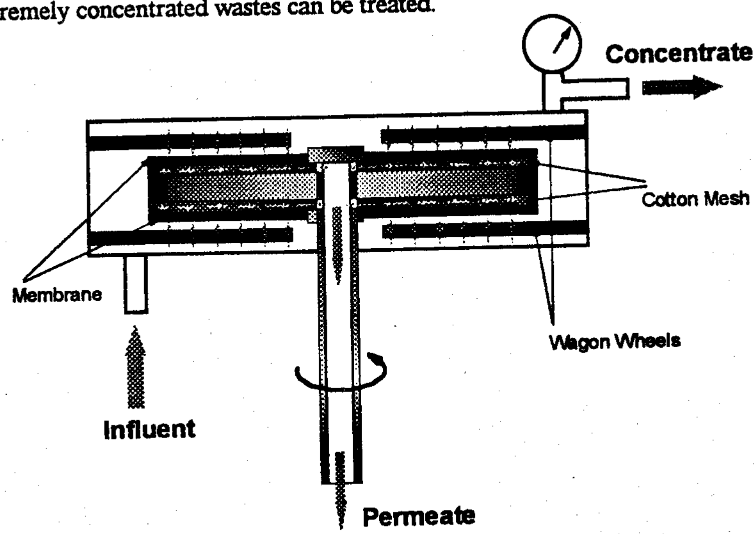

Figure 1. Schematics of ST-II System (Only One Disk Shown)

MATERIALS AND METHODS

A total of six runs were completed using two coolants/lubricants from an aluminum rolling mill operation. Three runs were conducted using a polymeric membrane (PV-100K, MWCO = 100,000) and three were completed using a ceramic membrane (avg. pore size = 0.1 μm). The coolants/lubricants had an initial oil content of about 5% and were taken directly from the milling process. Both coolants contained surfactants, film strength additives, and

In Figure 3, the permeate flux and concentration factor (CF) versus operation time are presented for ceramic run 3 (resulted from other runs were similar). For runs 2 and 3, the system was operated in the recycle mode at whole number values of CF to determine if the flux was temporal dependent at a given CF. In run 2 (coolant A), the flux decreased during changes in CF but then increased during the subsequent recycle operation to about one-half or more of the value observed at the previous CF. For run 3 (coolant B) this phenomenon was not as apparent and could be due to the differences between the coolants.

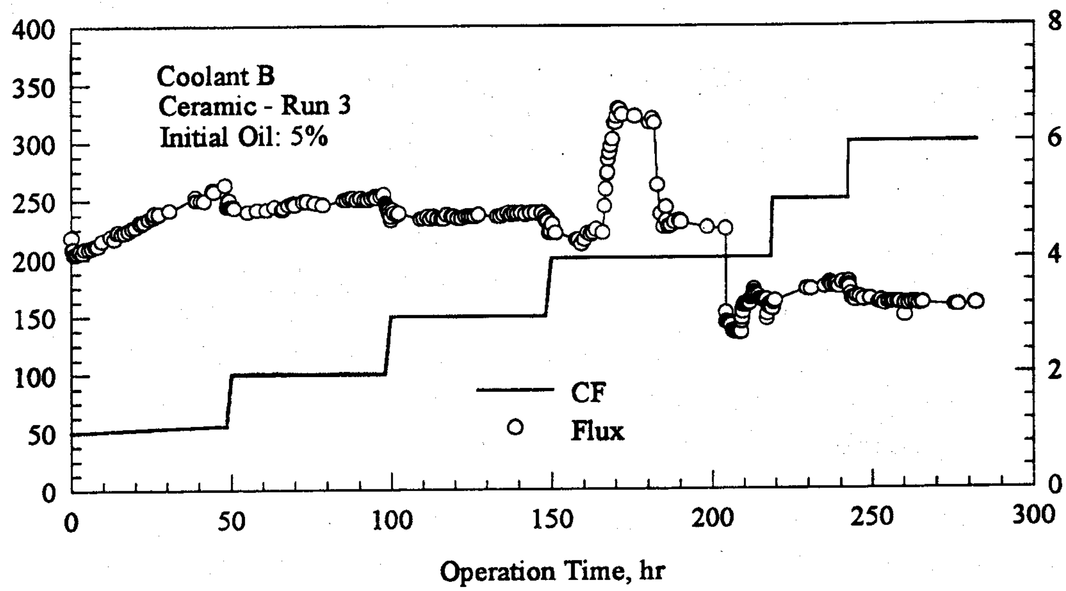

Figure 3 Permeate Flux and CF Vs Operational Time for Run 3 - Ceramic Membrane

In Figure 4, the effect of temperature and rotational speed on permeate flux is presented. At 166 hours and CF = 4X, the feed tank temperature was increased from 110°F to 140°F resulting in a flux increase of 220 to 319 gal/ft^2-d. The viscosity of water, which decreases by 24 percent over the temperature range investigated, accounts for only a portion of the flux increase. The remaining increase in flux is due to changes in the viscosity, density and diffusivity of the oil droplets. Coolant B's viscosity-temperature relationship was determined at a CF = 4X (data cannot be presented for proprietary reasons). The coolant viscosity decreased more sharply with temperature compared to what is predicted for water and this is hypothesized to be the primary reason for the 45 percent increase in flux with temperature. Because the flux-temperature relationship is so strong, a full-scale system should be operated at the highest temperature possible. Thus, the ceramic membrane, which has an maximum operating temperature of 160°F, has an advantage over the polymeric membrane (max. temp. of 120°F).

At 204 hr., rotational speed excursions were started. The flux decreased from 230 to 140 gal/ft^2-d as the rotational speed was decreased from 1750 to 1000 rpm. When the rotational speed was increased from 1000 to 1500 rpm and then back to 1750 rpm, the flux did not fully recover to the pre-rotational excursion value. Lipp *et al.* (1984) reported the gel layer, once formed, may be sufficiently stable to withstand increases in turbulence. It is hypothesized that this phenomenon was operative in the later portion of ceramic run 3. Until additional research is conducted on the J-ω relationship, the highest possible rotational speed should be used in actual operations. Permeate water quality (turbidity, O/G and TSS) was not affected by temperature or rotational speed excursions.

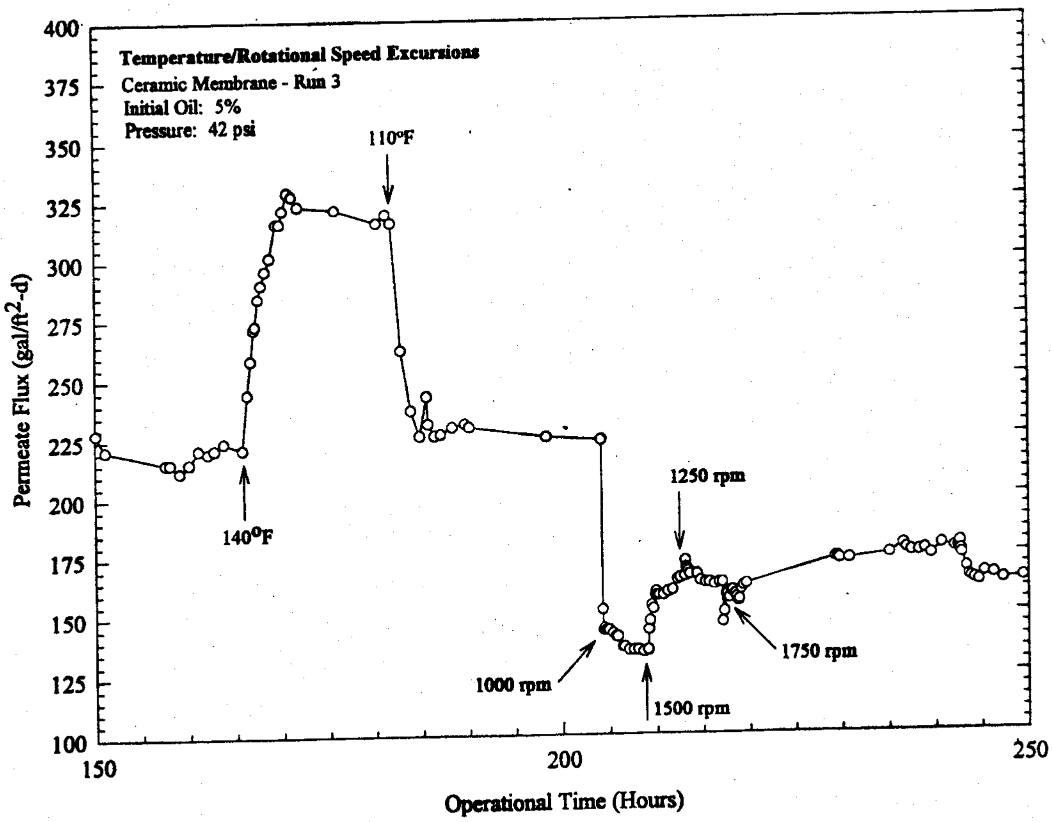

Figure 4. Temperature and Rotational Excursions

In Table 1, a summary of permeate flux results are presented for the six runs. The ceramic membrane had a larger flux compared to the PV-100K membrane. This was most likely due to the larger pore size of the ceramic membrane (0.1 μm compared to 100,000 MWCO (about 0.01 μm)). Although, the use of a membrane with a larger pore diameter does not guarantee a higher flux. If the solute size is about the size of the pore, the solute can easily plug the pore opening. For the polymeric membrane, a new membrane was required for each run. There was a noticeable layer of oil on the membranes in all runs while for runs 2 and 3, the clean water flux was never restored to near its original value. In contrast, the same ceramic membrane was used for all runs however, the washing solution was altered (no detergent) between runs 1 and 2. During ceramic run 1 cleaning, the flux was high but eventually decreased to zero. The membrane vessel was opened and a whitish deposit, believed to be the commercial detergent, was observed on the membrane. After removing the deposit and sponging the membrane with ≈ 1% sulfuric acid solution, the clean water flux was restored above its virgin value.

Table 1. Summary of Permeate Flux Results

Run ID	Average Flux[1] ± std gal/ft^2-d			CWF[2] gal/ft^2-d	
	Entire Run	Semibatch	Batchdown	Before	After
PV-100K					
Run 1	64 ± 14	73 ± 4.8	50 ± 12	118	118
Run 2	104 ± 44	128 ± 31	61 ± 31	589	172
Run 3	69 ± 18	78 ± 8.5	45 ± 14	718	115
Ceramic					
Run 1	87 ± 30	99 ± 18	61 ± 17	320	159
Run 2	135 ± 23	142 ± 19	103 ± 9	513	431
Run 3	205 ± 11	235 ± 13	165 ± 8	431	481

[1]At 110±2°F. [2]Clean Water Flux. Not Applicable.

In Table 2, a summary of the permeate quality parameters for both membranes during semi-batch and batchdown operation as well as for the entire run are presented. Permeate quality decreased as the feed concentration increased and was better for the ceramic membrane compared with the polymeric membrane.

Table 2. Summary of Permeate Water Quality Results

Parameter	Average ± std			Removal, %
	Entire Run	Semibatch	Batchdown	
Turbidity, NTU				
PV-100K Run 1	81 ± 182	20 ± 9.3	175 ± 267	---
Run 2	210 ± 313	90 ± 80	597 ± 459	
Run 3	147 ± 355	4.3 ± 6.1	595 ± 518	
Ceramic Run 1	81 ± 181	8.0 ± 6.1	355 ± 255	
Run 2	1.21 ± 0.9	1.25 ± 0.96	0.99 v 0.38	---
Run 3	0.23 ± 0.09	0.19 ± 0.04	0.27 ± 0.07	
O/G, mg/L				
PV-100K Run 1	221 ± 300	98 ± 10	289 ± 363	98.8
Run 2	832 ± 1,172	426 ± 494	1,481 ± 1,684	94.8
Run 3	945 ± 2,632	89 ± 11	2,310 ± 4,132	99.6
Ceramic Run 1	187 ± 107	121 ± 13	252 ± 121	99.4
Run 2	37 ± 5	40 ± 3	32 ± 0	99.9
Run 3	20 ± 15	11 ± 10	33 ± 2.6	99.9
TSS, mg/L				
PV-100K Run 1	56 ± 63	53 ± 28	57 ± 74	99.3
Run 2	120 ± 111	82 ± 107	161 ± 107	99.0
Run 3	59 ± 114	3.4 ± 3.4	147 ± 151	99.5
Ceramic Run 1	12 ± 15	3 ± 2.5	23 ± 17	99.5
Run 2	8.8 ± 8.3	7.7 ± 6.9	15 ± 11	99.7
Run 3	< 1	1.2 ± 1.4	< 1	99.7

CONCLUSION

The SpinTek ST-II system was effective in concentrating oily wastes from about 5% to as high as 75% while maintaining a high permeate flux. The decoupling of turbulence promotion from feed pressurization/recirculation by rotating the membrane is the primary reason for the increase in system performance over that observed with conventional cross-flow ultrafiltration systems. The following specific conclusions can be forwarded: 1) The ceramic membrane was superior to the PV-100K polymeric membrane in regards to flux quantity and quality as well as membrane cleaning/durability. In addition, because of its higher operating temperature (160°F compared with 120°F for the PV-100K membrane) its use in full-scale operations is recommended; 2) Permeate flux was dependent on the feed temperature and rotational speed. Flux increased by about 45% when the temperature was increased from 110 to 140°F. A larger decrease in waste viscosity, over that predicted for water alone, was the primary reason for the stronger than expected flux-temperature relationship. The flux-rotational speed (ω) relationship was described by $J = f(\omega)^{0.90}$ and the gel layer exhibited some sustainable stability with increases in ω. Until additional research is conducted on the J-ω relationship, the highest possible rotational speed should be used in actual operations. Permeate water quality was not affected by temperature or rotational speed excursions.

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