A laboratory study of poultry abattoir wastewater treatment by membrane technology

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Zhang, S.Q., Kutowy, O., Kumar, A. and Malcolm, I. 1997. **A laboratory study of poultry abattoir wastewater treatment by membrane technology**. Can. Agric. Eng. **39**:099-105. Ultrafiltration (UF) and nanofiltration (NF) were tested as potential methods of treating poultry abattoir chiller tank effluent for recycling. Various ultrafiltration and nanofiltration membranes were tested for their fouling propensities as well as for their ability to produce a permeate which meets Agriculture and Agri-food Canada's guidelines for recycling: total plate count of less than 1,000 organisms/mL; total *coliform* counts of less than 10 organisms/mL; total *E. coli* counts of less than 2 organisms/mL; total organic carbon less than 100 mg/L; and light transmittance of greater than 90%. Several UF membranes removed all bacteria and achieved the required 90% light transmittance but failed to meet the total organic carbon (TOC) target. However, the TOC effluent criterion was met by NF membranes. Both of the commercial thin film composite membranes not only produced permeate with less than 100 mg/L of TOC but also gave a reasonable flux of 46-66 $L \cdot m^{-2} \cdot h^{-1}$. It should therefore be possible to develop a recycling system for chiller tank effluent using any of the above nanofiltration membranes. Recycling would reduce water consumption and wastewater disposal and has the potential to reduce energy costs by reusing pre-chilled water.

Les systèmes d'ultrafiltration (UF) et de nanofiltration (NF) ont été étudiés afin d'évaluer leur capacité à traiter et à recycler les eaux provenant des bassins de refroidissement des abattoirs de volailles. Plusieurs membranes d'ultrafiltration et de nanofiltration ont été évaluées afin de comparer leur propension à colmater en présence de matière organique ainsi que pour déterminer leur capacité de produire un effluent qui respecte les recommandations d'Agriculture et agro-alimentaire Canada qui sont: nombre total de microorganismes sous 1000 organismes/mL, nombre total de *coliformes* sous de 10 organismes/mL, nombre total de *E. coli* sous de 2 organismes/mL, carbone organique total à moins de 100 mg/L et transmission de lumière supérieure à 90%. Plusieurs membranes UF éliminent toutes les bactéries, produisent un effluent ayant une transmission lumineuse supérieure à 90% mais qui dépasse les recommandations concernant la quantité acceptable de carbone totale. Cependant, le système nanofiltration peut satisfaire cette condition. Les membranes de nanofiltration commercial filtrent la quantité requise de carbone organique et laissent passer un flux raisonnable de 46 à 66 $L \cdot m^{-2} \cdot h^{-1}$. Il est donc possible de développer un système pour recycler l'effluent provenant d'un bassin de refroidissement en utilisant un système de nanofiltration avec l'un ou l'autre des deux films. Un système de recyclage permettrait de réduire la consommation d'eau ainsi que la quantité d'eau usée dont il faut disposer. De plus, une économie des coûts d'énergie est possible si l'eau pré-refroidie est réutiliser.

INTRODUCTION

The economic impact of new and more stringent environmental regulations governing effluent discharge is being felt in many industrial sectors. The procurement of clean water and the treatment of wastewater are essential for the operation of an abattoir. Water use for poultry slaughtering has been estimated to range from 18 to 30 m^3/t of finished product while water use for poultry processing is about 15 to 100 m^3/t of finished product. To meet environmental constraints, the cost of water and its disposal have been increasing. This may limit the potential production and profitability of an abattoir, particularly the rural slaughterhouses. One of the two solutions which could be implemented is : 1) a method of drastically reducing the volume of water discharged per chicken slaughtered; or 2) a system for treating the increased volume of wastewater resulting from the increase in plant capacity which allows direct discharge into an open water course.

Significant reduction in wastewater can be achieved by adopting recycling technologies. In poultry processing, live birds are slaughtered, scalded, de-feathered, eviscerated, cleaned, and chilled. Scalding and chilling generate a large amount of wastewater. Since the chiller effluent has lower biological oxygen demand (BOD) and chemical oxygen demand (COD) than scalder effluent, this stream was selected for the present study.

The main contaminants in chiller water are blood, fats/oils, grease and micro-organisms. Typically, total suspended solids are reported in the 600-800 mg/L range. Approximately 30% of these solids (200-250 mg/L) are large floating particles of grease and fat. The major portion of the suspended solids (55% of the 20-50 μm range particles) form an opaque haze and are believed to be emulsified oils of entrapped proteins and lipids as well as the bulk of the micro-organisms (Picek 1992). The remaining 5-10% of the particles are less than 5 mm in size and seem to be even more tightly bound with emulsified globules.

The Agriculture and Agri-food Canada meat inspection regulations suggest that reconditioned water may be used to replace potable water as make-up for poultry chiller baths if certain basic requirements are met: total plate count of less than 1000 organisms/mL, total coliform counts of less than

10 organisms/mL, total *E. coli* counts of less than 2 organisms/mL, total organic carbon less than 100 mg/L and light transmittance of greater than 90%.

The conventional methods reported in the literature for reconditioning poultry wastewaters can be divided into the following three categories :

1. Electrical and optical: Destruction of bacteria by electrical stimulation (Li et al. 1994) or UV irradiation (Sheldon and Carawan 1988).
2. Chemical and biochemical: Destruction of bacteria by ozonation; Biological degradation of organic matter using an anaerobic filter or sequencing batch reactor; Chemical separation of organic matter from waste stream by coagulation and flocculation (Morgan et al. 1988).
3. Physical: Dissolved air flotation, diatomaceous earth (DE) filtration (Sheldon and Carawan 1988) and microfiltration (Hart et al. 1988).

Electrical and optical destruction can kill the undesirable microorganisms present in the waste stream but the water will not be clarified and the concentration of organic carbon will not be reduced. Ozonation is capable of providing virtually sterile water, but may not be cost effective for treating wastewaters with high organic loading. In general, filters alone are very labor intensive, costly and unreliable. An additional problem is the disposal of filter media. Chemical additives and flocculants can improve filtration but will increase the cost of the process significantly.

Due to their capabilities to remove all the microorganisms and suspended matter, membrane processes are a potential alternative for reconditioning process water. Furthermore, membrane technology allows the minimization of chemical usage and in turn, disposal costs. Pressure driven membranes for dissolved liquid separations are generally classified in the following four categories based on mean pore size of membranes:

1. Reverse osmosis (RO) which separate species <1 nm (monovalent salts).
2. Nanofiltration (NF) which separates species in the range of 1-5 nm (sugars, divalent ions) while allowing the passage of monovalent ions.
3. Ultrafiltration (UF) which separates species in the range of 5-100 nm (proteins, pyrogens).
4. Microfiltration (MF) which separates species in the range of 100-10,000 nm (bacteria, blood cells, yeast).

Ultrafiltration and nanofiltration membranes are also characterized on the basis of their ability of separating 90% of a solute (such as polyethylene glycols, raffinose) of known molecular weight. This molecular weight cut-off (MWCO) rating of a membrane is expressed in kilo Dalton (kDa) and is proportional to the mean pore size of membrane.

The objective of this study was to determine the applicability of ultrafiltration and nanofiltration membrane systems to treat poultry abattoir wastewater in order to obtain a recycle stream that will meet the Canadian poultry wastewater reuse criteria. A variety of membranes were tested to find a suitable membrane which could provide the desired separation and flux. Special goals were to determine if (a) suitable flux rates could be achieved, (b) microbial count and TOC could be reduced such that permeate could be reused, and (c) pore sizes of membranes had an effect on flux and separation.

EXPERIMENTAL

Feed materials

Poultry abattoir wastewater was obtained from a nearby commercial plant. Each sample was transported to the laboratory within 10-12 h of slaughtering in a plastic pale in winter but the sample was not frozen. Before transferring to the feed tank of the membrane test setup, the wastewater was first allowed to pass through a 325 (45 µm) mesh sieve and then through a 400 (38 µm) mesh sieve lined with polypropylene fiber to remove large particles. In case the feed was not used immediately, 0.16% (w/w) of sodium azide (NaN_3) was added to prevent bacterial growth. All samples were subsequently stored at 4°C.

Analyses

Light transmission was measured using a spectrometer (Spectronic 301, Milton Roy Company, Rochester, NY). Total organic carbon was determined by total organic carbon analyzer (TOC-5000, Shimadzu Corporation, Kyoto, Japan). Total plate count, total coliform count, total *E. coli*, were analyzed by Accutest Laboratories, Ottawa, ON. The total coliforms and fecal coliform were measured by standard methods (Greenberg et. al. 1992) using standard total coliform membrane filter procedure and fecal coliform membrane filter procedure respectively. Fecal *streptococcus* was measured by standard methods (Greenberg et al. 1992) with a membrane filter technique and the standard plate count was measured by standard methods utilizing heterotrophic plate count procedure (Greenberg et al. 1992). *Escherichia coli* was measured using a novel chromogenic reagent detection method described by Ley et al. (1988).

Membrane testing and evaluation

The experimental setup for the ultrafiltration (UF) or nanofiltration (NF) system is a NRC standard test unit which has been described by Sourirajan and Matsuura (1985). This test unit consisted of 12 stainless steel pressure cells, arranged in four sets of three cells. Each cell can accommodate a membrane sample with an area of 1450 mm^2. Each set of membrane cells is connected in parallel to minimize the pressure drop across cells. The permeate from each membrane can be sampled individually allowing the evaluation of 12 different membranes samples simultaneously (Fig. 1). The temperature of the feed is controlled by a water cooled heat exchanger. Occasionally, an ice bag is immersed in the feed tank to maintain the temperature.

A variety of commercial UF/NF membranes were chosen for this investigation: Regenerated cellulose, Radel A polysulfone, Udel polysulfone, Desal thin film composite and Filmtech thin film composite membranes. Some NRC laboratory-made membranes such as carboxyl and hydroxyl substituted polysulfone membranes were also evaluated.

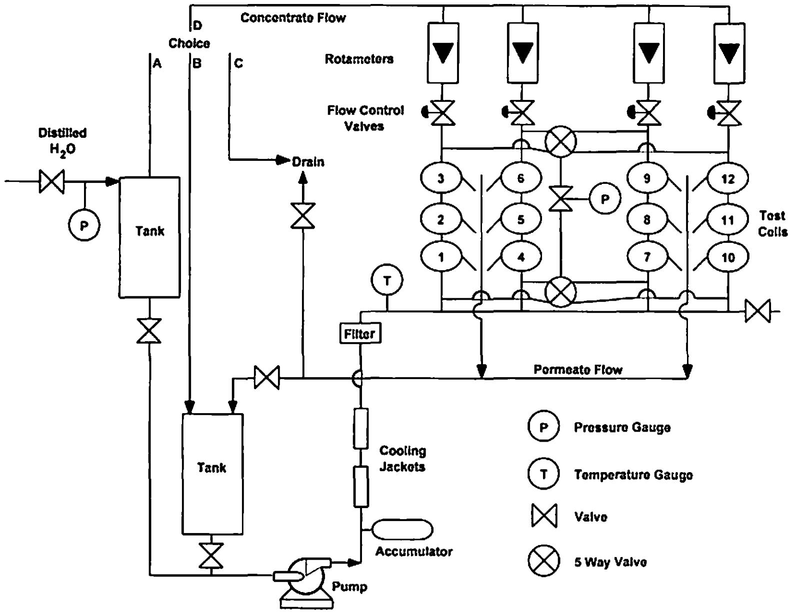

Fig. 1. A schematic diagram for the experimental set up.

Ultrafiltration membranes

Performance of ultrafiltration membranes is dependant on their surface properties and pore size distribution. A membrane will attract or repel components of the feed depending upon the hydrophillic or hydrophobic nature of the membrane surface. Permeation of dissolved or suspended components will also be affected by the pore size distribution and morphological structure of the membranes. To evaluate the performance of membranes with different characteristics, three ultrafiltration membranes with different surface properties and pore sizes were chosen. These membranes were Regenerated cellulose (hydrophillic), Radel A polyethersulfone (slightly hydrophillic) and Udel PS (hydrophobic). Membrane performances were obtained using a standard membrane characterization protocol described by Sourirajan and Matsuura (1985). The pure water permeation rate (PWP) and separation of different molecular weight polyethylene glycols (6, 12, and 35 kDa) were determined at an operating pressure of 345 kPa and a temperature range of 10-15°C.

A static adsorption test (sometimes referred to as a "dip" test) was used to screen membranes for their fouling propensities. Two characterized membrane coupons were removed from the test cell. These membranes were then immersed for 3 h in a poultry feed water solution. The membrane was rinsed by distilled water then recharacterized in the ultrafiltration test system. A membrane which showed highest "flux recovery" (i.e. highest PWP after adsorption) in this test was chosen for subsequent testing with the poultry water. This high flux rate was attributed to a lower adsorption of foulants on membranes.

Ultrafiltration membrane's ability to separate substances is usually reported in terms of separation of standard organic solutes (for example polyethylene glycol) of known molecular weight. Several membranes with different molecular weight cut-off (MWCO) from the same membrane materials were first characterized with polyethylene glycol and then tested at an operating pressure of 345 kPa with the actual poultry abattoir wastewater. Actual performance evaluation was done in both batch and continuous operations. In batch operation, the permeate was discarded. Batch operation was used to concentrate insoluble solids in the retentate (a concentration trial) and to investigate the flux decline and TOC separation. In continuous operation, permeate was recombined with retentate and recirculated thus maintaining a constant insoluble solids concentrate in the retentate. Continuous operation was used during stabilization of the membrane system.

Nanofiltration membranes

Several commercial nanofiltration membranes were investigated to determine if the permeate would meet the TOC requirements at operating pressures of 345, 689, and 1034 kPa, respectively.

Membrane cleaning

It is likely that exposure of membranes to complex feeds can impact on their performance. Therefore, the membranes were cleaned after each use with feed to ensure that base line performance was restored. The membranes were first flushed with warm reverse osmosis water at 50°C followed by a wash with 0.2N NaOH for 30 minutes. Finally, the system was thoroughly flushed with room temperature reverse osmosis water. Thoroughness of the cleaning was tested by measuring the pure water permeation rate after 30 minutes. The system was deemed clean when water permeation rate did not significantly differ from that of an unexposed membrane.

RESULTS AND DISCUSSION

Ultrafiltration membranes

A summary of the membrane characterization studies for three types of membrane materials is given in Table I. The pure water permeation rate (PWP), the product rate (PR) and separation of a probe solute (PEG 6 kDa) are listed for regenerated cellulose, Radel A polysulfone (Radel A PS) and Udel polysulfone (Udel PS) membranes. Four membrane coupons were characterized for each polymeric material. An average separation and flux were calculated and considered to be representative of the performances of each type of membrane. A variation of 10% in flux and separation between membrane coupons is expected for the more open membranes of the same material (Dal-Cin et al. 1995). Regenerated cellulose membrane had the highest PEG separation (90%) and the lowest flux (83.6 $L{\bullet}m^{-2}{\bullet}h^{-1}$). These were considered to be "tight" ultrafiltration membranes with the "smallest" pore size. Udel PS had the lowest PEG 6 kDa separation (56%) and the largest flux (185.0 $L{\bullet}m^{-2}{\bullet}h^{-1}$). Udel PS membranes were considered to have the "larger" pore size. Radel A PS membranes had intermediate membrane performances with flux and separation of 67% and 156.8 $L{\bullet}m^{-2}{\bullet}h^{-1}$, respectively.

The results from the static adsorption test are given in

Table I: Membrane performance data for three different polymeric materials

Replicate	Regenerated cellulose			Radel A PS			Udel PS		
	PWP ($L \bullet m^{-2} \bullet h^{-1}$)	PR ($L \bullet m^{-2} \bullet h^{-1}$)	PEG (%)	PWP ($L \bullet m^{-2} \bullet h^{-1}$)	PR ($L \bullet m^{-2} \bullet h^{-1}$)	PEG (%)	PWP ($L \bullet m^{-2} \bullet h^{-1}$)	PR ($L \bullet m^{-2} \bullet h^{-1}$)	PEG (%)
1	84.55	84.34	95.89	171.03	146.02	74.24	222.83	188.55	56.48
2	84.62	82.34	93.54	166.83	144.76	70.85	246.21	204.55	41.80
3	80.90	77.23	90.60	192.34	167.10	56.46	217.59	181.31	59.21
4	92.41	90.62	80.30	193.72	169.38	66.86	193.03	165.45	65.62
Average	85.62	83.63	90.08	180.98	156.82	67.10	219.92	184.97	55.78
Std. Dev.	4.85	5.54	6.87	14.03	13.24	7.71	21.82	16.23	10.08

Note: Effective membrane area of 1450 mm^2. Operating temperature between 13.6 to 13.8 °C.
Operating pressure was 345 kPa. PWP: Pure water permeation rate. PR: Product rate.
PEG: Polyethylene glycol (molecular weight, 6 kDa).

Table II. A comparison could be made for the PWP, PR and PEG 6 kDa separation before (denoted by a subscript b) and after (denoted by a subscript f) "soaking" the membrane in the poultry abattoir wastewater. The ratio of the flux (PWP_f/PWP_b) and (PR_f/PR_b) and the ratio of the separation (SEP_b/SEP_f) gave the relative magnitude of those changes. In general, there were no significant changes (< 2%) in the flux and separation for regenerated cellulose. The ratios of PWP, PR, and PEG 6 kDa separation before and after "soak" were 1.0 for both regenerated cellulose membranes. This means that the membrane performances were not changed as a result of exposure to the components of the poultry abattoir wastewater. In other words, this membrane had a good resistance for fouling. For Udel polysulfone membrane, the ratios of PWP, separation of PEG 6 kDa before and after "soak" were 0.77-0.87 and 1.2-1.6, respectively. This indicated adsorption on the surface had taken place which partially decreased the number and/or size of the membrane pores. Consequently, the permeation rates decreased by 23 to 13% of the original while the separations increased by 1.2 to 1.6. The experimental results indicate that Radel A polysulfone membrane have fouling propensities that are intermediate between that of regenerated cellulose and Udel polysulfone. The ratios of PWP, PR, and PEG (6 kDa) separation were 0.9, 0.8, and 1.1, respectively. Radel A was chosen as the membrane material for further evaluation because of its physical material advantage (i.e. strength, acid/base resistance) and an overall performance including separation and flux.

The effects of pore size (related to MWCO of membranes) on the treatment of poultry waste effluent stream were studied with five different Radel A PS membranes with molecular weight cut-off of 4.5, 10, 35, and 100 kDa. An additional

Table II: Static adsorption data for ultrafiltration membranes of different polymeric materials

Membranes	PWP_b ($L \bullet m^{-2} \bullet h^{-1}$)	PWP_f ($L \bullet m^{-2} \bullet h^{-1}$)	PWP_f/PWP_b	PR_b ($L \bullet m^{-2} \bullet h^{-1}$)	PR_f ($L \bullet m^{-2} \bullet h^{-1}$)	PR_f/PR_b	SEP_b (%)	SEP_f (%)	SEP_f/SEP_b
Regenerated cellulose	84.48	85.03	1.00	82.34	84.14	1.02	93.54	94.19	1.01
	92.00	91.17	0.99	90.62	89.03	0.98	80.30	80.53	1.00
Radel A PS	138.14	119.93	0.87	144.76	121.03	0.84	70.85	87.64	1.24
	163.14	145.24	0.89	169.38	142.97	0.84	66.86	75.22	1.13
Udel PS	205.38	177.79	0.87	204.55	177.79	0.87	41.80	66.26	1.59
	165.45	128.21	0.77	165.45	165.45	1.00	65.62	76.79	1.17

Note: Effective membrane area of 1450 cm^2. Operating temperature between 13.6 to 13.8 °C.
Operating pressure was 345 kPa. PWP_f / PWP_b, PR_f/PR_b, and SEP_f/SEP_b were the ration of pure water permeation rate, product rate and PEG 6kDa separation before (denoted by a subscript b) and after (denoted by a subscript f), respectively.

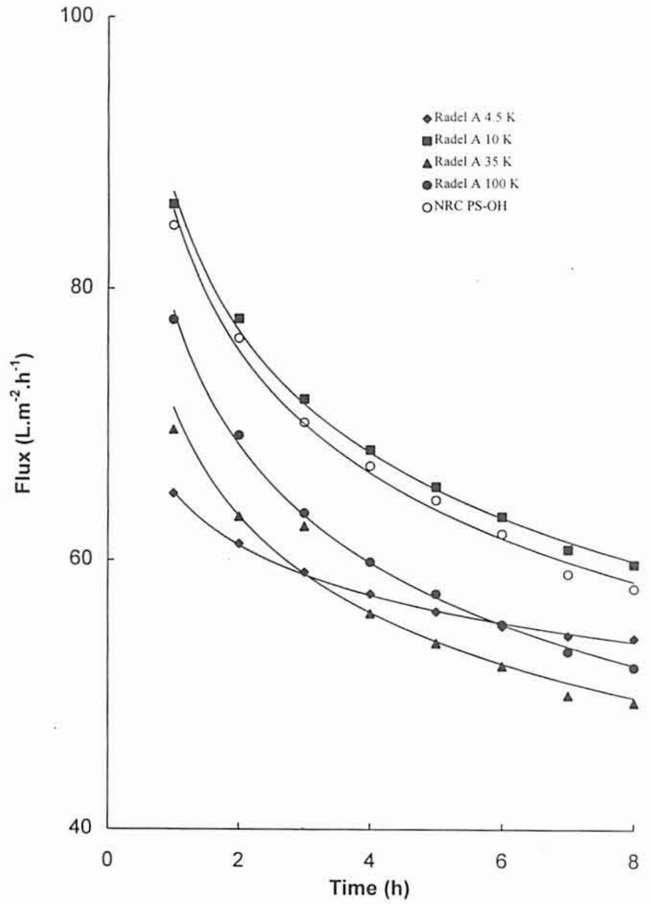

Fig. 2. The effect of pore size on the permeate flux by using Radel A PS and NRC Hydroxyl PS membranes.

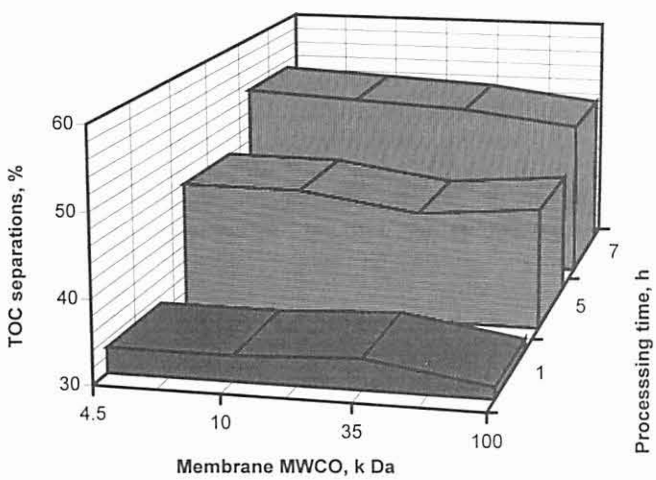

Fig. 3. Effects of processing time and membrane MWCO on TOC separations by using Radel A Polysulfone membranes.

membrane with substituted hydroxyl group on polysulfone material was also evaluated using a typical feed (540 mg/LTOC) and operating pressure (345 kPa). Figure 2 shows some representative flux decay curves for a concentration run (where permeate was not recycled to the feed) for eight hours. During this experiment, a reduction of up to 55% in initial feed volume was observed. As the experiment progressed, a steady decrease in flux was observed for all membranes. This flux decline was due to both membrane fouling as well as the increase in concentration of the feed as experiment was performed in concentration mode.

Figure 2 also shows the effects of pore size on flux. Membranes with a large MWCO (10, 35, and 100 kDa) along with hydroxyl polysulfone showed a rapid flux decline and the flux did not stabilize even after eight hours of operation. However, Radel A polysulfone membranes with MWCO of 4.5 kDa, gave a relatively smaller flux decline after five hours of operation (< 2%). This observation suggests the need for a small pore size (< 10 kDa) membrane to prevent pore plugging in this application. The addition of hydrophillic groups such as hydroxyl did not affect membrane performance. It seemed that beyond certain MWCO of the membrane (>10 kDa), the pore size of the membrane had a more dominant effect than the surface properties of the membranes. Even though hydroxyl, dibrominated polysulfone membranes were more hydrophillic than polysulfone and have less affinity for proteins, the difference between Radel A PS and modified Radel R PS was negligible both in terms of steady state flux and TOC separation.

The effects of membrane pore sizes on the TOC separation are shown in Fig. 3. In general, all membranes tested showed the same level of TOC separation (50%). It was observed that separation increased with the processing time. However, relative insensitivity of separation to membrane material and the weak correlation with membrane pore size suggested that a "gel" layer is controlling the separation rather than the membrane. It is commonly reported (Hsieh et al. 1979) that the suspended solids can form a coating or gel layer on the surface of the membranes resulting in regions of higher concentration near the surface of the membrane. Such gel layers play a very important role as a dynamic membrane for the TOC separation. The examination of feed exposed membranes were found to have gel like deposits on their surface.

An important criteria of recycled water concerns microorganism concentration and percent light transmission. Based on a visual test, all permeates were completely clear and colorless. Permeate obtained with membranes of greater than 10 kDa MWCO had a foul odour. This odour might be due to the poor separation of low molecular weight components like amines and sulfur compounds. The microorganism analysis showed that total coliforms, faecal *Streptococci*, faecal coliforms and *E. coli* were all undetectable in the permeates from the 4.5 kDa MWCO membranes.

The light transmission rate at 500 nm was 98% using tap water as a reference. The above microorganism analysis results and other permeate properties were expected because UF/NF membranes should effectively retain all the molecules which have larger molecular sizes than membrane pore sizes. Depending upon the specific membranes (e.g. UF and NF), solute molecules larger than 1.0 nm (> 0.2 kDa MWCO) are retained, so bacteria with molecular size >100 nm (>30 kDa) should be retained. The results confirmed that the permeate was able to meet a majority of the regulations governing water reuse for poultry industry.

The major limitation in the use of ultrafiltration membranes was the TOC content of the permeate above the required Agriculture Canada meat inspection regulations of 100 mg/L. This criteria was not met with ultrafiltration membranes. Using the series of Radel A PS and hydroxyl substituted Radel A PS membrane, the TOC separation ranged from 35 to 55% (Fig. 3) for a feed concentration of 580 to 780 mg/L. The TOC concentration in the permeate was therefore at least 260 mg/L. Nanofiltration membranes (with lower MWCO rating than ultrafiltration) were then investigated to meet this more stringent requirement.

Nanofiltration Membranes

Several commercial nanofiltration membranes were chosen for this series of tests. Figure 4 shows the relationship between the permeate flux and the TOC separation for several nanofiltration and ultrafiltration membranes. Generally, there is an inescapable trade-off between flux and separation while selecting membranes with different MWCO rating and materials for a particular application. A higher separation does not necessarily result in a lower flux and vice versa. Under the operating pressure of 345 kPa, the TOC separation and flux of thin film composite (NF 45) membranes were 72 -82% and 17.2 L•m^{-2}•h^{-1}, respectively, compared with that of 4.5 kDa Radel A polysulfone membranes at 30 - 50% and 65.5 L•m^{-2}•h^{-1}, respectively. Both of these thin film composite membranes (NF 45 and DS) could produce permeate quality which meets the guidelines of less than 100 mg/L of TOC.

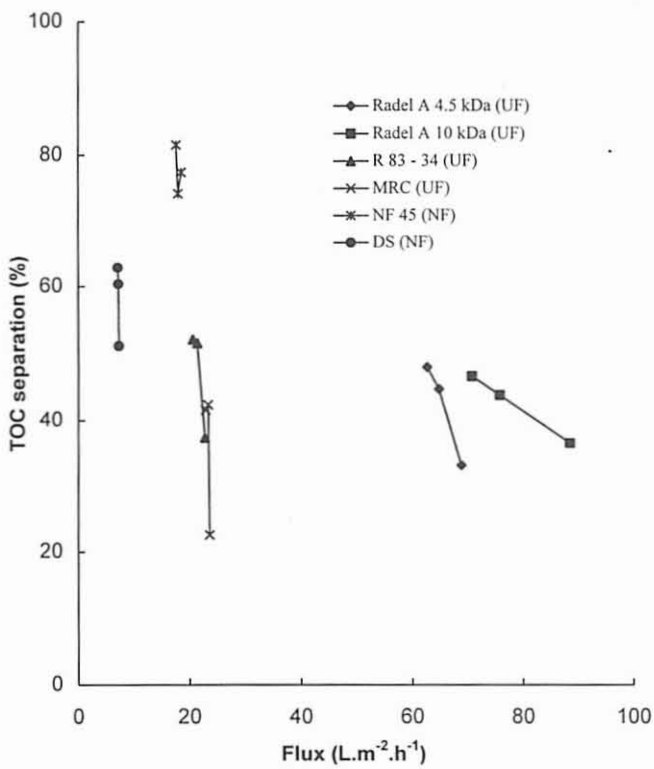

Fig. 4. The relationship between the permeate flux and the TOC separation for some UF and NF membrane. Radel A 4.5 kDa and Radel A 10 kDa: Radel A Polysulfone membranes with MWCO of 4.5 kDa and 10 kDa, respectively. DS: Desal thin film composite membrane. R83-34: NRC Radel R polysulfone membrane. MRC: Regenerated cellulose membrane. NF 45: Thin film composite membrane.

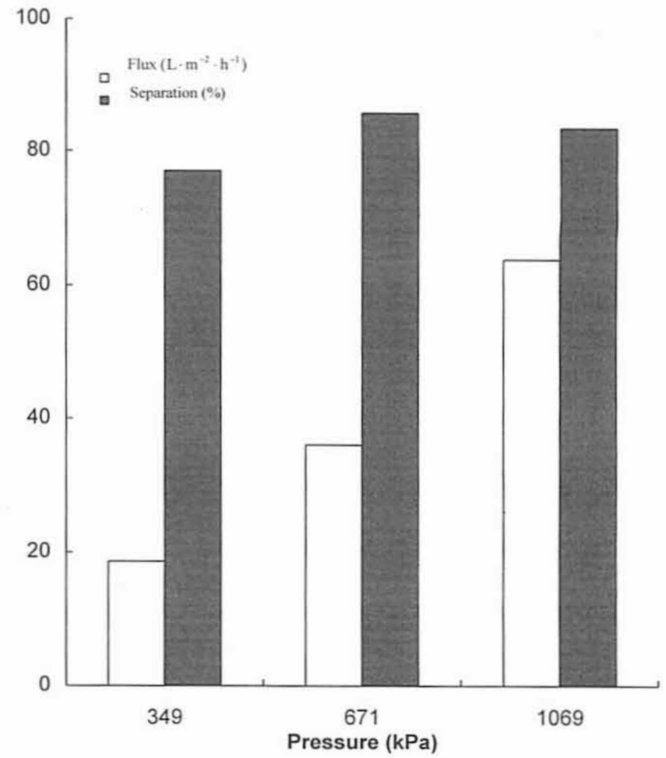

Fig. 5. Effects of operating pressure on membrane performance by using thin film composite membrane (NF 45). Operating temperature was 13_0C.

Membrane flux can be increased by increasing the effective driving force (or pressure) of the system. Figure 5 shows that the permeate flux was increased from 18.6 to 63.8 L•m^{-2}•h^{-1} when the operating pressure was changed from 345 to 1069 kPa. After three hours of continuous operation, a flux of 48.3 to 51.7 L•m^{-2}•h^{-1} with a TOC concentration of 47 mg/L in the permeate was obtained with the NF 45 membrane. A flux of 47.6 L•m^{-2}•h^{-1} with a TOC concentration of 65 mg/L in the permeate was obtained using another thin film composite membrane (DS). Both of these TOC values met the Agriculture and Agri Food Canada criteria for recycled water.

Out of the several factors influencing flux (pore size, pressure, temperature, cross flow velocity and the nature and starting concentration of dissolved and suspended solids), the effects of cross flow velocity and the nature of feed on flux merit investigation. NF 45 membranes were selected because of their superior performance as described previously. Flux was increased almost proportionally with operating pressure (Fig. 5). However, an increase in operating pressure also increases the materials cost. Cross flow velocity increased permeate flux also (Table III). Thus, pilot plant equipment should use the highest possible cross flow velocity.

For the NF membrane, flux was completely restored to

Table III: The effect of cross flow velocity on the permeate flux

Pressure (kPa)	Velocity (m/s)	Flux ($L \cdot m^{-2} \cdot h^{-1}$)											
		Radel A PS 4.5K			Radel A PS 10K				Radel A PS 35K		Radel A PS 100K	Hydroxyl-PS	
		1	2	3	1	2	3	4	1	2	1	1	2
344.7	0.8	59.8	50.8	51.9	58.8	59.7	58.8	61.7	53.7	45.2	52.1	58.8	57.0
217.9	1.0	37.8	32.5	33.5	43.0	43.4	42.4	61.5	40.9	37.8	39.0	50.2	47.4

Note:Effective membrane area of 1450 mm^2. Operating temperature between 9.7 to 9.9°C

original values by the post trial in line cleaning technique. This consisted of successive washing with warm water (50°C), alkaline solution and water.

CONCLUSIONS AND RECOMMENDATIONS

Ultrafiltration membranes were unable to reduce TOC concentration to less than 100 mg/L while nanofiltration membranes not only produced a permeate with less than 100 mg/L of TOC but also gave a reasonable flux of 46 to 66 $L \cdot m^{-2} \cdot h^{-1}$. These limited tests have indicated that nanofiltration is a promising method of reconditioning process water for reuse. Effects of pre-treatment of the chiller water on membrane performance should be investigated. These preliminary membranes flux will allow for an initial estimate of the cost and benefits of applying a membrane technology to the treatment of abattoir wastewater. The virtual absence of microorganisms in the permeate, along with increased waste treatment efficiency, or byproduct recovery from the concentrate, should all help the process economics. Based on the results from this study, nanofiltration membranes at a poultry abattoir site merits pilot testing for recycling wastewater.

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