Asian Journal of Chemistry; Vol. 24, No. 6 (2012), 2593-2597

ASIAN JOURNAL OF CHEMISTRY

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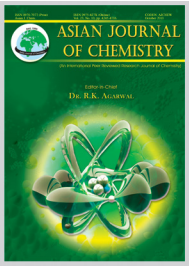

Investigation of Ultra-and Nanofiltration for Separation of Proteins and Lactose from Dairy Wastewater

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(*Received*: 19 May 2011; *Accepted*: 17 January 2012) AJC-10952

In this study, the proteins and lactose were separated from dairy wastewater using ultrafiltration. The effect of transmembrane pressure, feed flowrate, concentration factor on the recycle results are studied systematically. The permeate flux, protein and lactose content in the permeation and in the concentrate fractions were measured during the experimental runs. Meanwhile, the removal efficiency of COD is checked. It was found that ultrafiltration membrane provided 94-97 % recovery of protein in dairy wastewater and nanofiltration membrane provided 100 % recovery of lactose in ultrafiltration permeate. An increase in transmembrane pressure (TMP) increased the permeate flux which increased the rate of protein and lactose being recovered. The nanofiltration membrane showed approximately 96-99 % rejection of COD, the percentage being low at lower transmembrane pressures (greater than 10 bar) and high and higher transmembrane pressures (less than 10 bar). The nanofiltration permeate could be up to the standard of reusable water.

Key Words: Dairy wastewater, Protein separation, Ultrafiltration, Lactose separation, Nanofiltration.

INTRODUCTION

Water quality standards are becoming stringent. Conventional technology for dairy wastewater treatment suffers from several disadvantages like high cost of erection and maintenance and considerable power requirements[1]. Meanwhile, the nutrients (protein and lactose) in the dairy wastewater have been wasted. The major purpose of this study is utilization of dairy wastewater and to decrease the amount of waste in the dairy industry.

Many works have shown the advantage of the membrane techniques[2,3], for example the use of spiral-wound reverse-osmosis (RO) membranes for the concentration of whey, which gives rise to energy savings of approximately 60 % in comparison with those consumed when evaporation is used[4]. Membrane technology is finding increasing applications in the dairy industry[5-11]. Membrane processes have some advantages that make the membrane treatment attractive such as continuous operation, no pollution of the environment, little floor space required, simple operation, no civil construction necessary at the site and reduced cost with technological improvements. In this study, fractionation of dairy wastewater into lactose-enriched and protein-enriched streams using ultra- and nanofiltration membrane technique was examined.

Ultra- and nanofiltration can be defined as pressure-driven membrane processes for the separation and concentration of substances having a molecular weight between 103 and 106 Da for ultrafiltration and between 100 and 500 Da for nanofiltration. In both processes, the solution flows under pressure along the surface of a suitably supported membrane. The solvent and certain dissolved components pass through the membrane and are collected as permeate. Depending on the characteristics of the applied membrane some other components from the solution are retained by the membrane and concentrated, as the retentate fraction[10]. In this study, two series of experiments were proformed. The first one is ultrafiltration of dairy wastewater. The second one is nanofiltration of ultrafiltration permeate.

EXPERIMENTAL

The average composition of dairy wastewater, which was ultrafiltered by microfiltration membrane in this study are shown in Table-1.

TABLE-1
AVERAGE COMPOSITION OF FEED SOLUTIONS

Feed solutions	Protein	Loctose	Fat
Dairy wastewater [g/L]	1.6154	0.6673	0
Ultrafilteration permeate [g/L]	0.0776	0.6673	0

In present study one ultrafiltration membranes and one nanofiltration membrane have been investigated. GM2540C

TABLE-2
CHARACTERISTICS OF THE INVESTIGATED MEMBRANES

Membrane type	Membrane materials	Producer company	Membrane Cut-off	Process parameters		
				Pressure [bar]	Temperature [^{0}C]	pH
GM2540C (UF)	Polyamide	GE Osmonics	8 kDa	3.45-13.79	0-50	2-11
DK2540F (NF)	Polyamide	GE Osmonics	200 Da	4.83-27.58	0-50	2-11

membrane for ultrafiltration of the dairy wastewater and DK2540F membrane for nanofiltration of the ultrafiltation permeate. The characteristics of the investigated membranes are shown in Table-2.

The measured filtration characteristics were defined as follows:

Solute (protein and lactose) rejection (R):

$$R = (1 - \frac{C_p}{C_r})100\ \%$$

where, C_p-solute concentration in the permeate (g/L),C_r-solute concentration in the concentrate (g/L).

Concentration factor (CR):

$$CR = \frac{V_f}{V_r}$$

where, V_f-volume of feed (L); V_r-volume of concentrate.

The experiments were conducted in an open loop system where the concentrate and the permeate are recycled back to the feed tank, maintained at a temperature of obout 30-35 ºC (Fig. 1). Each experimental run consisted of two steps, ultrafiltration of dairy wastewater and nanofiltration of ultrafiltration permeate.

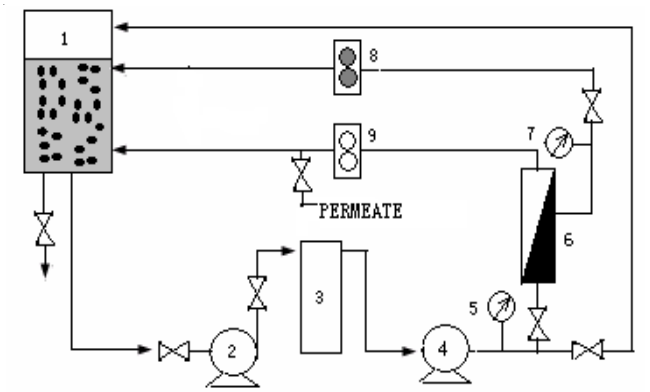

Fig. 1. Schematic diagram of ultrafiltration and nanofiltration membrane experimentation; 1. Tank, 2. Low-pressure pump, 3. Microfiltration membrane (Mf), 4. High-pressure pump, 5. Feed pressure gauge, 6. Uf Or Nf, 7. Concentrate pressure gauge, 8. Flow meter, 9. Flowmeter

The solution was pumped through the system using a high-pressure pump and a low-pressure pump. The pressures were regulated using pressure gauges. The flow rate of concentrate and permeate solutions were measured using flow meter.

After filtration the equipment was rinsed with tap water and the membrane was cleaned using 0.4 % hydrogen peroxide. The cleaning agent was circulated through the membrane module at 2 bar pressure and 1920 l/h for 0.5 h while the temperature was 30 ºC.

Ultrafiltration of dairy wastewater: In ultrafiltration the constituents of dairy wastewater are fractionated according to molecular size. The protein fraction is retained very well in the concentrate, while the lactose, minerals and vitamins are divided between concentrate and the permeate. The ultrafiltration experiments were carried out in a laboratory unit. The effective area of the spiral membrane in the ultrafiltration cell was 2.6 m^2. The solution was circulated in contact with the membrane from the feed tank. The constant temperature of feed (30-35 ºC) was maintained by using cooling water. The volume of permeate was measured during the experimental runs in the collector. The pressure (2-12 bar) and the recycle flow rate (1200-2160 l/h) were controlled by regulation valves. The protein content in the permeate and in the concentrate fractions were determined by taking samples from this fractions during the experimental runs, which were analyzed by UV-VIS, spectrophotometer. Using these UV absorbance values and the calibration plot, the protein concentration in the diluted sample was determined.

Nanofiltration of ultrafiltration permeate: The nanofiltration apparatus is the same as the ultrafiltration. The area of the spiral membrane was 2.6 m^2. The solution was circulated in contact with the membrane from the feed tank. The constant temperature of feed (30-35 ºC) was maintained by using cooling water. The permeate was measured during the experimental runs in the collector. The pressure (4-16 bar) and the recycle flow rate (720-2160 l/h) were controlled by regulation valves. The lactose content in the permeate and in the concentrate fractions were analyzed during the experimental runs using UV-VIS, spectrophotometer.

RESULTS AND DISCUSSION

Pure water flux: Pure water flux was measured at the beginning of the experiment. The influence of the pressure at different flow rates on the permeate flux of purewater flux is shown in Figs. 2 and 3. The flux increased linearly with transmembrane pressure within the tested range, 2-12 bar(UF) and 4-16 bar (NF). Pressure significantly influenced the premeate flux.

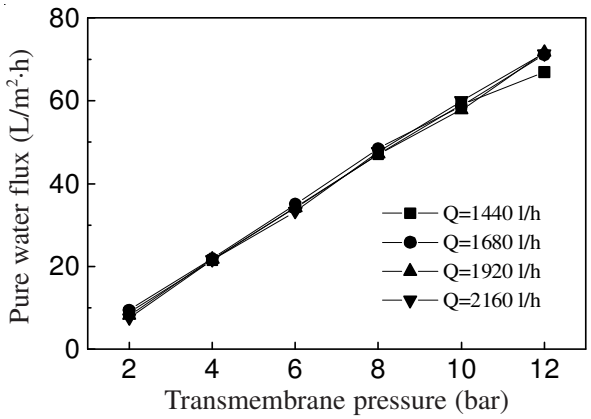

Fig. 2. Pure water flux as a function of transmembrane pressure for four different flow rates (Q) in the ultrafiltration membrane

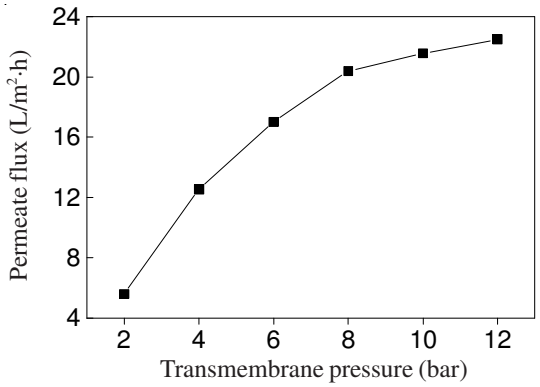

Fig. 3. Pure water flux as a function of transmembrane pressure for three different flow rates (Q) in the nanofiltration membrane

Ultrafiltration with 8kDa membrane

Effect of transmembrane pressure: Fig. 4 shows that the transmembrane pressure increased the permeate flux increased.

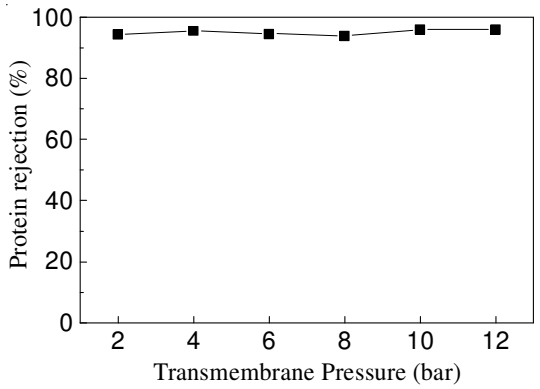

Fig. 4. Permeate flux as a function of transmembrane pressure in the ultrafiltration membrane (Feed flow rate =1440 l/h, remperature = 30-35 ºC, feed COD concentration = 3000 mg/L)

The flux increased linearly with transmembrane pressure within 2-8 bar. Above a critical transmembrane pressure (greater than 8 bar) the flux also showed a slow increase, because the protein molecules deposited on the surface of the membrane cause a concentration polarization controlled by two factors, the type of membrane and the flow rates.

Fig. 5 reveals that as the transmembrane pressure (TMP) increased, the protein rejection increased from 94% at transmembrane pressure of 2 bar to approximately 96 % at transmembrane pressure of 12 bar. According to these results, at all transmembrane pressures, protein rejection remained practically stable for ultrafiltration membranes.

Effect of feed flow rate: Using higher velocity the deposited molecules are continuously removed from the membrane surface and thus the hydraulic resistance of the fouling layer is reduced. The mass transfer of solutes through the boundary layer increases so that the required protein content in the permeate fraction can be achieved at shorter time.

It can be seen in Fig. 6 that the permeate flux slowly increase with an increase in the feed flow rate because of concentration polarization. The protein rejection of ultrafiltration was higher: 94-97 % (Fig. 7) at all feed flow rate.

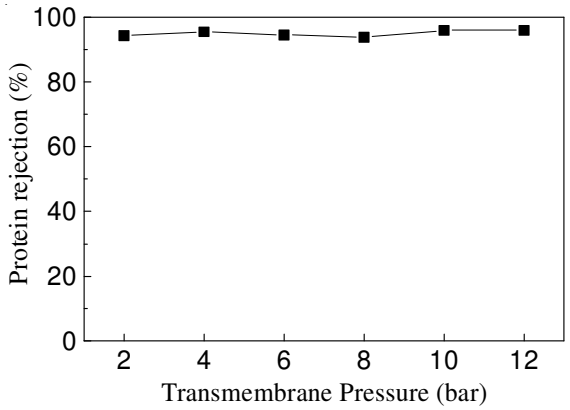

Fig. 5. Protein rejection as a function of transmembrane pressure in the ultrafiltration membrane (Feed flow rate =1440 l/h, temperature = 30-35 ºC, feed COD concentration = 3000 mg/L)

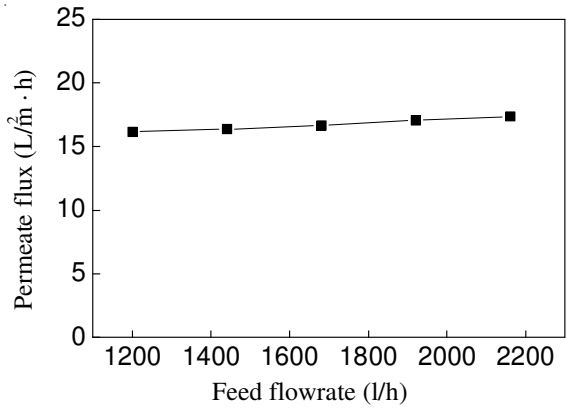

Fig. 6. Permeate flux variation as a function of feed flow rate in the ultrafiltration membrane (Transmembrane pressure =10 bar, temperature=30-35 ºC, feed COD concentration = 3000 mg/L)

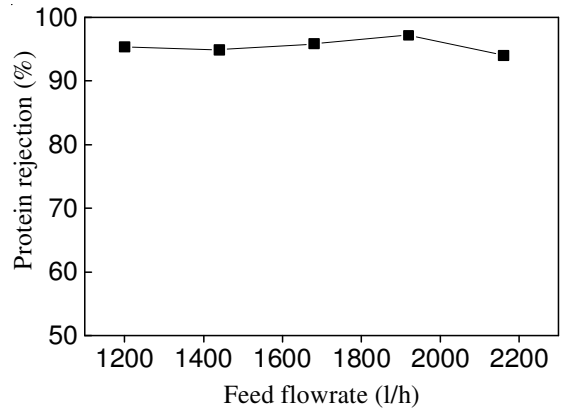

Fig. 7. Protein rejection as a function of feed flow rate in the ultrafiltration membrane (Transmembrane pressure =10 bar, temperature = 30-35 ºC, feed COD concentration=3000 mg/L)

Effect of concentration factor: The influence of concentration factor on permeate flux is shown in Fig. 8. From Fig. 8, it is observed that the permeate flux decreases with the increasing of concentration factor. This could be due to faster build up of molecules covering larger porion of the membrane surface and obstructing the permeate flow when operated at higher concentrations. In the lower concentration range, the decrease in flux is slight, suggesting less intensive fouling of the membrane.

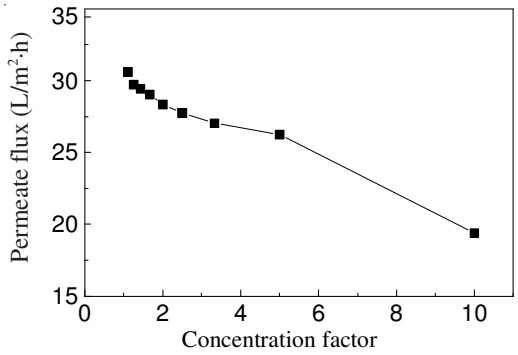

Fig. 8. Permeate flux variation as a function of concentration factor in the ultrafiltration membrane (Transmembrane pressure = 10 bar, feed flow rate = 1920 l/h, temperature = 30-35 ºC, feed COD concentration = 3000 mg/L)

From Fig. 9, it can be observed that as the concentration factor increased, the protein rejection increased. It is believed that this increase is mainly due to the initial compaction and less due to fouling of the membrane surface.

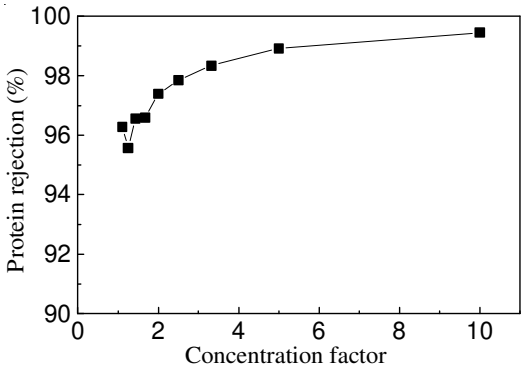

Fig. 9. Protein rejection as a function of concentration factor in the ultrafiltration membrane (Transmembrane pressure = 10 bar, feed flow rate = 1920 l/h, temperature = 30-35 ºC, feed COD concentration = 3000 mg/L)

Nanofiltration of ultrafiltration permeate with 200 Da membrane

Effect of transmembrane pressure: The nanofiltration membrane was used for the recovery of lactose from ultrafiltration permeate. The nanofiltration membranes have lower molecular weight cut-off (Table-2), thus they reject the lactose molecules, which are smaller than proteins.

Variation of permeate flux and lactose rejection with transmembrane pressure are shown in Fig. 10. From this diagram it is obvious that the permeate flux in the nanofiltration membrane rapidly increased with increasing transmembrane pressure up to about 16 bar. At a pressure of 16 bar, permeate fiux of 44.31 l/m^{2}h, was measured with flow rate of 1680 l/h, respectively, at a feed COD of 570 mg/L. The lactose rejection of nanofiltration was 100 % at all transmembrane pressure.

As the transmembrane pressure was increased from its lowest value, the COD rejection increased until a maximum, where further pressure increases had no advantage (Fig. 11). The value of COD in permeate was 3-15 mg/L. It could be up to the standard of reusable water. Higher pressure increases the permeate flux; the concentration of the protein on the membrane surface increases, nullifying the effect of the effect of the additional pressure.

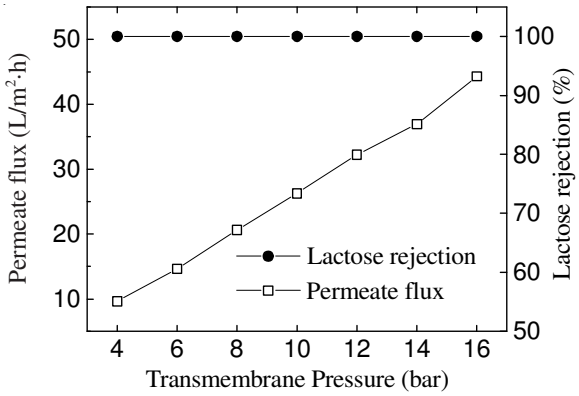

Fig. 10. Variation of permeate flux and lactose rejection with transmembrane pressure in the nanofiltration membrane (Feed flow rate = 1680 l/h, temperature = 30-35 ºC, feed COD = 570 mg/L, feed flow rate = 1440 l/h)

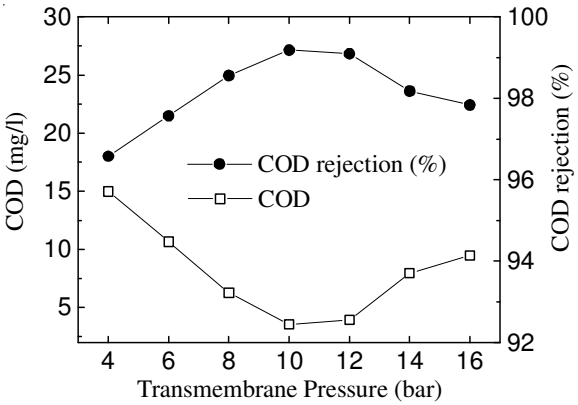

Fig. 11. Variation of COD and COD rejection with transmembrane pressure in the nanofiltration membrane (Feed flow rate =1680 l/h, temperature = 30-35 ºC, feed COD concentration = 570 mg/L)

Effect of feed flow rate: From Fig. 12, it can be observed that the permeate flux increased slowly in the feed flow rate of 720-1200 L/h, after that, it increased sharply when the feed flow rate increased from 1200-1440 L/h. This could be attributed to the gradual build up protein and similar molecules on the membrane surface nullifying the effect of increase in feed flow rate. The membrane was fouled and the permeate flux was difficult to stabilize. Fig. 12 also showed that the lactose rejection percentage was 100 % at all feed flow rate.

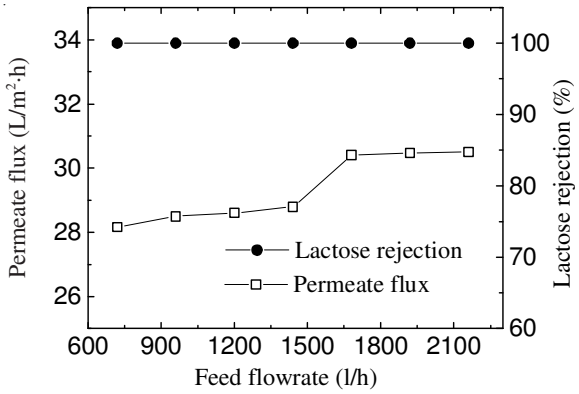

Fig. 12. Variation of permeate flux and lactose rejection with feed flow rate in the nanofiltration membrane (Transmembrane pressure =10 bar, temperature = 30-35 ºC, feed COD concentration = 570 mg/L)

It is oberved in Fig. 13 that COD rejection increased up to a feed flow rate of 1200 L/h, after that it decreased when the feed flow rate increased from 1200-2160 L/h. Fig. 13 also show that the value of COD decreased to a feed flow rate of 1200 L/h, after that it increased when the feed flow rate increased from 1200-2160 L/h. The value of COD in permeate could be up to the standard of reusable water.

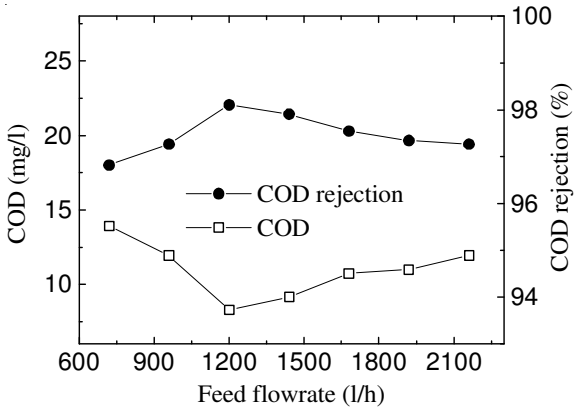

Fig. 13. Variation of COD and COD rejection with feed flow rate in the nanofiltration membrane (Transmembrane pressure = 10 bar, temperature = 30-35 ºC, feed COD concentration = 570 mg/L, feed flow rate = 1440 L/h)

Effect of concentration factor: The concentration by membranes is a low temperature process, which preserves the nutritional value of the lactose and which is more economical than the traditional concentration processes (evaporation).

From Fig. 14, it is observed that the permeate flux nearly hold the line with increasing concentration factor. This could be due to less fouling of the membrane surface at all concentrations.

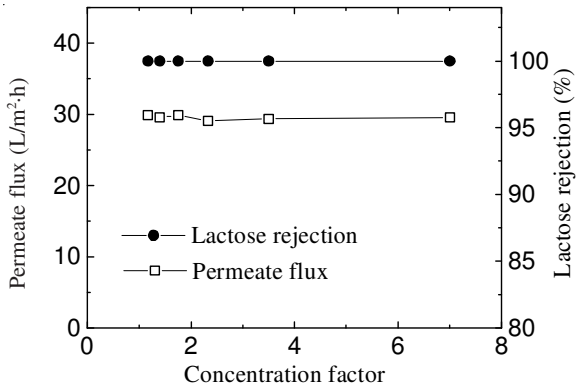

Fig. 14. Variation of permeate flux and lactose rejection with concentration factor in the nanofiltration membrane (Transmembrane pressure = 10 bar, feed flow rate = 1680 L/h, temperature = 30-35 ºC, feed COD concentration = 570 mg/L).

From Fig.15, it can be observed that as the concentration factor increased the protein rejection increased. It is believed that this increase is mainly due to the initial compaction and less due to fouling of membrane surface. The value of COD in permeate was 4-8 mg/L. It could be up to the standard of reusable water.

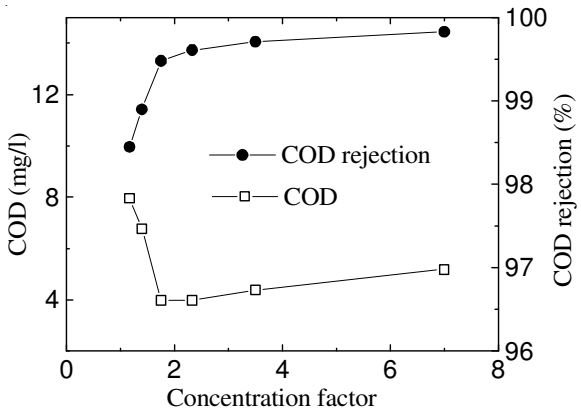

Fig. 15. Variation of COD and COD rejection with concentration factor in the nanofiltration membrane (Transmembrane pressure = 10 bar, feed flow rate = 1680 L/h, temperature = 30-35 ºC, feed COD concentration = 570 mg/L, feed flow rate = 1440 l/h

Conclusion

The increase of transmembrane pressure increases the permeate flux significantly. Protein recovery of approximately 94-97 % can be achieved using an 8 kDa membrane (UF). Lactose recovery of 100 % can be achieved using a 200 Da membrane (NF). As the increase of concentration of protein in the dairy wastewater, the permeate flux decreases. An increase in concentration of lactose in the ultrafiltration permeate the permeate flux nearly hold the line. The value of COD in nanofiltration permeate could be up to the standard of reusable water.

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