Ekoloji 22, 88, 21-27 (2013)
doi: 10.5053/ekoloji.2013.883

Pretreatment of Cheese Whey Effluent Using a Microfiltration Process: A Statistical Design Approach

Ezgi OKTAV AKDEMIR*, Adem OZER

[1]Dokuz Eylul University, Engineering Faculty, Department of Environmental Engineering, Tinaztepe Campus, 35160 Buca, Izmir- TURKIYE

*Corresponding author: ezgi.oktav@deu.edu.tr

Abstract
Pretreatment of cheese whey effluent from the dairy industry using chitosan as a coagulant and a microfiltration process such as a solid/liquid separator was investigated in this study. The optimization of major process variables, such as chitosan concentration, transmembrane pressure, and operation time on permeate flux and COD removal efficiency was investigated. To find the most appropriate result for the experiment, The Box–Wilson experimental design was employed. Response function coefficients were determined by regression analysis of experimental data and predictions were found to be in good agreement with the experimental results. The optimal concentration of chitosan and transmembrane pressure was 5 mg/L and 2 bar pressure for maximum permeate flux with a 23.0 L/m^2.h flux value, respectively. On the other hand, the maximum COD removal efficiency (68.1%) was achieved at 15 mg/L chitosan concentration and 1 bar pressure.

Keywords: Box-Wilson experimental design, cheese whey effluent, chitosan, and microfiltration process.

Peyniraltı Suyunun Mikrofiltrasyon Prosesiyle Ön Arıtımı: İstatiksel Tasarım Yaklaşımı

Özet
Bu çalışmada, süt endüstrisinden alınan peyniraltı suyunun, çitosanın koagülant olarak kullanılmasıyla ve katı/sıvı ayrımının yapıldığı mikrofiltrasyon prosesiyle ön arıtımı incelenmiştir. Çitosan konsantrasyonu, membran basıncı, işletme zamanı gibi önemli proses değişkenlerinin akı ve KOI giderme verimi üzerine etkileri araştırılmıştır. En az deney ile en uygun sonucu bulmak için Box-Wilson deneysel tasarımı kullanılmıştır. Tepki fonksiyon katsayıları deneysel verilerin regresyon analizleri ile belirlenmiş deneysel sonuçlar ile uyum içinde olduğu tespit edilmiştir. 23,0 L/m^2.sa'lik maksimum akı değeri için optimum çitosan konsantrasyonu 5 mg/L ve optimum basınç 2 bar olarak bulunmuştur. Diğer taraftan, maksimum KOİ giderme verimi (%68,1) 15 mg/L çitosan konsantrasyonu ve 1 bar basınçta elde edilmiştir.

Anahtar Kelimeler: Box-Wilson deneysel tasarımı, çitosan, mikrofiltrasyon prosesi, peyniraltı suyu

Akdemir EO, Ozer A (2013) Pretreatment of Cheese Whey Effluent Using a Microfiltration Process: A Statistical Design Approach. Ekoloji 22(88): 21-27.

INTRODUCTION

The liquid wastes produced by the dairy industries and cheese dairies constitute one of the most important industrial pollutants. These wastes can be divided into two main categories. The first one refers to washing and pasteurization waters which constitute almost two–thirds of the effluents and the effluent is considered mainly harmless. The second category refers to the cheese whey classified into raw whey and milk sugar (Papachristou and Lafazanis 1997). Whey is the aqueous phase that is separated from the curds during cheese making or casein production. It is characterized by high biological-oxygen demand (BOD) and chemical oxygen demand (COD) concentrations, and generally contains fats, nutrients, and lactose (Kushwaha et al. 2011). Whey contains 93-94% water, 63-67 g/L dry matter, 45-50 g/L lactose, 7-9 g/L protein, 6-8 g/L salts, and 1-2 g/L fat. The pollutant load represents 30-50 g/L BOD_5, 60-65 g/L COD, and 1.2 g/L suspended matter. The production of 1 kg of pressed cheese generates 9 to 10 liters of whey with respect to the quantity of the water used in the production process (Bonnet et al. 1999).

Various technologies in different ranges of complexity, reliability, and cost have been developed to forestall pollution by waste whey and to find a method or a field for the utilization of whey. These treatments very often involve separating the major components which is the elimination of water. The extraction of lactose, proteins, and salts affords various substances that are useful in the food and pharmaceutical industries. Other technologies

Received: 10.08.2011 / Accepted: 17.02.2013

(anaerobic digestion, various fermentations, and use of plants) can also be used for treatment. These processes, which mostly rely on industrial technology, are generally unsuited for small production units. However, small dairy farms cannot be allowed to go on discarding crude whey into the environment, which most often means slow-flowing waterways (Mawson 1994).

Developments in membrane technology have created the opportunity for an entirely new approach to cheese technology. The application of the membrane technique to the treatment of cheese whey was discovered in the last decades (Atra et al. 2005). However, the proteinous materials of the dairy wastewater were found to be a severe foulant for the existing membrane materials (Madaeni et al. 2004). With the advent of the newer membrane materials which are less prone to fouling, the research thrust into this area has increased tremendously. To control the fouling and to improve the productivity and the life of membranes, the use of a coagulant and adsorbent before membrane application were used in the primary and secondary effluent treatment and in the sewage effluent treatment (Abdessemed et al. 2002; Kim et al. 2002). Traditional coagulants, such as ferric chloride and alum, result in a high metal content in the sludge, which is undesirable in food (Odegard 1987). Carboxy Methyl Cellulose (CMC) is commonly used together with H_2SO_4 for the treatment of dairy wastewater after reducing the wastewater pH to 4 (Rusten 1993). Some researchers investigated the efficiency of a process using chitosan as an alternative to the CMC process as pretreatment of cheese whey (Mukhopadhyay et al. 2003). Chitosan had lowered the TDS and COD values considerably at a very low dosage as compared to the common coagulants. Since the required dosage was very low, it might be used commercially as a coagulant in the pretreatment of dairy wastewater (Sarkar et al. 2006). Olsen et al. (1996) used chitosan as a biological cationic polymer for the treatment of dairy industry wastewater at different pH values (4.5-5.25) by coagulation. They obtained 60 % removal efficiencies of phosphates and CODt, and 90 % removal efficiencies of suspended solids at a pH=5.25. Chitosan can efficiently function at a pH of 5.25, while other chemical polymers, such as CMC functioned only at a pH below 4.5

Sarkar et al. (2006) investigated the reuse of wastewater from the dairy industry using coagulation, adsorption, and membrane separation. Chitosan was found to be a better coagulant compared to inorganic and organic coagulants at a very low dosage (10 mg/L). A PAC treatment after chitosan was found to be useful in complete removal of color and the odor of wastewater before membrane processing. They obtained 57 % reduction in TDS and 62 % reduction in COD with chitosan and the PAC treatment. After that, microfiltration and then reverse osmosis were applied. A 71% FOG and 81% BOD reduction was observed after microfiltration. However, no COD reduction was obtained. The reverse osmosis treatment reduced 98% of the COD from the original. The BOD and COD values of the wastewater decreased to 8 mg/L and 16.5 mg/L respectively after the reverse osmosis treatment.

The major purpose of this study is characterization and pretreatment of cheese whey with a microfiltration process. Chitosan was added to wastewater as a coagulant before the microfiltration process. A Box–Wilson statistical experiment design method was used to investigate the effects of important operating parameters such as chitosan concentration, system pressure, and operation time.

MATERIALS AND METHODS

Experimental Set-up

The microfiltration membrane used in this study was a JX membrane (PVDF) supplied by Osmonics as a flat sheet, and the technical characteristics of the membrane are given in Table 1. The experimental system, also supplied by Osmonics Inc., consisted of an Osmonics Sepa CF II membrane cell and essentially is the same as described in previous works (Akdemir and Ozer 2008, Akdemir and Ozer 2009). The concentrate stream flowed back to the feed vessel while the permeate stream was collected separately as shown in Figure 1. All experiments were carried out at aconstant water temperature of 25±1°C.

Wastewater Composition

The cheese whey effluent used in this study was obtained from the Ege University Food Engineering Department, Izmir-Turkey, and kept in the dark at 4°C. The average composition of cheese whey used in this study is shown in Table 2.

Table 1. The technical characteristics of the membrane used during the experiments.

	Microfiltration membrane
Manufacturer	Osmonics
Designation	JX
Polymer type	PVDF
Rejection size	0.3
Area, m^2	0.0155
Maximum pressure, bar	3
pH range	2-11

Table 2. Characterization of the raw wastewater.

Parameter	Unit	Value
pH	-	4.7
COD	mg/L	60000
BOD	mg/L	30000
SS	mg/L	2513
TOC	mg/L	22210
PO_4-P	mg/L	153
Total N	mg/L	88
Oil and Grease	mg/L	1650

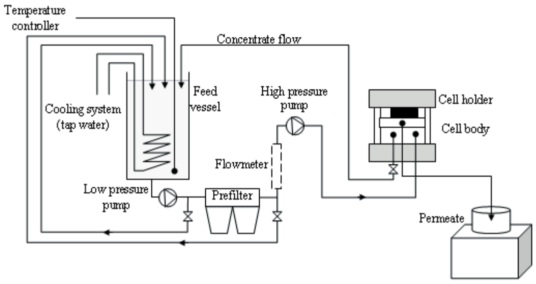

Fig. 1. A Laboratory-scale membrane system.

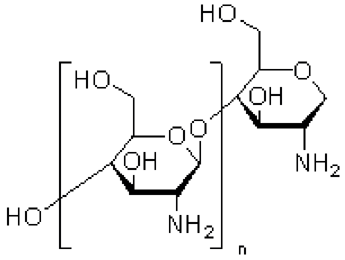

Fig. 2. The chemical structure of chitosan.

Chitosan

Chitosan has been used to treat the effluents in a wide number of food processes. In these operations, chitosan has demonstrated to be a very good coagulating agent (Xue 1998). Olsen et al. (1996) reported that chitosan can achieve high removal efficiencies even at a pH of 5.25. Thus, this method can save up to 50% of pH-adjusting chemicals require for both acidification and neutralization. In light of this information, chitosan was used in order to improve microfiltration efficiency without pH adjustment.

Chitosan was obtained from Sigma-Aldrich (product number of 419419) with a high molecular weight and the chemical structure of chitosan is shown in Figure 2. Chitosan was used as a polyelectrolyte in the coagulation step. The coagulation experiments were carried out using 1 L of the cheese whey samples in the beakers by means of a Jar-test apparatus (The Arm field Flocculation Test Unit). After the chitosan addition, the samples were subjected to a rapid mixing step at 225 rpm for 5 min, to a slow mixing step at 25 rpm for 45 min, and to a subsequent sedimentation step for 120 min. Then, samples were collected from the clear supernatant and the microfiltration process was applied to these samples. In order to achieve very efficient settling and prolong the fouling time, the microfiltration process was applied after sedimentation. Thus, good compressed sedimentation sludge was obtained and the volume of the liquid decreased to 10%.

Analytical Methods

The COD, TOC, pH, SS, oil and grease, BOD_5, TN, and $PO^{-}{}_{4}{}^{3}$-P measurements were carried out on the influent; the characterization and COD analyses were done on the effluent samples for the treatment studies. The COD, BOD_5, $PO^{-}{}_{4}{}^{3}$-P, SS, and oil and grease analyses were carried out according to Standard Methods (Anonymous 2005). The TN experiments were done using a spectroquant cell test. A DOHRMANN DC-190 High Temperature TOC Analyzer was used for the TOC measurements and the pH measurement was accomplished using a 890 MD pH METER.

Box–Wilson Experimental Design

The Box-Wilson experimental design method is employed to evaluate the effects of major process variables (chitosan concentration, pressure, operation time, and etc.) on the permeate flux of cheese whey effluent using a microfiltration process. The Box–Wilson design is a response surface methodology, which is an empirical modeling technique, devoted to the evaluation of the relationship of a set of controlled experimental factors and observed results. Basically this optimization process involves three major steps: performing the statistically designed experiments, estimating the coefficients in a mathematical model, and predicting the response and checking the adequacy of the model (Parilti 2010, Akdemir and Ozer 2011).

Chitosan concentration, system pressure, and operation time were considered as independent variables and designated as X_1, X_2, and X_3, respectively. The permeate flux and COD removal efficiency was considered as dependent variables in the Box–Wilson statistical design method. The chitosan concentration (X_1) was varied between 5 and 25 mg/L; pressure (X_2) varied between 1 and 2 bar, and the operation time (X_3) between 30 and 120 minutes.

The experimental conditions determined by the Box–Wilson statistical design for both processes are presented in Table 3. The experiments consist of six axial (A), eight factorial (F), and centre (C) points. The center point was repeated four times. Computation was carried out using multiple regression analysis using the least squares method. The following response function was used in correlating the permeate flux and COD removal efficiency with independent parameters (X_1, X_2, and X_3).

$$Y=b_0+b_1X_1+b_2X_2+b_3X_3+b_{12}X_1X_2+b_{13}X_1X_3+b_{23}X_2X_3+b_{11}X_1^2+b_{22}X_2^2+b_{33}X_3^2 \qquad (1)$$

The Statistica 5.0 computer program was employed for the determination of the coefficients of Eq. (1) by regression analysis of the experimental data where Y is the predicted yield, b_o is constant, b_1, b_2, and b_3 are the linear coefficients, b_{12}, b_{13}, and b_{23} are cross product coefficients, and b_{11}, b_{22}, and b_{33} are quadratic coefficients.

RESULTS AND DISCUSSION

The permeate fluxes and COD removal efficiencies obtained from the experiments are summarized in Table 4. The observed permeate fluxes varied between 15.9 and 20.8 L/m^2.h, and the COD removal efficiencies varied between 54% and 68%. The observed permeate fluxes and COD removal efficiencies were compared with the predicted ones obtained from the response function. The experimental results were used to determine the coefficients of the response functions (Eq. (1)) by the Statistical regression analysis program. The determined coefficients are listed in Table 5. The coefficients were used in calculating the predicted values of permeate flux and COD removal efficiencies. The correlation coefficients (R^2) between the observed and predicted values were 0.996 and 0.979 for the permeate flux and COD removal, respectively. These results indicated excellent agreements between the observed and predicted values. The effects of the operating variables on the permeate flux and COD removal performance of the system was determined by obtaining the projections of the response functions on certain planes of the known parameter values.

Table 3. Experimental conditions according to a Box–Wilson statistical design.

	Chitosan concentration (mg/L)	P (bar)	t (min)		Chitosan concentration (mg/L)	P (bar)	t (min)
Axial points				Factorial points			
A1	25	1.5	75	F1	9.2	1.79	101
A2	5	1.5	75	F2	20.8	1.21	101
A3	15	2	75	F3	20.8	1.79	49
A4	15	1	75	F4	20.8	1.21	49
A5	15	1.5	120	F5	9.2	1.21	101
A6	15	1.5	30	F6	9.2	1.79	49
Center point				F7	20.8	1.79	101
15	15	1.5	75	F8	9.2	1.21	49

Table 4. Observed and predicted permeate flux and COD removal efficiency.

Experiment number	Observed permeate flux (L/m^2.h)	Predicted permeate flux (L/m^2.h)	Observed COD removal efficiency (%)	Predicted COD removal efficiency (%)
A1	17.7	17.7	60.0	59.8
A2	18.7	18.5	54.0	55.0
A3	19.5	19.5	64.0	64.7
A4	15.9	15.8	68.0	68.1
A5	15.9	15.9	66.0	66.2
A6	20.4	20.3	64.0	64.6
F1	17.5	17.6	62.0	61.3
F2	15.6	15.7	65.0	65.0
F3	20.3	20.4	64.0	63.6
F4	17.5	17.5	65.0	65.1
F5	16.1	16.1	64.0	63.8
F6	20.8	20.8	60.0	59.3
F7	17.5	17.4	64.0	64.0
F8	18.0	18.2	63.0	62.3
C	18.1	18.1	66.0	66.0

Table 5. Coefficients of the response functions for permeate flux and COD removal.

	Permeate flux	COD removal
B_0	9.6827549	0.5324795
B_1	-0.1387777	0.0266357
B_2	11.5541065	-0.1313122
B_3	0.0030366	0.0007298
B_{12}	0.0371581	0.0022295
B_{13}	0.0004145	-0.0000249
B_{23}	-0.0381300	0.0001658
B_{11}	0.0004031	-0.0008574
B_{22}	-1.8387420	0.0170247
B_{33}	-0.0000046	-0.0000029

Effects of Chitosan Concentration

In order to determine the effect of chitosan concentration on the permeate flux and COD removal efficiencies at a constant pressure of 1 bar, the results for different concentrations of chitosan are predicted by using the response equation with determined coefficients. Figure 3 depicts the variation of permeate flux as a function of the operation time for different chitosan concentration at a constant pressure of 1 bar. Maximum permeate flux was achieved as 18 L/m^2.h at an initial chitosan concentration of 5 mg/L and an operation time of 30 minutes. An increase in the chitosan concentration, results in a decrease in the permeate flux because of the organic content of the chitosan. This could be that the membrane pores are blocked with the increasing chitosan concentration, so permeate fluxes decrease.

Figure 4 depicts the variation of COD removal efficiency with the same experimental conditions. Maximum COD removal efficiencies were achieved at a chitosan concentration of 15 mg/L and this result was in agreement with another study (Olsen et al. 1996). A low concentration of chitosan is less effective on COD removal efficiency. If a high concentration of chitosan is used, the COD concentration will also increase due to the organic content of chitosan. The increase in time on COD removal efficiency is not very effective. COD removal efficiencies for the all operation times are approximately the same for the 15 mg/L of chitosan concentration and it varies between 67% and 68% as total removal efficiency.

Effects of Operation Time

In order to determine the effect of operation time on permeate flux at an optimum chitosan concentration, the results are predicted by using the response equation with determined coefficients. Figure 5 depicts the variation of permeate flux with the pressure at a constant chitosan concentration of 15 mg/L. The maximum permeate flux obtained was 22.5 L/m^2.h in 30 minute at a chitosan concentration of 15 mg/L and a pressure of 2 bar. As shown in Figure 5, the increase in pressure also increases the permeate flux. The reason for this situation can be explained by Darcy's law. According to Darcy's law, the increasing pressure gradient increases permeate flux. This data is in agreement with the findings of other authors (Akdemir and Ozer 2009, Mohammadi and Esmaeelifar 2004). The permeate flux did not reduce drastically with the operation period. Therefore, membrane fouling is not too important for the cheese whey effluent in this study. According to Figure 5, at each pressure after about 90 minute operation time, the permeate flux reaches a more or less constant value. As it can be seen from the figure, permeate fluxes are 22.5, 19.5, and 19.0 L/m^2.h for a 30, 60, and 90 minute operation time, respectively at a pressure of 2 bar. Because, the layer of cake reaches equilibrium and does not increase after this time. As a result, the cake layer resistance and the permeate flux remains constant (Akdemir and Ozer 2009).

Figure 6 depicts the variation of COD removal efficiency with time as a function of pressure at an optimum chitosan concentration of 15 mg/L. The total COD removal efficiency decreased from 67% to 61% when increasing the pressure from 1 bar to 2 bar. The reason for this result is that the organic matter accumulated in the fouling layer were scoured and transported at high pressures. As a result, the organic matter kept on the surface of the membrane was carried into the permeate and hence, the COD concentration of permeate increased (Akdemir and Ozer 2008). The optimal pressure for maximum COD removal can be determined as 1 bar with less energy consumption.

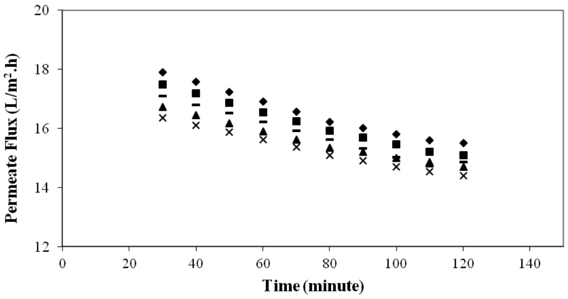

Fig. 3. Variation of permeate flux with time for different chitosan concentration at a constant pressure of 1 bar, (◆) 5 mg/L; (■) 10 mg/L; (−) 15 mg/L; (▲) 20 mg/L; (×) 25 mg/L.

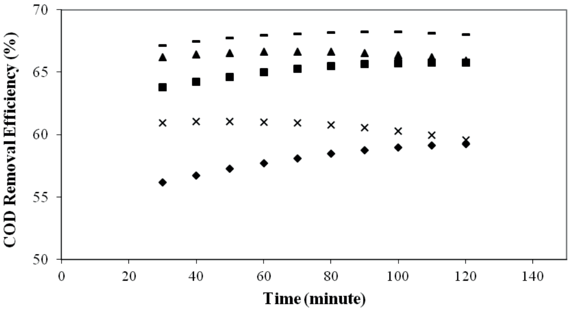

Fig. 4. Variation of COD removal efficiency with time for different chitosan concentration at a constant pressure of 1 bar, (◆) 5 mg/L; (■) 10 mg/L; (−) 15 mg/L; (▲) 20 mg/L; (×) 25 mg/L.

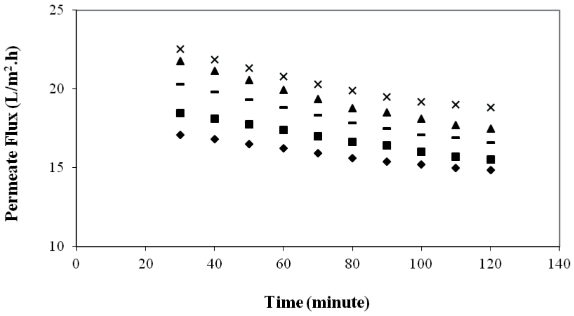

Fig. 5. Variation of permeate flux with time for different pressure at a constant chitosan concentration of 15 mg/L, (◆)=1 bar, (■)=1.2 bar, (−)= 1.5 bar, (▲)= 1.8 bar, (x)= 2 bar.

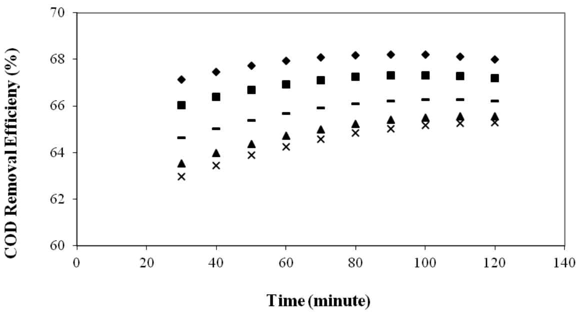

Fig. 6. Variation of COD removal efficiency with time for different pressure at a constant chitosan concentration of 15 mg/L, (◆)= 1 bar, (■)= 1.2 bar, (−)= 1.5 bar, (▲)=1.8 bar, (x) = 2 bar.

Effects of Pressure

In order to determine the effect of pressure on the permeate flux at a constant operation time of 30 minutes, the results were predicted for different chitosan concentration by using the response equation with calculated coefficients. Figure 7 depicts the variation of permeate flux with pressure at different chitosan concentration and a constant operation time of 30 minute. The permeate flux increases when increasing the pressure to 1.6 bar. At the pressure of 1.8 and 2 bar, almost a constant value of flux is reached. As it can be seen in Figure 7, approximately 21 L/m^2.h permeate flux is obtained for the pressure of 1.8 and 2 bar. Higher pressures cause the cake layer on the membrane surface to compress and accelerate membrane fouling. Higher pressure also increases energy consumption for the same amount of water. Pressure at which flux reaches a constant value can be considered as optimum pressure (Benitez et al. 2006, Akdemir and Ozer 2009). At optimum pressure, permeate flux must be high and a tendency for cake layer formation should be low. Therefore, pressures less than 1.8 bars can be selected for safer operations, avoiding membrane fouling, and obtaining a higher COD removal efficiency. By considering this fact 1 bar can be determined as optimum pressure.

Figure 8 shows the variation of COD removal efficiency with pressure as a function of chitosan concentration at a 30 minute operating time. The COD removal efficiency decreases with increasing pressure. The application of lower pressures gives better removal efficiencies. These results are in agreement with the results of the ultrafiltration studies on olive oil mill wastewater (Akdemir and Ozer 2008, Mohammadi and Esmaeelifar 2004). They have obtained a decreasing retention coefficient for increasing pressure. The same result was obtained for the microfiltration of cheese whey effluent in this study for the repeated experiments. The maximum COD removal efficiency was achieved at the chitosan concentration of 15 mg/L and a pressure of 1 bar at 67%.

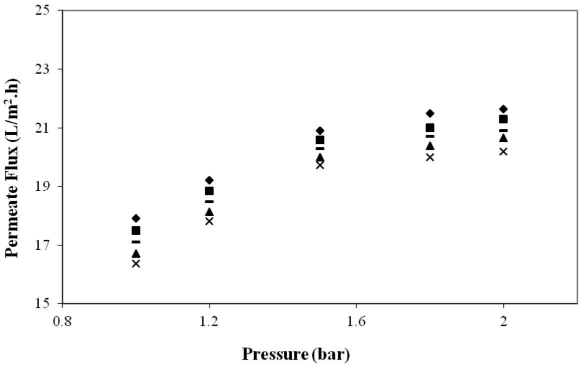

Fig. 7. Variation of permeate flux with pressure for different chitosan concentration at a constant operation time of 30 minutes, (◆) 5 mg/L; (■) 10 mg/L; (−) 15 mg/L; (▲) 20 mg/L; (×) 25 mg/L.

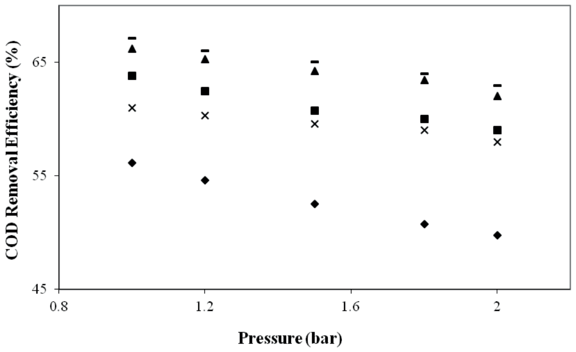

Fig. 8. Variation of COD removal efficiency with pressure for different chitosan concentration at a constant operation time of 30 minutes, (◆) 5 mg/L; (■) 10 mg/L; (−) 15 mg/L; (▲) 20 mg/L; (×) 25 mg/L.

CONCLUSIONS

A Box–Wilson statistical experiment design was used to determine the optimization of operating parameters such as chitosan concentration, transmembrane pressure, and operation time on the permeate flux and COD removal efficiency for the microfiltration of cheese whey effluent. In a Box–Wilson statistical experiment design, response function coefficients were determined by regression analysis of the experimental data and the predicted results obtained from the response functions were in good agreement with the experimental results. The correlation coefficients (R^2) between the observed and predicted values were 0.996 and 0.979 for the permeate flux and COD removal, respectively. These results indicated excellent agreements between the observed and predicted values indicating the reliability of the methodology used.

The experimental results indicated that, the chitosan concentration and transmembrane pressure are significant important parameters for permeate flux and COD removal efficiency. The optimum chitosan dosage and transmembrane pressure was found to be 5 mg/L and 2 bar for permeate flux, respectively. In this case, 22.5 L/m^2.h permeate flux was obtained. In contrast, a maximum COD removal efficiency of 67% was achieved at 15 mg/L chitosan concentration and 1 bar pressure. Therefore, the objective parameter (COD removal or permeate flux) should be selected at the beginning of the microfiltration process.

REFERENCES

Abdessemed D, Nezzal G (2002) Treatment of primary effluent by coagulation–adsorption–ultrafiltration for reuse. Desalination 152: 367–373.

Akdemir EO, Ozer A (2008) Application of a statistical technique for olive oil mill wastewater treatment using ultrafiltration process. Separation and Purification Technology 62: 222-227.

Akdemir EO, Ozer A (2009) Investigation of two ultrafiltration membranes for treatment of olive mill wastewaters. Desalination 249: 660-666.

Akdemir EO, Ozer A (2011) Efficiency of filtration process in the pretreatment of olive oil mill wastewaters (OMWW). Fresenius Environmental Bulletin 20: 597-602.

Anonymous (2005) Standard Methods for the Examination of Water and Wastewater. American Public Health Association, American Water Works Association, Water Environment Federation, 21st edition, Washington DC USA.

Atra R, Vatai G, Bekassy-Molnar E, Balint A (2005) Investigation of ultra and nanofiltration for utilization of whey protein and lactose. Journal of Food Engineering 67: 325-332.

Benitez FJ, Acero JL, Leal AI (2006) Application of microfiltration and ultrafiltration processes to cork processing wastewaters and assessment of the membrane fouling. Separation and Purification Technology 50: 354–364.

Bonnet JL, Bogaerts P, Bohatier J(1999) Biological treatment of whey by tetrahymena pyriformis and impact study on laboratory-scale wastewater lagoon process. Chemosphere 38: 2979-2993.

Kim SL, Chen JP, Ting YP (2002) Study on feed pretreatment for membrane filtration of secondary effluent. Separation and Purification Technology 29: 171–179.

Kushwaha JP, Srivastava VC, Mal ID (2011) An Overview of Various Technologies for the Treatment of Dairy Wastewaters. Critical Reviews in Food Science and Nutrition, 51:442–452.

Madaeni SS, Mansourpanah Y (2004) Chemical cleaning of reverse osmosis membranes fouled by whey. Desalination 161: 13–24.

Mawson AJ (1994) Bioconversions for whey utilization and waste abatement. Bioresource Technology 47: 195-203.

Mohammadi T, Esmaeelifar A (2004) Wastewater treatment using ultrafiltration at a vegetable oil factory. Desalination 166: 329-337.

Mukhopadhyay R, Talukdar D, Chatterjee B, Guha A (2003) Whey processing with chitosan and isolation of lactose. Process Biochemistry 39: 381-385.

Odegard H (1987) Optimization of flocculation/flotation in chemical wastewater treatment. Water Science and Technology 19: 1233-1237.

Olsen ES, Ratnaweera HC, Pehrson R (1996) A novel treatment process for dairy wastewater with chitosan produced from shrimp-shell waste. Water Science and Technology 34: 33-40.

Papachristou E, Lafazanis C (1997) Application of membrane technology in the pretreatment of cheese dairies wastes and co-treatment in a municipal conventional biological unit. Water Science and Technology 36: 361-367.

Parilti NB (2010) Treatment of A Petrochemical Industry Wastewater by A Solar Oxidation Process Using The Box-Wilson Experimental Design Method. Ekoloji 19 (77): 9-15.

Rusten B (1993) Chemical pretreatment of dairy wastewater. Water Science and Technology 28: 67-72.

Sarkar B, Chakrabarti PP, Vijaykumar A, Kale V(2006) Wastewater treatment in dairy industries — possibility of reuse. Desalination 195: 141–152.

Xue C (1998) Antioxidative activities of several marine polysaccharides evaluated in a phosphatidylcholine-liposomal suspension and organic solvents. Bioscience Biotechnology and Biochemistry 62: 206-209.