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Empirical modelling of chemically enhanced backwash during ultrafiltration process

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Abstract. In this study, response of reversibility of membrane flux during chemically enhanced backwash (CEB) to changes in filtration time, filtration flux and coagulant concentration dosing during ultrafiltration (UF) process was investigated using a regression model. The model was developed via empirical modelling approach using response surface methodology. In developing the model, statistically designed UF experiments were conducted and the results compared with the model output. The results showed that the performance of CEB, evaluated in terms of the reversibility of the membrane flux, depends strongly on the changes in coagulant concentration dosage and the filtration flux. Also the response of the reversibility of membrane flux during CEB is independent of the filtration time. The variance ratio, $VR \ll F_{value}$ and $R^2 = 0.98$ obtained from the cross-validation experiments indicate perfect agreement of the model output with experimental results and also testify to the validity and suitability of the model to predict reversibility of the membrane flux during CEB in UF operation.

Keywords: ultrafiltration; empirical model; response surface methodology; backwash

1. Introduction

For almost two decades, membranes have been applied to water treatment and purification. In some cases, membranes have been combined with conventional processes like distillation, in the form of membrane distillation process for water purification (Gryta 2010). For these hybrid processes, huge costs are still incurred in terms of energy usage. In contrast, ultrafiltration (UF), a kind of low pressure-driven membrane process with applied pressure ranges from 0.3 to 5 bar applied to drinking water production has demonstrated its reliability and its cost effectiveness (Moll *et al.* 2003, Moll *et al.* 2007). UF membrane usually has a pore size distribution of about 0.01-0.1 μm and would therefore prevent particles, colloids, microorganisms and dissolved solids that are larger in dimension than the membrane pores from permeating through the membrane. The membrane therefore acts as a physical size-exclusion barrier, and it is for that reason that UF membranes give such a high quality product.

UF has found its applications in areas such as industrial wastewater treatment (Fabiani *et al.* 1997, Shaalan *et al.* 2001), removal of colour from tannery wastewaters (Alves and de Pinho, 2000), combination with Reverse Osmosis (RO) after a conventional physical-chemical treatment of tannery wastewaters (Fababuj-Roger *et al.* 2007), pre-treatment step prior to nanofiltration (NF) or reverse osmosis (RO) for recycling and reuse of textile wastewaters in textile industry (Marcucci *et al.* 2001); in combination with centrifugation for reducing organic polluting compounds in olive-mill

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waster waters (Turano *et al*. 2002) and even in the artificial kidney mechanisms (Serra *et al.* 1998).

UF can be operated either in cross-flow mode or dead-end mode. Compared to the cross-flow mode, in dead-end mode the retentate outlet is blocked and thus the UF membrane module is pressurized. Also in dead-end mode, resistance increases with time because of the continuous arrival of new matter. During this period there is decline in the flux indicated by high transmembrane pressure (TMP), thus low permeate production. To maintain constant amount of permeate; more energy consumption is needed to maintain the flow rate leading to higher operating cost. One of the common techniques used to minimize this problem is the periodic reversal of membrane flux achievable through hydraulic backwash (HB). During HB, permeate flows back through the membrane, lifts off the cake and flushes it out of the module. Each operating cycle is thus made up of a filtration phase (FP) followed by a HB phase that allows the membrane to recover its initial properties. Usually, HB does not lead to 100% recovery due to availability of some particles embedded within the membrane pores. Therefore another form of backwash procedure known as chemically enhanced backwash (CEB) is needed. As revealed in previous studies, effectiveness of cleaning procedures (e.g., CEB, HB, chemical-in-place (CIP)) plays an important role in the performance of membranes (Heijman *et al*. 2007, Alklaibi and Lior 2005). In some cases, some of these procedures (e.g., CIP) require break in production, use of chemicals and consumption of part of the permeate produced, thus reducing the productivity of the process and increasing the total operating costs with additional chemical costs, energy costs and waste water disposal costs. This problem hampers the economic viability for the development and spreading of UF process (Reith and Birkenhead 1998). Even in a long term, if the membranes are not cleaned, membrane fouling and scaling could eventually cause permanent damages to the membranes. Fundamental understanding of the fouling and scaling phenomenon in UF would ultimately provide information about the mechanisms of fouling /scaling thereby paving the way for the development of suitable technique to minimize or eradicate it. Eradicating or minimizing fouling in UF will enhance permeate flux leading to better performance and reduction in operating costs.

Previous studies on the optimization of cleaning procedures (Zondervan *et al.* 2008) have revealed that that frequency of cleaning procedure will not reduce operating costs but fouling control is essential in prolonging membrane life time. Also, a recent study on the optimization of hydraulic backwash reveals that performance of the cleaning procedure (*e.g.* HB) in fouling control depends significantly on the filtration flux and backwash frequency but not on the backwash flux (Daramola *et al.* 2011). But as far as could be ascertained, no optimization study on CEB has appeared in literature. During CEB coagulant-promoting chemicals (*e.g*., Fe^{3+} solution) are used to promote online coagulation of the suspended particles during the filtration. Performance of CEB could be influenced by this coagulant concentration dosing. Also filtration flux and filtration time may influence the performance of CEB. Thus, in-depth understanding of the nature of the dependency of the performance of CEB on these variables could stimulate useful ideas to optimize the process.

Nowadays, mathematical models do play an increasingly important role in today's competitive industries. Such models are greatly desired for various tasks including process design, process analysis and optimization of process conditions, as well as for model-based control (Brendel *et al.* 2006). Several open reports in literature have enumerated the significant role of mathematical models in the design of membrane processes and thus considered them as a useful tool in understanding these processes (El-Halwagi 1992, Qi and Henson 1998, Marriott *et al.* 2001, Marriott *et al.* 1999, Anunziata and Cussa 2008). Availability of mathematical models describing behaviour of CEB could be a useful tool to understanding the performance of CEB during UF and eventually provide hints on fouling control.

Against this background, procedure for the development of a mathematical model for CEB through empirical modelling using response surface methodology (RSM) is presented in this paper. As far as could be ascertained, there is no report in literature that has explored RSM for CEB modelling. In contrast to mechanistic modelling approach that requires physical knowledge of a system before modelling, empirical modelling approach via RSM is usually applied when physical knowledge of a system is absent or incomplete. In empirical modelling via RSM approach, a statistically designed experiment is employed to obtain appropriate data that can be analyzed statistically to produce concrete and valid conclusions. Also, in contrast to the conventional method of experimentation in which one of factors is varied maintaining the other factors fixed at constant levels, RSM involves simultaneous variation of all factors over a set of experimental runs (Cojocaru and Zakrzewska-Trznadel 2007). In some cases, conventional methods of experimentation usually involve many experimental runs being time consuming, ignoring interaction effects between the considered factors and leading to low efficiency in process optimization. In contrast, RSM involves a few number of experimental runs, allows the detection of interactions between experimental variables within the range studied, leading to a better knowledge of the process (Lau and Ismail 2010, Lazic 2004). Also, RSM provides vast information in a relatively small number of experiment and hence reduction in research time and costs (Lau and Ismail 2010, Lazic 2004). In addition, statistically designed experiments have the advantages of eliminating the systematic errors and obtaining an estimate of the experimental error (Gonzalez *et al.* 1996). Also with this approach, initiated with the work of Box and Wilson in 1950's (Box and Wilson 1951), the main process variables and their interactions can be assessed with specific confidence (Box *et al.* 1978).

2. Experimental study

2.1 Materials

All chemicals used were of analytical reagent grades. Concentrated Iron (III) chloride ($FeCl_3$) purchased from Aldrich was used to prepare 14wt% of Fe^{3+} used as the coagulant. $FeCl_3$ was used instead of alum because $FeCl_3$ does act both as coagulant and flocculant and very efficient in removing turbidity, colour and arsenic from raw water (Johnson and Amirtharajah 1983). Due to the low pH resulted from the addition of $FeCl_3$, solutions of hydrochloride acid (HCl) and sodium hydroxide (NaOH) were used for pH adjustment. SMART-XIGA ultrafiltration pilot plant used for experimentation was provided by Norit membrane, The Netherlands. Feed water used for the experiment was obtained from a nearby pond at Wageningen University and Research Centre, The Netherlands.

2.2 Methods

Three operating parameters namely, filtration flux, filtration time and coagulant concentration were investigated. The upper and lower limits of the variables adopted for the experimental design were based on the previous experience with hydraulic backwash (HB) (Daramola *et al.* 2011). The actual values and their corresponding coded factors, as used for the experimental design, are presented in Table 1. A 2^3 fractional factorial design + star was used for the experimental design thereby reducing

Table 1 Experimental range and levels of the actual and coded factors

Level	Factors (input variables)					
	Filtration flux (J_f) (L.m^{-2}.s^{-1})		Filtration time (t_f) (minute)		Coagulant concentration (C_c) (ppm)	
	actual	coded	actual	coded	actual	coded
High value	98.9	+1	95.7	+1	5.00	+1
Centre value	70.0	0	62.5	0	2.50	0
Low value	41.1	-1	29.3	-1	0.00	-1

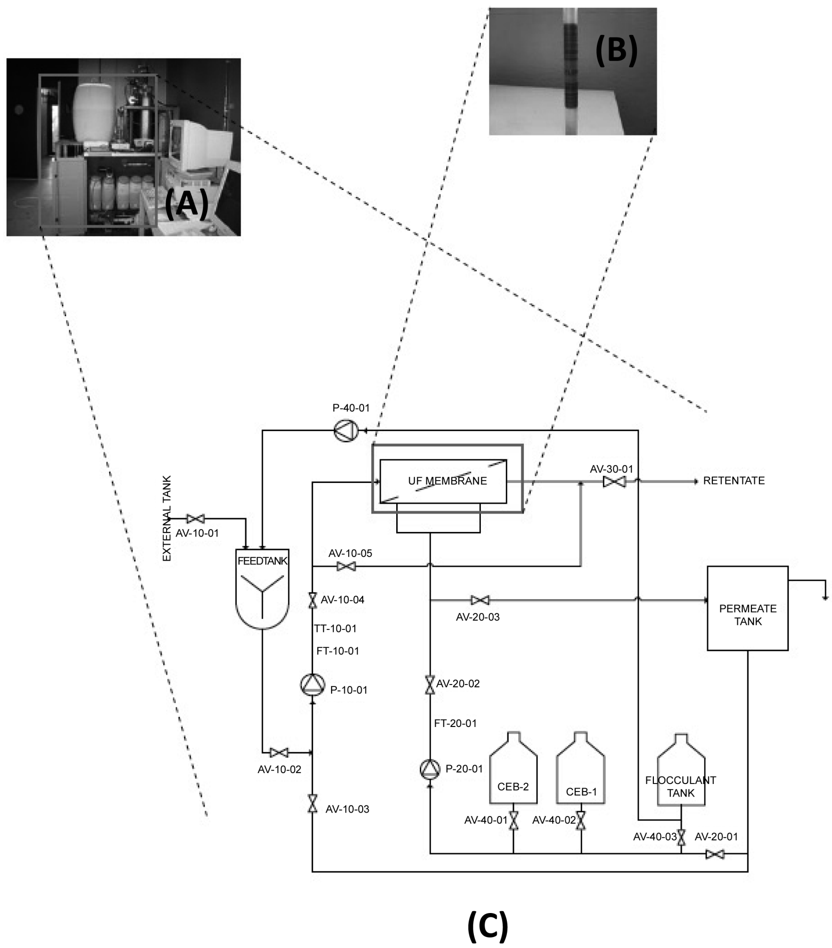

Fig. 1. Description of the UF pilot plant used for experimentation (A) picture of the SMART-XIGA pilot plant showing the raw water tank, (B) clean X-Flow PES UF membrane used for the experimentation, (C) process flow diagram of the UF pilot plant (CEB-1 , NaOH tank; CEB-2, HCl tank).

the number of experimental run to eleven. Ten filtration cycles were always completed before CEB and at the end of each cycle, HB was performed. The UF pilot plant used for the experimentation was equipped with an eight-inch X-flow polyether sulfone (PES) UF membrane module (effective length 25 cm; effective membrane area 0.0754 m^2; number of fibres 120) (see Fig. 1 for the pictorial description of the equipment). The plant was operated in dead-end mode. The coagulant was prepared from $FeCl_3$ and contained 14wt% of Fe^{3+} . A pre-calibrated peristaltic pump (model: Watson Marlow 323) was used for on-line dosing of the coagulant according to the statistically design experiments. Turbidity of the feed water and the permeate was measured using a turbidity meter. Bacteria population in the feed water and the permeate was quantified via the standard plate count method.

2.3 Estimation of reversibility

Effectiveness of the CEB during the UF operation was evaluated using reversibility (R_X) of the membrane flux. The reversibility was defined as the ratio between the change in the resistance of the clean membrane and the resistance of the fouling layer during the CEB. Consequently, the reversibility was expressed as

$$R_X = \left(\frac{\Delta R_{fo} - \Delta R_{fo,X}}{\Delta R_{fo}} \times 100 \right) \% \tag{1}$$

where R_X, the reversibility of the fouling layer during the CEB (%); $\Delta R_{fo,X}$, the change in resistance of the fouling layer after CEB (m^{-1}); $\Delta R_{fo} = R_{tot,end} - R_{tot,start}$, the change in the total membrane resistance after filtration and before the filtration without CEB (m^{-1}); $R_{tot,end}$, the total membrane resistance after filtration (m^{-1}); $R_{tot,start}$, the initial membrane resistance before filtration (m^{-1}).

Normally in UF, hydraulic backwash (HB) is performed after each filtration cycle before CEB. During HB, small quantity of permeate is used to flush the membrane in a reversed manner. But, after several filtration cycles, hydraulic backwash becomes inefficient for the recovery of membrane flux due to pronounced fouling/scaling. At this stage, CEB is necessary. Assuming 100% effectiveness of the HB, Eq. (1) can be expressed as

$$R_X = \frac{(R_{h,n} - R_o) - (R_{aCEB} - R_o)}{(R_{h,n} - R_o)} \times 100 \tag{2}$$

where $R_{h,n}$, the resistance after HB at the end of n filtration cycle; R_o, the initial resistance of the membrane before filtration; R_{aCEB}, the resistance of the membrane after CEB is performed; and n is the number of filtration cycle before CEB is performed. It is noteworthy to mention that CEB usually begins immediately after the n filtration cycle, thus $R_{h,n} = R_{bCEB}$ (R_{bCEB} is the resistance before the commencement of the CEB). Also, if μ and J are kept unchanged during the experiment, the resistance can be expressed as (Cheryan 1998)

$$R = \frac{TMP}{\mu \times J} \tag{3}$$

where R, the resistance of the membrane during filtration (m^{-1}); TMP, the transmembrane pressure during filtration in bar; J, the filtration flux ($l\ m^{-2}h^{-1}$)and μ, the viscosity of the liquid (Nsm^{-1}). Substituting Eq. (3) in Eq. (2) yields

$$R_X = \frac{(TMP_{bCEB} - TMP_{aCEB})}{(TMP_{bCEB} - TMP_o)} \times 100 \tag{4}$$

where, TMP_o is the transmembrane pressure before the start of the filtration (bar), TMP_{aCEB} is the transmembrane pressure after the CEB is performed (bar), and TMP_{bCEB} is transmembrane pressure before CEB is performed (i.e. after the *n* filtration cycle or at the commencement of the CEB). Eq. (4) was employed in estimating the reversibility of membrane flux during the UF experimentations.

3. Modelling

Second order polynomial regression model was adopted as the general regression model relating the filtration flux (J_f), filtration time (t_f) and the coagulant concentration dosage (C_c) to the reversibility of the membrane flux (R_X) (see Eq. (5)). The regression coefficients for linear, quadratic and interaction terms ((α_1,..., α_{10}) and R_{XO}) were estimated using the Least Square (LS) parameter estimation method implemented in the *matlab* environment.

$$R_X = R_{XO} + \alpha_1 J_f + \alpha_2 t_f + \alpha_3 C_c + \alpha_4 J_f^2 + \alpha_5 t_f^2 + \alpha_6 C_c^2 + \alpha_7 J_f t_f + \alpha_8 t_f C_c + \alpha_9 J_f C_c + \alpha_{10} J_f t_f C_c \quad (5)$$

Results of the experiments described in section 2.2 were used to estimate the regression coefficients in Eq. (5) and the model was cross-validated. During the cross-validation of the model a cross-validation technique known as rotation estimation (Geisser 1993, Devijver and Kittler 1982) was used. The technique involves performing the analysis on a training set of data (data used to obtain the regression model) and validating the analysis on validation or testing set of data obtained from repeated experiments using independent experimental runs. Further, the results of the cross-validation were compared with the model output. Analysis of variance (ANOVA) was also computed to evaluate the statistical significance and validity of the model.

4. Results and discussion

4.1 Experimental

Table 2 presents the composition of the feed water before and after the UF experiment. As can be seen in Table 2, the permeate shows very low value of turbidity (<0.09 NTU) when compared with the feed water (600 NTU). After the UF experiments, quantification of bacterial cells carried out using the standard plate count technique revealed no detection of bacterium in the permeate. Low level of turbidity of the permeate (<0.09 NTU) also corroborated the results obtained from the bacteria count of the permeate, indicating no presence of bacterium in the permeate. The reversibility of flux, R_X, obtained from equation (4) are presented in Table 3. A maximum of R_X = 96.1% was obtained at filtration flux, filtration time and coagulant concentration corresponding to 120 L.m^{-2}.s^{-1}, 62.5 min and 2.50 ppm, respectively. Lowest R_X = 45.9% was obtained at filtration flux, filtration

Table 2 Composition of the feed water before and after filtration

Characteristic	Feed	Permeate
Turbidity (NTU)	600	<0.09
Bacteria (CFU/mL)	200	Not detected
Colour (Pt-Co)	200	12

Table 3 Estimated membrane reversibility from experiments

J_f ($L.m^{-2}.h^{-1}$)	t_f (minute)	C_c (ppm)	B_f ($L.m^{-2}.h^{-1}$)	TMP_o (bar)	TMP_{aCEB} (bar)	TMP_{bCEB} (bar)	R_X (%)
70.0	62.5	0.00	250	0.092	0.094	0.128	94.38
98.9	29.3	1.44	250	0.090	0.094	0.132	90.53
20.0	62.5	2.50	250	0.099	0.162	0.215	45.88
120.0	62.5	2.50	250	0.163	0.175	0.472	96.12
70.0	120.0	2.50	250	0.162	0.180	0.421	93.05
98.9	95.7	1.06	250	0.227	0.261	0.419	82.31
41.1	95.7	1.44	250	0.261	0.273	0.382	90.09
70.0	62.5	2.50	250	0.094	0.099	0.166	93.08
70.0	62.5	5.00	250	0.093	0.097	0.113	80.00

B_f : CEB backwash flux

time and coagulant concentration corresponding to 20 $L.m^{-2}.h^{-1}$, 62.5 min and 2.50 ppm, respectively. However, knowledge of the interaction between the variables is necessary to draw suitable conclusions regarding these observations. Thus, developing of a CEB model that could explain the relationship and interaction existing between the variables is necessary.

4.2 Modelling

Using the experimental results provided in Table 3, a regression model was developed. General polynomial regression model (Eq. 5) was used as the basis. Several model candidates were explored and Mean Square Error (MSE) was employed as a tool to evaluate the suitable model candidates. Consequently, the most suitable model candidate was selected. In statistical model (e.g., regression models) two or more statistical models may be compared using their MSEs as a measure of how well they explain a given set of observations. The model with the smallest MSE is generally interpreted as best explaining the variability in the observations and thus adopted as the suitable model. Regression coefficients of the response model were computed by means of Least Squares (LS) in order to minimize the sum of the squares of prediction errors (residuals) (Norton 1986). Estimation of the model parameters of the regression coefficients was according to Eq. (6)

$$\hat{\alpha} = [X^T X]^{-1} X^T Y \tag{6}$$

where $\hat{\alpha}$ is a (u ×1) vector of the regression coefficients; X, a (N × u) matrix of the coded levels of input variables; X^T, the transpose of X; and Y, a (N × 1) vector of the reversibility determined experimentally according to the experimental design, N. The CEB model with model parameters and standard deviations (in enclosed brackets) is presented in Eq. (7)

$$R_X = 102.213(\pm 10.60) + 0.562(\pm 0.150)J_f - 0.019(\pm 0.086)t_f - 31.747(\pm 4.815)C_c - 0.009(\pm 0.009)J_f^2 - 1.127(\pm 0.360)C_c^2 + 0.491(\pm 0.042)J_f C_C - 0.002(\pm 0.046)t_f C_c \tag{7}$$

Response surfaces and contour plots were obtained from Eq. (7) to explain the relationship and interactions between the variables and the response, R_X. It is not possible to represent all the four parameters on a 3-D plot, therefore, one variable was held unchanged at a time, and the influence of other two variables on the reversibility, R_X, is presented on a 3-D surface. The interaction between other two variables is presented on a 2-D contour plot.

Fig. 2 depicts the response of R_X to the change in C_c and the change in t_f at filtration flux of 70 L.m^{-2}.h^{-1}. As can be deduced from Fig. 2(top), the response of the reversibility of the fouling layer to C_c is parabolic in nature. R_X increased as C_c decreased from 5 ppm to 2.5 ppm, reaching a maximum of about 95 % at C_c ~ 2.5 ppm before it slightly decreased to ~ 83 % at 0.0 ppm. This implies that the more the coagulant concentration dosage, the higher the tendency for more coagulation of the particles on/in the membrane, thereby making the *CEB* not so efficient. This occurrence led, therefore, to a reduction in the reversibility of the membrane flux. In addition, R_X displays a linear (but inverse) relation with t_f (see Fig. 2 (top)), indicating a decrease in R_X at increasing t_f. This observation may be attributed to the pronounced scaling/fouling at increasing filtration time, thereby making reversibility of the membrane flux via the CEB inefficient. At this stage, chemical-in-place (CIP) cleaning procedure may be required to remove the scale and embedded organics thereby achieving 100% reversibility of the membrane flux. Interaction between

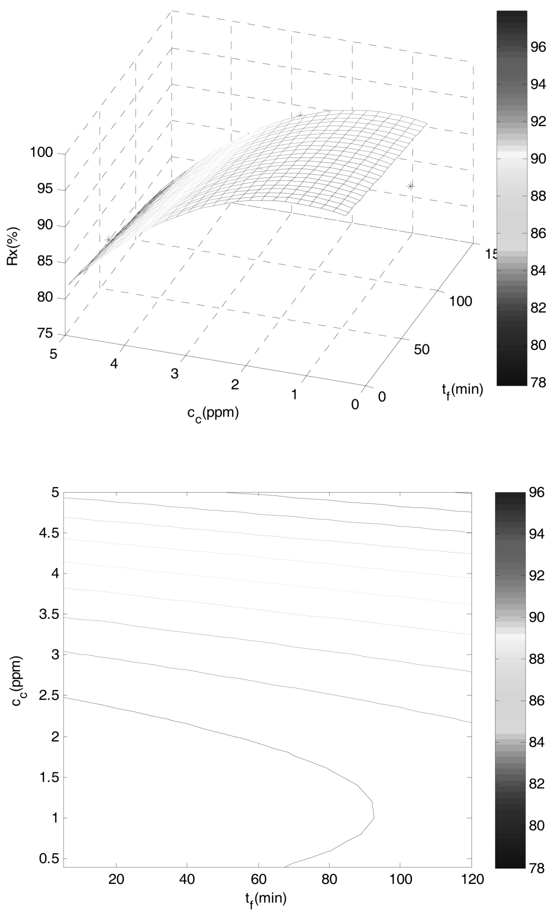

Fig. 2. Response surface plot (top) and contour plot (bottom) indicating the effect of C_c and t_f on R_X at J_f = 70 L.m^{-2}.h^{-1}.

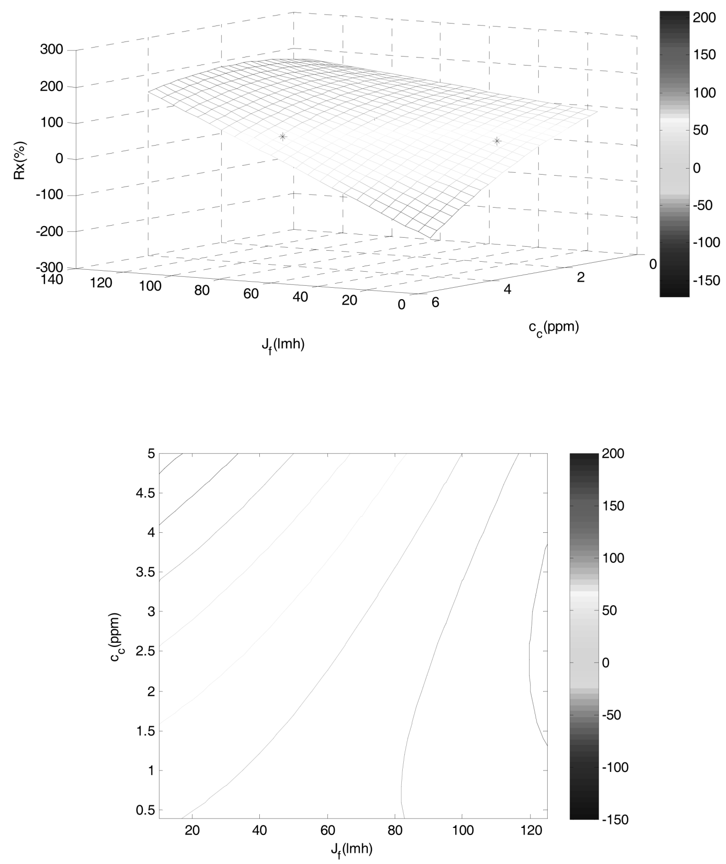

Fig. 3. Response surface plot (top) and contour plot (bottom) indicating the effect of C_c and J_f on R_X at t_f = 62.5 min.

t_f and C_c also indicates a maximum R_X >95% could be obtained at C_c = 1.5 ppm with corresponding t_f = ~90 min (see Fig. 2(bottom)).

For the response of R_X to the change in J_f and the change in C_c at t_f = 62.5 min, see Fig. 3. First and foremost it is noteworthy to mention that $0 \leq R_X \leq 100$. However, in Fig. 3 (top), it can be seen that R_X increased with increasing J_f and decreased with increasing C_c. Regarding the effect of C_c on R_X, similar behaviour was observed at filtration flux, J_f = 70 L.m^{-2}.h^{-1} (see Fig. 2). The increase in R_X at increasing J_f is attributable to an enhanced cleaning of the fouling layer as the filtration flux increased. In addition, the decrease in the reversibility of the membrane flux at increasing coagulant concentration dosage may be attributed to the formation of more foulants on the surface of the membrane resulting from the enhanced coagulation and flocculation of the feed water. Continuous scaling/fouling formation eventually blocks the membrane pores, thereby creating difficulty in cleaning the surface of the membrane, even at increasing filtration flux.

Fig. 4 depicts the influence of J_f and t_f on R_X at C_c = 2.5 ppm. Fig. 4 reveals that R_X increased with increasing J_f at the beginning, reached a maximum of > 95 % at J_f = ~100 L.m^{-2}.h^{-1} and then dropped to R_X = 70 % at J_f = ~125 L.m^{-2}.h^{-1}. Also Fig. 4 apparently shows that R_X slightly depends on t_f (see Fig. 4 (top)). Fig. 4 (bottom) also shows no interaction between t_f and J_f . The response of

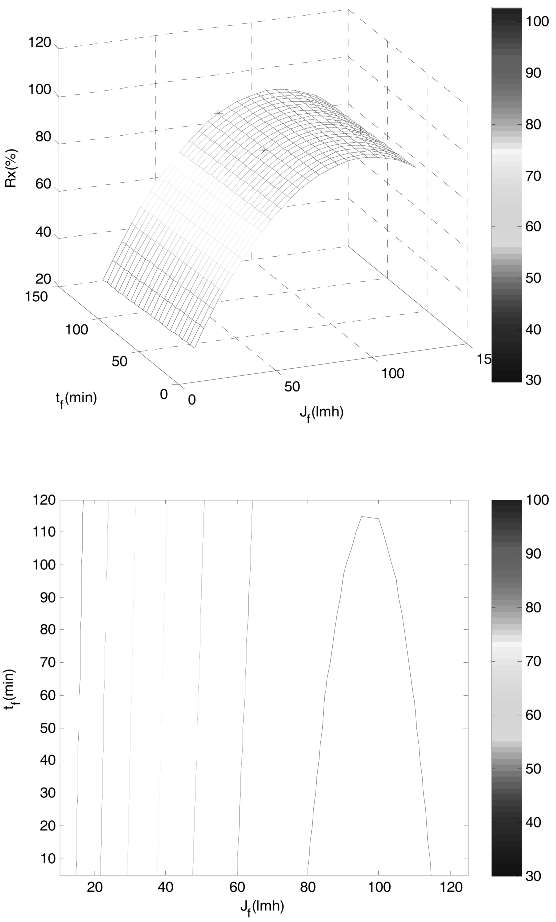

Fig. 4. Response surface plot (top) and contour plot (bottom) indicating the effect of t_f and J_f on R_X at C_c = 2.5 ppm.

R_X to the change in J_f keeping the concentration dosage at 2.5 ppm is similar to the nature observed at the filtration time, t_f = 62.5 min, corroborating the fact that change in t_f has little or no effect on the response of R_X to J_f at C_c = 2.5 ppm. Response of R_X with respect to change in J_f and t_f, as observed in this study, can be exploited towards optimizing CEB at constant coagulant concentration dosage.

4.3 Model validation

During model validation, four experiments were conducted using four training set data. The results of the validation are presented in Table 4. The results compared with the model output are depicted in Fig. 5. As can be seen in Fig. 5, the experimental R_X correlates well with the model output with R^2 = 0.98 (see Fig. 5). In order to ensure whether a good model was developed, the test for significance of the regression model was performed applying the analysis of variance (ANOVA).

Table 4 Reversibility from the validation experiment for CEB model validation

J_f ($L.m^{-2}.h^{-1}$)	t_f (min)	C_c (ppm)	TMP_o (bar)	TMP_{CEB} (bar)	TMP_{hCEB} (bar)	R_x (experiment) %
41.1	95.7	1.06	0.118	0.1183	0.122	92.50
98.9	29.3	1.06	0.102	0.1200	0.221	84.87
41.1	29.3	1.44	0.100	0.1020	0.121	90.58
70.0	62.5	2.50	0.187	0.1900	0.236	93.92

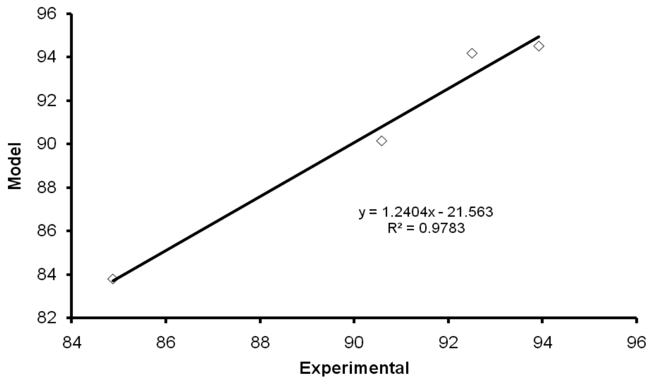

Fig. 5. Comparison of the results of the cross-validation of the model

Table 5 ANOVA analysis of the model

	SS	d_f	*MS*	$F_{0.995}$	*VR*
Between	0.067	1	0.067	0.0055	3.278×10^{-3}
within	121.928	6	20.321		
Total	121.995	7			

MS : mean squares; *SS* : Sum of squares; *VR* : Variance ratio

The results of the ANOVA analysis for R_X are presented in Table 5. The relationships employed in the calculation of the ANOVA estimators (F_{value}, *VR*, R^2) can be obtained from the literature, for example Lazic (2004). Comparing the results obtained from the cross-validation experiments with the model output shows that both results agree with an average residual of 0.184849 and *MSE* of 5.802. Also the variance ratio (*VR*) and F_{value} obtained via ANOVA analysis show that the $VR \ll F_{0.995}$ (see Table 5), indicating a good correlation of the model. In view of this, it can be concluded that the model is valid for other experiments conducted around the nominal working points. Consequently, the model is accurate to describe the performance of CEB during UF process and also to explain the response of the reversibility of membrane flux to changes in the filtration time, filtration flux and coagulant concentration dosage.

5. Conclusions

In this study, CEB model was developed via RSM approach and cross-validation. The response of reversibility of the membrane flux after fouling or scaling to changes in filtration time, filtration flux and coagulant concentration dosage during CEB also was investigated and discussed. The results revealed that the performance of CEB depends significantly on the change in coagulant concentration dosage and the filtration flux. In addition, response of R_X to change in filtration time is insignificant. Cross-validation of the model revealed that $VR \ll F_{value}$ and $R^2 = 0.98$, indicating the validity of the model for predicting reversibility of membrane flux during CEB. It is noteworthy to mention that the procedure described in this study holds only for the feed water used in the study and also considers the parameters of the model to be static with time. In hydrological systems, temporal variations, such as seasonal evaporation and soil-moisture variation, do occur naturally. In such circumstances it is unlikely that parameters in a model of the system remain constant over time. However, the procedure described in this paper could ensure the development of CEB model suitable for such situation with minor modifications to the model presented in this study. Modification to the model is possible by using time variable parameters (TVP) modelling approach. In the TVP, estimation of parameters could be done using recursive estimation technique. Recursive estimation technique accounts for time variation and non-linearity in the modelling (Whitehead 1979).

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