ENHANCEMENT OF SEPARATION PERFORMANCE OF ASYMMETRIC CELLULOSE ACETATE MEMBRANE FOR PRODUCED WATER TREATMENT USING RESPONSE SURFACE METHODOLOGY

Article Highlights
- Effects of cellulose acetate concentration on membrane performance for produced water treatment
- Effects of polyethylene glycol addition on membrane performance for produced water treatment
- Effects of nonsolvent addition on membrane performance for produced water treatment
- Optimization of the cellulose acetate membrane fabrication using response surface methodology

Abstract
Produced water is the wastewater generated from the process of exploration in oil and gas production, which needs special treatment. A membrane with cellulose acetate is widely used for produced water treatment, but further developments and improvements are still required. Therefore, it is important to determine the factors of separation efficiency of an ultrathin cellulose acetate membrane by assessing the influence of the composition of the dope solution. The response surface methodology was employed to determine the optimal conditions for this application. The investigations were conducted by varying the cellulose acetate polymer concentration at 18-20 wt.%, polyethylene glycol 4000 at 2-3 wt.% and nonsolvent addition at 3-5 wt.%. The evaluation of membrane performance for the produced water treatment was performed in a dead-end filtration cell with permeate water flux and rejection parameters for turbidity, total dissolved solids, Ca$^{2+}$, Mg$^{2+}$ and sulfides of produced water upstream and downstream of the membrane. The optimal composition of the dope solution was: 19 wt.% of cellulose acetate, 3 wt.% of polyethylene glycol, and 5.67 wt.% of non-solvent.

Keywords: optimization, asymmetric membrane, cellulose acetate, produced water, response surface methodology.
ency of the membrane separation process have been proposed by previous researchers [5-7]. Nevertheless, the optimal conditions were rarely studied.

There are many variables that can be investigated in order to improve the efficiency of membrane separation processes such as membrane composition, membrane properties and membrane fabrication process [8]. The transport properties of the membrane depend on its structural properties such as porosity, hydrophilicity, and pore size, whereby those properties were influenced by three main factors: polymer composition, additives and nonsolvents. Kusworo and his coworkers stated that polymer concentration was the dominant factor during the fabrication of a high-performance membrane [9]. Lai and his coworkers also indicated that the addition of non-solvent in the solution and porosity of the membrane significantly increase the morphology of membrane [10]. In addition, Xu and Qusay also reported that different amounts of added additives greatly affect the performance and membrane morphology [11]. A higher concentration of nonsolvent additives will increase the molecular weight cut-off (MWCO) and membrane permeation (flux). Furthermore, the additives have been introduced to increase hydrophilicity and diffusion of solute transport properties through a polysulfone hollow fiber membrane. These investigations were mostly applied for reverse osmosis, ultrafiltration and gas separation membranes. The effects of non-solvent addition on the performance of a nanofiltration membrane have not yet been systematically investigated. Therefore, the investigation on the effect of the composition of the dialysis membrane to the membrane performance is very important [12].

The mechanical design of experiments and mathematical modeling techniques were considered to simplify the use of the pertinent variables. The use of statistical design of experiments, such as factorial designs and RSM, has been applied in many investigations. Ismail and Lai studied the influence and interaction factors in the manufacture of membranes using RSM [13]. In their study, they used a factorial design in order to obtain the most influential factor in the separation performance. Ismail and Lai also reported that the shear rate, concentration of polymer and solvent amount are the most prominent factors of membrane separation performances [13]. Idris and co-workers performed a response surface methodology technique in order to develop mathematical models and to optimize the aqueous generation process in the thin film membrane fabrication process [12]. The final conclusion showed that the technique was very useful in optimizing processes and mathematical modeling of thin film composite fabrication.

As discussed in the preceding paragraph, the performance of the membrane can be affected by the concentration of the polymer, the ratio of non-solvent and additives. Therefore, obtaining the optimal conditions of cellulose acetate membrane fabrication for produced water treatment is very important. By employing response surface methodology, the objective of this research was to generate the appropriate mathematical model and to demonstrate that the response surface model could serve as a tool to perform and optimize control variables in the CA nanofiltration membrane for produced water treatment.

.MATERIALS AND METHODS

The materials used in this research included CA (MKR Chemicals Semarang, Indonesia), which was used as a membrane forming polymer, PEG 4000 (Sigma Aldrich Chemie GmbH, Steinheim, Germany), as an additive, acetone 99.75% (Mallinckrodt Chemicals, Dublin, Ireland), and distilled water (UPT Integrated Laboratory of Diponegoro University). The produced water samples were obtained from PT. Pertamina E & P, Ltd. (Cirebon, Indonesia).

This study was divided into three stages. The first stage is the production of cellulose acetate membranes, followed by optimization using RSM for membrane applications in the processing of produced water, and phase characterization. At this stage, the cellulose acetate membrane was fabricated by preparing solutions with compositions of 18, 19, and 20 wt.% cellulose acetate polymers, 2-4 wt.% PEG 4000 and 3-5 wt.% acetone as the solvent. For membrane casting the phase inversion method was used and was carried out on a glass plate using a casting knife. The membrane was immersed into the coagulation bath with distilled water as the nonsolvent for 1 h, followed by immersion in a different coagulation bath at ambient temperature (30±2 °C) for 24 h. The membrane was dried using an oven at a temperature of 60 °C for 24 h. After this process, the membrane was ready to be applied for the treatment of produced water. Rejection and permeate water flux measurements were conducted using a dead-end separation system. The membrane effective area in the module was determined to be 12.57 cm². Before performing the permeability test, the membrane compaction process was conducted by using distilled water for 30 min. After the compaction process, the distilled water was replaced with produced water and kept at a constant temperature of 30±2 °C. Produced water flux
determination was done by measuring the volume of produced water every 15 min. Membrane rejection was performed by determining the concentration of Mg$^{2+}$, Ca$^{2+}$, TDS and S$^{2-}$ before and after passing through the membrane barrier. Determination of TDS was carried out using a TDS meter while for the analysis of Mg$^{2+}$, Ca$^{2+}$ and S$^{2-}$, the titrimetric method was used. Figure 1 illustrates the simple process diagram of a dead-end cell apparatus for a produced water separation process using a prepared CA membrane. The permeate water flux was calculated by the following equation [14]:

$$ J = \frac{V}{PAt} $$  \hspace{1cm} (1)

where $J$ = flux ($L \cdot m^{-2} \cdot bar^{-1} \cdot h^{-1}$), $V$ = permeate volume ($L$), $P$ = pressure (bar), $t$ = time (h) $A$ = membrane effective area ($m^2$). Determination of the coefficient of rejection was done by analyzing the concentration of pollutants in the upstream and downstream from the membrane.

$$ R = 100 \left(1 - \frac{C_p}{C_f}\right) $$ \hspace{1cm} (2)

where $R$ is percent of rejection, $C_p$ is permeate concentration and $C_f$ is feed concentration. The manufacture parameter of membranes was optimized using a technique called response surface methodology (RSM) [15]. The central composite design (CCD) was used to design the number of experiments. Three independent variable trials were used for controlled variables such as concentration CA ($X_1$), polyethylene glycol ($X_2$), and nonsolvent ($X_3$). Lower, upper, center and star point of the design were encoded as -1, 1, 0, and $\alpha$, where +1 indicates a high level, low level –1, $\alpha = 2^{n/4}$ ($n =$ number of variables or factors). The star point was added to the design to produce an estimate arch in the mathematic model and it took 17 experimental runs [16]. Based on this design, the total number of experimental runs are $2^k + 2k + n_0$, where $k$ is the number of independent variables and $n_0$ is the number of repeated experiments at the center point. For statistical calculation, the variable $X_i$ was coded as $x_i$ according to equation:

$$ X_i = (x_i - x_{i0}) / \delta x $$ \hspace{1cm} (3)

where $x_i$ is a dimensionless number of variables $i$, $x_i$ is the original value of the variable $i$, $x_{i0}$ is the value $x_i$ at the center point, and $\delta x$ is a step change, respectively [16]. Response surface methodology resulted in a second-degree polynomial equation. The equations were used as a prediction of the effect of experimental variables and their interactions with the response variables. Each response can be presented by $Y$ and $x$ as independent variables which are expressed by a quadratic mathematical model:

$$ Y_i = \beta_0 + \sum_{j=1}^{3} \beta_j x_j + \sum_{i<j}^{3} \beta_{ij} x_i x_j + \sum_{j=1}^{3} \beta_{jj} x_j^2 $$ \hspace{1cm} (4)

where $Y_i$ is the predicted response, $\beta_0$ is the offset term, $\beta_j$ the linear effect, $\beta_{ij}$ interaction effect, and $\beta_{jj}$ is the squared effect. In this study, the flux and rejection of Ca$^{2+}$, Mg$^{2+}$, sulfide, and TDS were investigated as the responses of the experimental result. The response contour and surface plots, analysis of variance, and standard deviation were developed using Statistica software and ANOVA was performed for statistical analysis of the model. This analysis included the Fisher’s $F$-test (overall model significance), its associated probability $p(F)$, correlation coefficient $R$, and determination coefficient $R^2$ which measures the goodness of fit of the regression model. It also includes the student’s $t$-value for the estimated coefficients and the associated probabilities $p(t)$. For each variable, the quadratic models were represented as contour plots and surface plots.

**RESULTS AND DISCUSSION**

**Characterization of Produced Water**

The produced water was characterized to obtain the concentration of contaminants in the produced water (Table 1). The initial characteristics of the produced water were used for rejection calculation and the analysis of results. The characterization results showed that the produced water still had a high content of S$^{2-}$ (1536 mg/L), Ca$^{2+}$ (2834 mg/L) and Mg$^{2+}$ (267 mg/L) as well as TDS (6500 mg/L).

<table>
<thead>
<tr>
<th>No.</th>
<th>Parameter</th>
<th>Unit</th>
<th>Numerical value</th>
</tr>
</thead>
<tbody>
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<td>TDS</td>
<td>mg/L</td>
<td>6500</td>
</tr>
<tr>
<td>2.</td>
<td>Turbidity</td>
<td>NTU</td>
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</tr>
<tr>
<td>3.</td>
<td>Sulfide</td>
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</tr>
<tr>
<td>4.</td>
<td>Ca$^{2+}$</td>
<td>mg/L</td>
<td>2834</td>
</tr>
<tr>
<td>5.</td>
<td>Mg$^{2+}$</td>
<td>mg/L</td>
<td>267</td>
</tr>
<tr>
<td>6.</td>
<td>COD</td>
<td>mg/L</td>
<td>150.82</td>
</tr>
<tr>
<td>7.</td>
<td>Oil content</td>
<td>mg/L</td>
<td>0.15</td>
</tr>
</tbody>
</table>

**Optimization of membrane CA with PEG and nonsolvent addition using RSM**

The most significant and influential factors were investigated in order to optimize the process of forming an ultrathin cellulose acetate membrane. For interactions and effects that consist of CA concentration ($X_i$), PEG concentration ($X_i$) and the non-sol-
vent ($X_3$), the permeate flux and solute rejection were observed. The comparison between experimental and prediction responses of 17 runs is presented in Table 2. 

Optimization of membrane CA for permeate water flux

The flux was the highest (44.25%) in run 16 in which 19 wt.% CA concentration, 3 wt.%, PEG and 5.67 wt.% of non-solvent were used, as shown in Table 2. This result is not significantly different from the predicted results (43.19%), with the percentage error of 1.05%. This is supported by ANOVA analysis, which evaluates the accuracy and significance of the experimental results.

As shown in Table 2, the influence of the three control variables on CA membrane separation performance is represented in term of permeate water flux. The interaction between the factors were determined by developing the mathematical model and the significant parameters of the model are shown in Table 3.

From Table 3, the value of $F$-value for the regression is defined as $MS_{reg}/MS_{res}$, where $MS_{reg}$ is a mean square of regression, which is obtained by dividing the sum of squares of regression with the degree of freedom. $MS_{res}$ is the mean square of the residuals data. $F$-value also shows the influence of variables on the model with the hypothesis $H_0$ (there is no influence of variables on the model); and $H_1$ (there is influence of variables on the model). In this experiment, the $F$ value of the calculation ($F_{model}$) is 16.03 and higher than $F_{table}$ value ($F_{0.05;9.10} = 3.68$) [17], meaning that $H_0$ must be rejected and that the independent variables $x_i$ contributed the effects to the proposed model [16]. The accuracy of this model can

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**Table 2. Factorial central composite experimental design for fabrication of ultrathin cellulose acetate (CA) membrane and the observed response in terms of flux; PFU: permeate flux unit (L h$^{-1}$ m$^{-2}$ bar$^{-1}$)**

<table>
<thead>
<tr>
<th>Run</th>
<th>Conc. of CA wt.%</th>
<th>Conc. of PEG wt.%</th>
<th>Conc. of non-solvent, wt.%</th>
<th>Yo Flux, PFU</th>
<th>Yp Flux, PFU</th>
<th>Yo TDS rejection, %</th>
<th>Yp TDS rejection, %</th>
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<tr>
<td>1</td>
<td>18</td>
<td>2</td>
<td>3</td>
<td>35.21</td>
<td>35.65</td>
<td>0.44</td>
<td>95.61</td>
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<tr>
<td>2</td>
<td>18</td>
<td>4</td>
<td>5</td>
<td>31.15</td>
<td>30.90</td>
<td>0.25</td>
<td>87.72</td>
</tr>
<tr>
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<td>20</td>
<td>2</td>
<td>5</td>
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<td>83.77</td>
</tr>
<tr>
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<td>4</td>
<td>3</td>
<td>31.19</td>
<td>32.43</td>
<td>1.24</td>
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<tr>
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<td>19</td>
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<td>4</td>
<td>41.66</td>
<td>39.93</td>
<td>1.72</td>
<td>98.25</td>
</tr>
<tr>
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<td>18</td>
<td>2</td>
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<td>1.24</td>
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<td>20</td>
<td>4</td>
<td>3</td>
<td>35.36</td>
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<td>0.68</td>
<td>96.49</td>
</tr>
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<td>19</td>
<td>3</td>
<td>4</td>
<td>38.89</td>
<td>39.93</td>
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<tr>
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<td>3</td>
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<td>85.53</td>
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<td>28.39</td>
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<td>19</td>
<td>3</td>
<td>2.33</td>
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<td>0.54</td>
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<tr>
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<td>3</td>
<td>5.67</td>
<td>44.25</td>
<td>43.19</td>
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<td>99.12</td>
</tr>
<tr>
<td>17</td>
<td>19</td>
<td>3</td>
<td>4</td>
<td>38.94</td>
<td>39.93</td>
<td>0.99</td>
<td>98.25</td>
</tr>
</tbody>
</table>

**Table 3. ANOVA of permeate water flux**

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of squares</th>
<th>Degree of freedom</th>
<th>Mean square</th>
<th>$F$ Value</th>
<th>$F_{0.05}$ Value</th>
<th>$R^2$</th>
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<tr>
<td>SS regression</td>
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<td>9.00</td>
<td>70.88</td>
<td>16.03</td>
<td>3.68</td>
<td>0.95</td>
</tr>
<tr>
<td>S.S. error</td>
<td>30.95</td>
<td>7.00</td>
<td>4.42</td>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S.S. total</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ANOVA of TDS Rejection</td>
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<tr>
<td>SS regression</td>
<td>444.21</td>
<td>9.00</td>
<td>49.36</td>
<td>17.02</td>
<td>3.68</td>
<td>0.96</td>
</tr>
<tr>
<td>S.S. error</td>
<td>20.30</td>
<td>7.00</td>
<td>2.90</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S.S. total</td>
<td>464.51</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
</tr>
</tbody>
</table>
also be seen from the value of the regression coefficient, \( R^2 = 0.95 \). This indicates that 95% of the total variation has been covered by the model \([9]\). The mathematical model was developed as:

\[
Y_{\text{pred}} = 39.93 - 1.55X_1 + 1.55X_2 + 0.19X_3 - 4.33X_1^2 - 4.95X_2^2 + 1.05X_1X_2 + 2.53X_1X_3 + 2.53X_2X_3 + 0.03X_1X_2X_3 \tag{5}
\]

From Eq. (5), it can be seen that three factors dominantly influence the value of \( Y \) (membrane flux). The effects were described as the linear effect, quadratic effect, and interaction effect. Based on regression coefficient values, it can be concluded that the dominant factors are concentration of CA \( (X_1) \) and PEG \( (X_2) \). The introduction of nonsolvent in this case does not have significant effect due to the fact that the ranges of nonsolvent concentrations are beyond the optimal range. The \( X_1 \) (CA concentration) has a negative coefficient that indicates the increase in concentration of CA will reduce the permeate flux. On the other hand, the \( X_2 \) (PEG) has a positive coefficient; it indicates that with the increase in concentration of PEG, the value of flux will also increase. The quadratic effect exhibits negative coefficients for \( X_1 \) and \( X_2 \). This is because the process variable has exceeded the optimal conditions and therefore the permeate flux decreases. The interactions between CA concentration and PEG concentration in the dope solution are strong, as well as the interaction between PEG concentration and nonsolvent concentration, while the interaction between CA concentration and non-solvent concentration is very weak. This phenomenon shows that CA and PEG concentrations have influences in the structural formation of the membrane. Both CA and PEG serve important roles in pore formation. Moreover, PEG also serves as a hydrophilicity enhancing agent. The interaction between PEG concentration and the nonsolvent has significant influence on the separation performance. The non-solvent (water) has a high affinity to PEG molecules. When the non-solvent is added to the dope solution, it attracts the PEG and it leaves the void fractions in the membrane material.

The optimal composition in fabricating a CA membrane can be depicted from 3D surface contours. The contour graphs in this study represent a rising ridge surface. The surface plot and contour plot showed the optimal conditions corresponding to the maximum of flux, because the linear \( P \)-value is lower than the square \( P \)-value. The surface plot and contour plot are presented in Figure 1.

In Figure 1, the non-solvent concentration has less significant influence on the yield, where the increase in non-solvent concentration slightly increases the yield. On the other hand, the concentration of CA has a negative effect on the yield, meaning that the increase in concentrations of CA causes a decrease in the yield. The concentration of CA has a greater impact on the yield than non-solvent concentration. It can be shown through the coefficient values in the regression equations. The higher coefficient value indicates greater influence on the response variable. It is clear that the region of the highest water flux of 99.12% corresponds to the concentration CA of 19 wt.%, PEG concentration of 3 wt.%, and non-solvent of 5.67 wt.% (Table 2).

Optimization of membrane TDS towards rejection

The evaluation of \( Ca^{2+}, Mg^{2+}, S^{2-} \) and TDS rejection were performed and the responses are presented in Table 2. The TDS rejection was studied in order to analyze the influence of soluble mineral pollutants.

Based on the \( F \)-value (Table 3), the \( F_{\text{model}} \) of TDS rejection (17.02) is higher than the value of \( F_{\text{table}} \) \( (F_{0.05} = 3.68) \). It indicates that the three variables have effect on TDS rejection \([9]\). According to the value of \( F_{\text{model}} \), which is higher than \( F_{\text{table}} \), the decision is to reject \( H_0 \), which means that the independent variables \( X \) influence response variables \([18]\). The accuracy of this model can be observed in the value of the determination coefficient \( (R^2) \) of TDS rejection, as shown in Table 4. The regression equation has an \( R^2 \) value of 0.96 and the \( P \)-value of < 0.05, which means the model fits according to experiment results \([9]\). The regression equation for TDS rejection is:
From Eq. (6), it can be seen that the most influential factors that affect membrane separation performance in terms of TDS rejection are CA concentration ($X_1$) and PEG concentration ($X_2$). CA concentration contributed to the formation of a dense layer in the membrane, while PEG contributed to pore formation during membrane fabrication. The dense layer and membrane porosity are structural properties of the membrane that controls the separation performance. The non-solvent in this case does not have a significant effect, because the range of the non-solvent concentration used in this experiment is out of the optimal range. The $X_1$ coefficient (concentration CA) has a negative coefficient (-0.94), it indicates that the decrease in the concentration of CA will increase the rejection rate. On the other hand, the increase in concentration of PEG, the rejection performance will decrease. The quadratic effect shows a negative sign for $X_1$ and $X_2$ that indicates the optimal concentration for each variable. If the variables exceed the optimal concentration, it would result in low rejection value.

The maximum TDS rejection is depicted in Figure 2. On the $Ca^{2+}$ and sulfide rejections, the concentration of CA exhibits the dominant influence on the rejection performance. Another case in $Mg^{2+}$ and TDS rejections, the concentration of PEG has the greatest influence on rejection performance. Furthermore, the optimal process variables in membrane fabrication are 19 wt.% CA, 3 wt.% PEG, and 5.67 wt.% non-solvent.

Regression coefficient significance

Table 4 exhibits the regression coefficient significance of the flux and rejection models. The student’s test was used to determine the significance of the regression coefficient [9]. The coefficients with single factors represent the effects of a certain factor, while the coefficients with two factors and second order equation terms represent the interaction between two factors and the quadratic effect, respectively. Table 4 shows that the coefficient of concentration of polyethylene glycol as additive contributing the most significant effect to the determination of optimal fluxes with $p$-value of 0.03. Moreover, the polymer concentration and cellulose acetate had a significant negative effect, with $p$-value of 0.03. Figure 3 shows that with the increase in CA concentration in the dope solution, the membrane flux declines. The results are consist-
ent with previous studies, where the polymer concentra-
tion contributes to controlling the permeate water flux of the membrane. The higher concentration of polymer in the dope solution produces high density membrane material [9]. The experiment also showed that increasing the concentration of PEG in the dope solution would increase the permeate flux. This is in accordance with previous research conducted by Arthanareeswaran et al. [19], who showed that increasing the concentration of PEG will enhance the flux of water through improvement in pore formation. The addition of PEG to the dope solution has influence on pore formation, wherein the pores formed should become bigger with the addition of PEG. PEG will stimulate the formation of macrovoids [12]. The finger-like macrovoids will increase the membrane flux. Beside the formation of pores, the PEG addition improved the hydrophilic properties of the membrane. Therefore, the permeation of water increased.

Figure 3. Effect of cellulose acetate concentration on the flux.

The quadratic effects of CA and PEG concentration provide significant effect to the separation performance with level of significance (p-values) of 0.0002 and 0.0001, respectively. A significant factor represents the interaction between $X_1$ and $X_2$ ($p$-value = 0.011 < 0.05). The polymer concentration and additive combination could be used in controlling the viscosity of the dope solution during fabrication of asymmetric cellulose acetate process. Viscous dope solution causes improvement of the pore size of membrane which will produce asymmetric membrane with high performance in terms of fluxes.

The effect of polymer concentration on TDS rejection was also significant, with $p$-value of 0.008. One of the performance parameters of membrane separation is TDS rejection, which represents the mineral pollutants which are soluble in the produced water. Figures 4 and 5 show the effect of polymer concentration on the rejection of Ca$^{2+}$ and sulfide. The highest rejection was observed in the membrane with 20 wt.% concentration of CA, and the lowest rejection was observed in the membrane with 18 wt.% of CA. It can be seen that the rejection increases with an increase in concentration of cellulose acetate. This phenomenon might occur due to the increase in the concentration of polymer which will increase the viscosity of the casting film. Moreover, the diffusivity between the components in the system will be lower during the process of solidification of the casting solution and then inhibit the precipitation process and lead the surface membranes to having smaller pores [19].

Figure 4. Cellulose acetate concentration effect on Ca$^{2+}$ rejection.

Figure 5. Cellulose acetate concentration effect on S$^{2-}$ rejection.

The ANOVA analysis to obtain the best predicted parameters is depicted in Table 5. The maximum flux was achieved when CA concentration, PEG additive and nonsolvent were 18.86, 3.12 and 4.01
wt.%, respectively. As depicted in Table 5, experimental values are 89.29 and 98.18 for Mg$^{2+}$ and S$^{2-}$ rejection, respectively. The error percentages between the experimental and predicted results are 6.30 and 1.29% for flux and TDS rejection, respectively. From these results, it can be confirmed that the statistical model is feasible for predicting experimental conditions by obtaining the optimal flux and rejection for produced water treatment using a CA nanofiltration membrane.

CONCLUSIONS

The optimal separation performance in terms of flux and rejection were determined. The optimal process variables were 18.86 wt.% CA concentration with 3.12 wt.% PEG together with 4.01 wt.% of the non-solvent, exhibiting the best separation performance in terms of flux and rejection for produced water treatment using a cellulose acetate membrane. The main effects and interactions were successfully determined using response surface methodology. Generally, the significant variables in membrane fabrication were CA concentration in the total solid followed by the amount of the PEG additive. The errors between the experimental and predicted, using a model developed from response surface methodology, were 6.30% for flux, 3.20% for TDS rejection, that are within the acceptable limit (5%).

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List of abbreviations

- MWCO: Molecular weight cut off
- RSM: Response surface methodology
- CCD: Central composite design
- FFD: Fractional factorial design
- CA: Cellulose acetate
- PEG: Polyethylene glycol
- J: Permeate water flux
- V: Volume
- P: Pressure
- A: Effective area of membrane
- t: Time
- Rj: Rejection
- Ck: Concentration of pollutant in downstream
- Ck: Concentration of pollutant in upstream
- Xi: Independent variable represents as polymer concentration
- Xi: Independent variable represents as additive concentration
- Xi: Independent variable represents as non-solvent concentration
- a: Axial point
- xi: Dimensionless number of i
- x0: Value of xi in center point
- δx: Step change
- Yi: Response of i
- β0: Offset term
- βi: Linear effect
- βij: Interaction effect
- βjj: Quadratic effect
- p(F): Associated probability
- R: Correlation coefficient
- H0: Null hypothesis
- H1: Alternative hypothesis
- Fmodel: Ratio of two variances from model
- Ftable: Ratio of two variances from statistic table
- Y0: Experimental response
- Yp: Predicted response

REFERENCES

POBOJŠANJE SEPARACIONIH PERFORMANSI ASIMETRIČNE CELULOZNO ACETATNE MEMBRANE ZA OBRADU OTPADNE VODE PRIMENOM METODE ODZIVNE POVRŠINE

Otpadna voda nastala tokom eksploatacije nafte i gasa zahteva poseban tretman. Celulozno acetatna membrana se odavno široko primenjuje u tretmanu otpadnih voda, ali je potreban njen dalji razvoj i poboljšanje. Zbog toga je važno utvrditi faktore efikasnosti razdvajanja ultratankce celulozno acetatne membrane procenom uticaja polimera na sastav rastvora. Optimalni uslovi za ovu primenu određeni su 19% celuloznog acetata, 3% polietilen glikola i 5,67% nerastvarača.

Ključne reči: optimizacija, asimetrična membrana, celulozni acetat, proizvedena voda, metoda odzivne površine.