Kinetic Studies of Reactive Orange 16 (RO16) Dye Removal from Aqueous Solution using PIMs

Manassvinee Gunasegaran¹, Suganthi Ravi¹, Noor Fazliani Shoparwe¹

¹Faculty of Bioengineering and Technology, Universiti Malaysia Kelantan, Jeli Campus, Locked Bag No. 100, Jeli, Kelantan, Malaysia.
fazliani.s@umk.edu.my

Abstract. Polymer inclusion membrane (PIMs) was used as an extractant for the removal of Reactive Orange 16 (RO16) dye as it is an easy and effective way. The extraction process is used because it is found to be more economical and effective compared to other dye removal methods. The PIM consists of Polyvinylidene Fluoride Co-Hfp (PVDF-Co-HFP) as a base polymer, Aliquat 336 as a carrier with the solvent of Tetrahydrofuran (THF). The formulations of the components were varied to determine the optimum composition of membrane with the effective extraction ability. Various parameters such as effect of carrier, initial dye concentration and pH were investigated. The optimum extraction of RO16 dye using PIMs were found to be at composition M₃, 9 % of carrier which is worked best on 10 mg/L initial dye concentration in 4 hour time at pH 2 with agitation speed of 500 rpm at room temperature. Kinetic modelling was studied to analyse the extraction process and removal of dye by using the pseudo-first-order and pseudo-second-order. The kinetic model fits very well with the kinetic data using pseudo-second-order. The highest percentage removal of RO16 dye was 99.62 % and it is proven that PIMs has the potential to remove the dye.

1. Introduction
Water is vital for all living things and it is an essential element of life. However, the availability and accessibility to freshwater has been proved as one of the most severe case affected in recent years [1]. Dyes can be categorised as a chemical compound which releases colour on the surface which it binds. Nowadays, large amount of industrial textile colouring agents (dyes) are highly present in the effluent wastewater. This effluent wastewater gave negative impacts to environment, aquatic life and public health [2]. It had been estimated that textile industry alone are being released up to 200,000 tons of waste that contains of toxic substances into the waterway [3]. The release of small amount of dyes which is below 1 ppm into the waterways can lead to severe pollution as dye contain carcinogenic substances [4].

Reactive orange 16 (RO16) is classified under azo reactive dye. This dye is one of the reactive azo dyes most intensively produce and used universally. Excellent colouring properties, high water solubility, and outstanding covalent bonding with both natural and synthetic textile fiber are the advantages of RO16 [5]. This dye can cause pollution to the environment because of its highly toxic to surrounding and harmful due to its mutagenic properties. This can be easily absorbed by the body because it is water soluble. Therefore, it needs to be removed before the wastewater can be discharged into the environment [6]. If RO16 dye is being inhaled or swallowed, it can cause irritation in eyes, skin and digestive tract to mammalian cells [7].

Synthetic dyes such as RO16 are very difficult to remove. This is because they have a complex
aromatic structure which provides them physico-chemical thermal and optical stability [8]. Actually, wastewater with dyes can be treated with various type of methods such as chemical precipitation, oxidation, reverse osmosis, ion exchange, liquid-liquid membrane and etc. However, these methods and techniques have limitation due to high energy consumption and expensive synthetic chemicals [9]. Moreover, these methods generate large amount of toxic sludge and are ineffective at lower concentrations of dye. So, to overcome this problem, membrane technology has become an attractive alternative option for the treatment of industrial wastewater and water purification.

Membrane technology is well known for wastewater treatments. This is due to its high productivity, high removal capacity, cost effective, easy scaling up, simplicity in operation and no addition of chemical additives [10]. According to statistic, membrane technology contributes up to 53% of total world processes for production of clean water and is an effective approach for water treatment. Looking at this situation, membrane method has appeared as better approach for RO16 dye removal.

Polymer inclusion membranes (PIMs) is a type of liquid membrane that has been developed for various type of usage such as removal of metal ions and dye [11]. This method is also well known equilibrium separation process as well as the process can be easily conducted studied due to significant advantages over solvent extraction method. Thus, this method has been used in the industries for the process of dye removal from the wastewater.

This research will develop a new composite of membrane with the formula of a base polymer, plasticizer and a carrier. According to [12], PVDF-Co-HFP is the type of polymer that has been widely used in fabrication of ultrafiltration (UF), microfiltration (MF) and nanofiltration (NF) due to its good thermal, mechanical stability and high chemical resistance. Moreover, they are very limited study used this PVDF-Co-HFP polymer in PIMs. The fabrications of this PIMs indicates a higher performance for the applications in various effluent in wastewater treatment. Thus, this research analysed the efficiency of PIMs fabricated for the removal of dye.

The present study focuses on kinetic studies of RO16 dye removal from aqueous solution using PIMs. A various formulation of PIMs were fabricated using PVDF-Co-HFP as a base polymer, Aliquat 336 as a carrier and act as a plastizer too. The kinetic modelling of PIMs for the dye extraction process was performed to identify the best fit model and significant parameters.

2. Experimental methods

2.1. Chemicals
All the chemicals and reagents used for membrane fabrication and membrane performance test. PVDF-Co-HFP, Aliquat 336, Tetrahydrofuran (THF) and RO16 dye were obtained from Sigma-Aldrich (USA). Ethanol, Acetone, Hydrochloric acid (HCl), Sodium hydroxide (NaOH) and Nitric acid (HNO₃) were obtained from Merck, Malaysia.

2.2. Equipment
The equipment used in this study are magnetic stirrer, weighing balance, UV-visible spectrophotometer, pH meter and H-cell device.

2.3 Fabrication of PVDF-Co-HFP PIMs
PVDF-Co-HFP, Aliquat 336 and THF were weighted separately in 50mL beaker. The solution of PVDF-CO-HFP was prepared by dissolving 9 g of PVDF-CO-HFP in 39.5 g of THF. Then, 1.5 g of the carrier Aliquat 336 was poured into the solution. All this three solutions were mixed and stirred for at least 4 hours to form a homogenous casting solution. After 4 hours, 25 ml of the homogenous casting solution was poured into membrane casting machine and spread evenly to form uniform PIM formation [13]. The casted membrane glass was left to allow a gradual evaporation of THF. This process was carried out in fume hood at room temperature for overnight. On the next day, the PIMs was peeled off from the glass and washed with distilled water for a few times. Thus, the procedure
above repeated with different composition of carrier which was shown in the Table 1.

Table 1. Compositions of PIMs

| MATERIALS          | Polymer       | Carrier    | Solvent |
|--------------------|---------------|------------|---------|
|                    | PVDF-Co-HFP   | Aliquat 336| THF     |
| M₀                 | 9 g           | 0 g        | 41 g    |
| M₁                 | 9 g           | 1.5 g      | 39.5 g  |
| M₂                 | 9 g           | 3 g        | 38 g    |
| M₃                 | 9 g           | 4.5 g      | 36.5 g  |
| M₄                 | 9 g           | 9 g        | 32 g    |

2.4. Performance Studies of PVDF-Co-HFP PIMs for RO16 Dye Extraction

Different concentration of dye was prepared to study the performance of the dye extraction. RO16 stock solution was prepared by dissolving 0.1 g in 1000 mL of distilled water to produce a concentration of 1000 mg/L using a 1000 mL volumetric flask. Serial dilutions were made by diluting the RO16 stock solution in accurate proportions using distilled water. For the constructions of calibration curve, a few series of RO16 dye concentrations was prepared in the range of 0.5 mg/L to 100 mg/L by diluting the prepared stock solutions with distilled water. The concentration of solution was measured using UV-visible spectrophotometer at the wavelength of 493 nm [14]. Figure 1 shows the set up of the H-cell device with the performance studies of the PIMs for RO16 dye extraction.

Figure 1. Schematic diagram of PIMs system

Based on Figure 1, 50 mg/L of 120 mL RO16 dye solution was poured into the feeding compartments. The 120 mL of 1.0 M HNO₃ solution was place at the receiving compartment. These both solutions were stirred throughout the process by using the magnetic stirrer under 500 rpm. For adjusting the pH of the aqueous solution, 1.0 M of HCl and 1.0 M of NaOH were used. The process was run for 4 hours. The final concentration from the feeding phase was determined by UV-visible spectrophotometer at the wavelength of 493 nm. All the procedures above were repeated by using different composition of carrier in PIMs. Aluminium foil was used to wrap the reagent bottle containing dye to avoid the degradation of dye and stored for further use. The procedures were repeated by using optimum composition of PVDF-Co-HFP PIMs to test the effect of initial dye concentration from the range of 10 mg/L to 50 mg/L and effect of pH from the range of pH 2.0 to pH 12.0 to study the performance of the dye removal process. The percentage of removal was calculated as in equation (1).
2.5. Effect of carrier composition in PIMs

This study was conducted by using four different carrier compositions of PIMs while the amount of base polymer kept constant. This study used different amounts of carrier which were 1.5 g, 3 g, 4.5 g and 9 g. Thus, the fabricated PIMs were tested using 50 mg/L of RO16 dye for 4 hours to get the optimum PIMs. This was analysed by using the UV-Vis spectrophotometer at 493 nm. The optimum PIMs was kept constant throughout the other parameters which were effect of initial dye concentration and effect of pH.

2.6. Kinetic Modelling

The kinetic model was proposed using the pseudo-first-order and pseudo-second-order model which shown in equation (2) and equation (3) respectively. The experimental data was fitted with the kinetics data model. A nonlinear least-square regression analysis was performed using polymath software version 6.0 to determine the $K_1$ and $K_2$ value of the predicted profile of the dye extraction [16]. The coefficient of determination of $R^2$ and variance were calculated for each model to compare the accuracy of the studied model based on the equation (4) and equation (5) given below respectively [17].

$$E\% = \frac{C_0 - C_e}{C_0} \times 100$$

(1)

Where,
- $C_0$ = initial concentration of dye in the solution (mg/L);
- $C_e$ = final concentration of dye in the solution (mg/L) [15].

$$C = C_e - e^{-k_1 t}(C_e - C_o)$$

(2)

Where
- $C_0$ = amounts of dye removed (mg/g)
- $C_e$ = equilibrium removal capacity
- $t$ = time (min)
- $k_1$ = rate constant of removal (g/(mgmin))

$$C = C_e - \frac{1}{k_2 t} - \frac{1}{C_o - C_e}$$

(3)

Where
- $C_0$ = amounts of dye removed (mg/g)
- $C_e$ = equilibrium removal capacity
- $t$ = time (min)
- $-k_2$ = rate constant of removal (g/(mgmin))

$$r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{n[\Sigma x^2 - (\Sigma x)^2][n[\Sigma y^2 - (\Sigma y)^2]]}}$$

(4)
Where,
\( r \) = The Correlation coefficient
\( n \) = number in the given dataset
\( x \) = first variable in the context
\( y \) = second variable

\[
\sigma = \frac{\sum x^2}{N} - \mu^2 \tag{5}
\]

Where,
\( \mu \) = average or the mean of the individual data point
\( N \) = number of individual data point in the distribution
\( x \) = value of individual data point

3. Result and discussion

3.1. Kinetic Studies of RO16 Dye Removal using PIMs

3.1.1. First order model for effect of carrier composition. Figure 2 indicates that the first order model used to analyse the kinetics of effect of carrier in the removal of RO16 dye by the PIMs.

![Figure 2](image-url)

**Figure 2.** Comparison of predicted and experimental value of RO16 dye removal at different effect of carrier

The data plotted in the figure 2 indicates that the experimental data value fit with the predicted data value. This shows that the linear plots of both experimental and predicted value pass through together. The values of \( k_1 \) obtained in the removal of the dye with the membranes PVDF-Co-HFP- Aliquat 336 are summarized in table 2 below.
Table 2. Parameters value of first of order Kinetic model for the effect of carrier

| Carrier % | $C_e$   | $k_1$      | $C_o$  | $R^2$  | Variance |
|-----------|---------|------------|--------|--------|----------|
| 0         | 20.79994| 0.0000251  | 49.66218 | 0.983257 | 0.000478 |
| 3         | 18.82   | 0.0010896  | 51.03482 | 0.980197 | 0.400448 |
| 6         | 16.83991| 0.0017584  | 51.392  | 0.982441 | 0.658157 |
| 9         | 15.84993| 0.0027323  | 51.56292 | 0.993397 | 1.094172 |
| 18        | 15.84984| 0.000774   | 50.73025 | 0.990654 | 0.18816  |

From the data tabulated in the table 2, the $k_1$ value shows the rate of reaction of the dye removed by PIMs. As the amount of carrier increases in the PIMs composition, the $k_1$ value increases too. However, the rate of reaction was very high at 9% carrier of Aliquat 336 composition compared to 18% carrier of Aliquat 336 composition. At 9% carrier of Aliquat 336 composition the $k_1$ value is 0.00027 while at 18% carrier of Aliquat 336 composition the value become 0.0007. This situation due to the membrane saturation in the PIMs. The saturation capacity of the membrane for the complex reached at optimum 9% carrier. The equilibrium of reaction was achieved when all carriers get associated with dye ion and form complex [18].

3.1.2. First order model for effect of initial dye concentration. Figure 3 shows the first order model used to analyse the kinetics of effect of initial dye concentration in the removal of RO16 dye using PIMs.

![Figure 3. Comparison of predicted and experimental value of RO16 dye removal at different effect of initial dye concentration](image)

According to the figure 3 the relationship between the experimental data and predicted data value was fitted linearly against the period of time. The $k_1$ value was tabulated at table 3 below.
Table 3. Parameters value of first of order Kinetic model for the effect of initial dye concentration

| Initial Concentration | C_e   | k_1    | C_o   | R^2     | Variance  |
|-----------------------|-------|--------|-------|---------|-----------|
| 10 mg/L               | 8.919794 | 0.0035976 | 10.33825 | 0.974273 | 0.096052  |
| 20 mg/L               | 8.919926 | 0.0030979 | 20.60584 | 0.94414  | 0.451621  |
| 30 mg/L               | 10.9  | 0.0029294 | 30.7874  | 0.981819 | 0.339777  |
| 50 mg/L               | 14.85977 | 0.0027498 | 51.318   | 0.982949 | 1.086311  |

Based on table 3 above, it can be clearly seen that k_1 value decreases when the initial dye concentration increases. This shows that the highest rate of reaction occur at the lowest initial dye concentration which is 0.0036 at 10 mg/L. The removal percentage at the lowest initial dye concentration was 95.77 %. This proves that the optimum PIMs composition easily removed the lower initial dye concentration in the aqueous solution. As the concentration increased to 50 mg/L, the rate of dye removal become low due to the membrane becomes saturated.

3.1.3. First order model for effect of pH. Figure 4 shows the first order model used to analyse the kinetics of effect of pH in the removal of RO16 dye by the PIMs.

Figure 4. Comparison of predicted and experimental value of RO16 dye removal at different effect of pH

Figure 4 indicates that the kinetic predicted modelling fits the experimental data value of the pH. The range of pH in this study is for 2 and 4 for acidic, 7 as neutral whereas 10 and 12 as basic condition respectively. Data of k_1 for ph was tabulated at Table 4 below.
Based on the table 4, the pattern shows that as the pH decreases the rate of reaction increases. The $k_1$ value is higher at acidic condition which is 0.0386 at pH 2. This shows the reaction is effective and faster when the dye was alters into acidic solution. The dye removal percentage was highest at pH 2 which is 99.62 %. According to [19], the uptake of RO16 dye by the PIMs more efficient at low pH region due to the presence of electrostatic attractions between the RO16 anion dye and the positive charged surface.

### Table 4. Parameters value of first of order Kinetic model for the effect of pH

| pH   | $C_e$     | $k_1$    | $C_o$     | $R^2$    | Variance |
|------|-----------|----------|-----------|----------|----------|
| pH 2 | 0.171058  | 0.0386403| 9.948217  | 0.985948 | 0.061047 |
| pH 4 | 0.43373   | 0.017373 | 9.861132  | 0.985744 | 0.055936 |
| pH 7 | 1.734962  | 0.0034884| 10.47609  | 0.965631 | 0.14769  |
| pH 10| 2.745104  | 0.0097337| 9.867631  | 0.962714 | 0.033972 |
| pH 12| 6.939725  | 0.0099189| 10.13614  | 0.980474 | 0.051073 |

3.1.4. **Second order model for effect of carrier composition.** Figure 5 indicates that the second order model used to analyse the kinetics of effect of carrier in the removal of RO16 dye by the PIMs.

![Figure 5](image_url)

**Figure 5.** Comparison of second order of predicted and experimental value of RO16 dye removal at different effect of carrier

According to the figure 5 above, the second order of kinetic modelling shows that the experimental and predicted data value fitted on it. The values of $k_2$ obtained in the removal of the dye with the membranes PVDF-Co-HFP-Aliquat 336 are summarized in table 5.
Table 5. Parameters value of second of order Kinetic model for the effect of carrier

| Carrier | $C_e$     | $k_2$     | $C_o$     | $R^2$    | Variance |
|---------|-----------|-----------|-----------|----------|----------|
| 0 %     | 7.152072  | 0.000005  | 49.66044  | 0.996177 | 0.000106 |
| 3 %     | 50.49963  | 0.000008  | 51.1141   | 0.990075 | 0.462186 |
| 6 %     | 60.39811  | 0.00005   | 51.36572  | 0.991199 | 0.8045   |
| 9 %     | 60.49966  | 0.00008   | 51.78482  | 0.996583 | 1.154127 |
| 18 %    | 28.71957  | 0.00006   | 50.38234  | 0.991806 | 0.149864 |

Table 5 shows that $k_2$ value was higher at 9% amount of carrier which is 0.008. This shows the rate of reaction was faster at this PIMs composition. This shows the rate of reaction was faster at this PIMs composition by achieving highest percentage of RO16 dye removal. However, on further increase of carrier, the values of the intercept, $C_e$ was found to be drop, indicating a decrease in ion exchange in the removal process.

3.1.5. Second order model for effect of initial dye concentration. Figure 6 detailed out the second order model used to analyse the kinetics of effect of initial dye concentration in the removal of RO16 dye by the PIMs.

![Figure 6](image)

**Figure 6.** Comparison of second order of predicted and experimental value of RO16 dye removal at different effect of initial dye concentration

The pseudo-second-order kinetic model which represent in figure 6 predicts the behaviour between the experimental data and predicted data value was fitted well against the period of time compared to the pseudo-first-order kinetic model. The initial dye concentration of 10 mg/L shows the best fitted with the second order kinetic modelling. The $k_2$ value was tabulated at table 6 below.
Table 6. Parameters value of second of order Kinetic model for the effect of initial dye concentration

| Initial Concentration | $C_e$   | $k_2$     | $C_o$   | $R^2$  | Variance |
|-----------------------|---------|-----------|---------|--------|----------|
| 10 mg/L               | 8.919974| 0.0006    | 10.42345| 0.993396| 0.112708 |
| 20 mg/L               | 8.919977| 0.0001884 | 20.50071| 0.991414| 0.296373 |
| 30 mg/L               | 15.84995| 0.000194  | 30.90215| 0.991704| 0.439543 |
| 50 mg/L               | 15.84986| 0.0000537 | 51.81314| 0.990196| 1.53063  |

Table 6 indicates that the $k_2$ values were also found to decrease with increasing RO16 initial dye concentration. It was found that the removal of RO16 dye at 10 mg/L generally gave the highest rate constant values compared to other initial dye concentrations. This is due to the higher efficiency of the membrane area allows the ions exchange easily to form the neutral ion pair complex. Thus, this indicated that lowest initial dye concentration showed the fastest kinetics and reach equilibrium in the shortest time.

3.1.6. Second order model for effect of pH. Figure 7 shows the second order model used to analyse the kinetics of effect of pH in the removal of RO16 dye by the PIMs.

As can be seen from this plot, Figure 7 shows that with the increase in pH from pH 2 to 12, the RO16 dye removal was found to be decrease significantly. From the Figure 7, at pH 2, highest removal of RO16 dye was achieved due to more protons was available at lower pH. Thereby, it increased the electrostatic attractions between the RO16 anionic dye and negatively charged sites. Therefore, the ionic repulsion caused an increase in RO16 dye removal. Similar trend was reported in the mechanism in binding of Reactive Orange 16 on various types of sludge [19]. Table 7 used to describe the model kinetic parameters and fitting constants.
Table 7. Parameters value of second of order Kinetic model for the effect of pH

| pH  | $C_e$       | $k_2$       | $C_o$     | $R^2$   | Variance |
|-----|-------------|-------------|-----------|---------|----------|
| pH 2| 0.755436    | 0.006068    | 10.00452  | 0.998436| 0.023455 |
| pH 4| 1.060146    | 0.0022714   | 9.919847  | 0.993533| 0.080019 |
| pH 7| 10.89997    | 0.0001571   | 10.29702  | 0.995531| 0.115403 |
| pH 10| 1.304106   | 0.0007423   | 9.960087  | 0.995322| 0.013113 |
| pH 12| 0.426768    | 0.000714    | 10.12818  | 0.99054 | 0.065717 |

As can be seen from Table 7, the $k_2$ value increases when the pH decreases. The highest rate of reaction achieved at pH 2 which is an acidic condition. The $C_e$ values obtained for the pseudo-second-order model did not show a consistent trend for all the five pH studied as some $C_e$ values were relatively small especially at high pH. This is because the surface becomes more negatively charged influence the number of binding sites at RO16 dye for negatively charged amine decreased. However, at acidic pH, the RO16 dye was a weak acidic electrolyte would be undissociated which did not favour any repulsion. Thus the removal percentage of RO16 dye was highest at lowest pH value [20].

In a nutshell, all the experimental and predicted values together with the constants, $R^2$ values obtained from the pseudo-first-order and pseudo-second-order in the kinetic modelling of all the three parameters in this research tabulated respectively at previous discussion section. It is clearly proved that overall the pseudo-second-order kinetic model fitted the experimental data better than the pseudo-first-order kinetic model. The applicability of these kinetic models was further validated by the correlation coefficients, $R^2$ values. The closer the $R^2$ value to unity, the better the fit. The $R^2$ values of pseudo-second-order are relatively higher than the pseudo-first-order. The pseudo-second-order kinetic model, predicts the behaviour over the whole range of studies which strongly supports the validity and agrees with chemisorption being rate controlling based on equilibrium. Thus, it can be concluded pseudo-second-order kinetic model fits very well with the kinetic data. The results can be agreed with the works carried out by previous researchers which reported that pseudo-second-order kinetic model gave a better fit than the pseudo-first-order kinetic model.

4. Conclusion
PIMs is an easy and cost effective method to treat wastewater. This study proved that the best PIMs with the composition of 18 % of PVDF-Co-HFP, 9 % of Aliquat 336 and 23 % of THF solvent was achieved optimum extraction under initial dye concentration of 10 mg/L at pH 2 for 4 hours. Pseudo-first-order and pseudo-second-order were plotted to analyse which kinetic data fitted better with the experimental data. From the kinetic data, it could be concluded that the $R^2$ values of pseudo-second-order are relatively higher than the pseudo-first-order. The dye removal efficiency of 99.62 % with $R^2$ of 0.9984 proved the pseudo-second-order data were well fitted to this model.

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References
[1] Tepliakov V G, Kaem R I, Vtooirin B V, Panova N V and Bogatova I S 1992 [Aspects of modeling, etiology and pathogenesis of experimental sepsis]. Arkh. Patol. 54 14–9
[2] Toprak T and Anis P 2017 Textile Industry’s Environmental Effects and Approaching Cleaner Production and Sustainability: an Overview J. Text. Eng. Fash. Technol. 2 429–42
[3] Ogugbue C J and Sawidis T 2011 Bioremediation and Detoxification of Synthetic Wastewater Containing Triarylmethane Dyes by Aeromonas hydrophila Isolated from Industrial Effluent Biotechnol. Res. Int.

[4] Daneshvar N, Salari D and Khataee A R 2003 Photocatalytic degradation of azo dye acid red 14 in water: Investigation of the effect of operational parameters J. Photochem. Photobiol. A Chem.

[5] Fungaro D A, Borrely S I and Carvalho T E M 2013 Surfactant Modified Zeolite from Cyclone Ash as Adsorbent for Removal of Reactive Orange 16 from Aqueous Solution Am. J. Environ. Prot.

[6] Vandeivere P C, Bianchi R and Verstraete W 1998 Treatment and reuse of wastewater from the textile wet-processing industry: Review of emerging technologies J. Chem. Technol. Biotechnol.

[7] Badr Y, Abd El-Wahed M G and Mahmoud M A 2008 Photocatalytic degradation of methyl red dye by silica nanoparticles J. Hazard. Mater.

[8] Aljeboree A M, Alshirifi A N and Alkaim A F 2017 Kinetics and equilibrium study for the adsorption of textile dyes on coconut shell activated carbon Arab. J. Chem. 10 S3381–93

[9] Blackburn R S 2004 Natural polysaccharides and their interactions with dye molecules: Applications in effluent treatment Environ. Sci. Technol. 38 4905–9

[10] Zahid M, Rashid A, Akram S, Rehan Z A and Razzaq W 2018 A Comprehensive Review on Polymeric Nano-Composite Membranes for Water Treatment J. Membr. Sci. Technol. 08 1–20

[11] Urita S and Kikkawa M 1987 Effect Of Plasticizer On Carrier-Mediated Transport Of Zinc Ion Through Cellulose Triacetate Membranes Sep. Sci. Technol. 22 2263–8

[12] Xiao Y, Liu X D, Wang D X, Lin Y K, Han Y P and Wang X L 2013 Feasibility of using an innovative PVDF MF membrane prior to RO for reuse of a secondary municipal effluent Desalination

[13] Ling Y Y and Mohd Suah F B 2017 Extraction of malachite green from wastewater by using polymer inclusion membrane J. Environ. Chem. Eng.

[14] Obaid M K, Abdullah L C and Idan I J 2016 Removal of Reactive Orange 16 Dye from Aqueous Solution by Using Modified Kenaf Core Fiber J. Chem.

[15] Abdurrahman F Bin, Akter M and Abedin M Z 2013 Dyes Removal From Textile Wastewater Using Orange Peels Int. J. Sci. Technol. Res. 2 47–50

[16] Markandeya, Shukla S P and Kisku G C 2015 Linear and non-linear kinetic modeling for adsorption of disperse dye in batch process Res. J. Environ. Toxicol. 9 320–31

[17] Huang & Shih 2017 2017 Comparative Analysis of Different Linearized Expressions of Estimating the Pseudo-Second-Order Kinetic Parameters for the Adsorption of Methylene Blue 7 255–60

[18] Othman N, Fatihah N, Noah M, Zing O, Bukhari M, Abdul H and Rashid R 2017 Kinetic extraction of basic dye using vegetable oil as a solvent Malaysian J. Fundam. Appl. Sci. 13 685–9

[19] Won S W, Choi S B and Yun Y S 2006 Performance and mechanism in binding of Reactive Orange 16 to various types of sludge Biochem. Eng. J. 28 208–14

[20] Salima A, Ounissa K S, Fadila H and Mohamed B 2016 Equilibrium and kinetic modeling of acid dye removal from aqueous solution by polymer inclusion membrane (PIMs) Desalin. Water Treat. 57 3708–19

[21] Tseng A A 2005 Recent developments in nanofabrication using focused ion beams Small