

## Water remediation using *Casuarina equisetifolia* cone as adsorbent for the removal of methyl violet 2B dye using batch experiment method

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ORIGINAL RESEARCH ARTICLE

### ABSTRACT

*Casuarina equisetifolia* cone exhibited potential to remove methyl violet 2B dye from the aqueous solution. The experiments were performed using batch method whereby parameters such as contact time, dosage, temperature, pH, ionic strength and dye concentration were investigated. The kinetics of the adsorption process was described using the pseudo-first-order, pseudo-second-order and Weber-Morris intraparticle diffusion models with pseudo-second-order better described the adsorption kinetics and more than one diffusion mechanism may be involved. The maximum adsorption capacity was determined as 63 mg/g, according to the Langmuir model.

### KEYWORDS

adsorption; basic dye; isotherm; kinetics; lignocellulosic material; thermodynamics

## 1. INTRODUCTION

Synthetic dyes are produced 7 x 10<sup>5</sup> tonnes annually and two third of the dyes is used in textile industries. However, about 10 - 15% of the dyes used during the dyeing process are lost and released into the environment (Vijayaraghavan et al., 2015). The wastewater from the industries mainly comprises of leftover dyes, auxiliary chemicals, salts, surfactants and chlorinated compounds (Pandey et al., 2007). The dye molecules can affect the photosynthetic activity of the aquatic plants, have mutagenic and carcinogenic properties and due to their synthetic and stable natures, they can persist in the environment for a long time (Crini, 2006).

Adsorption is one of the water treatment methods that involve a simple concept of adhering pollutant to the surface of the adsorbent which can be made of biological or inorganic materials. This method is not only easy to use but also minimises the formation of chemical/biological sludge as well as cost effective and efficient (Wang and Chen, 2009). Adsorption

can also be easily adopted by industry as low-cost dye wastewater remediation without any need of advanced knowledge and machinery (Kooh et al., 2016d).

Activated carbon has been traditionally used as a highly effective adsorbent but the production cost is very expensive. Therefore, research efforts have been taken in the past decades in order to screen potential cheap materials to be used as adsorbents. Various materials have been studied for this purpose and they were discussed in the literatures (Vijayaraghavan, 2016; Kooh et al., 2016a; Kaur et al., 2016; Vijayaraghavan et al., 2015; Chieng et al., 2015; Kooh et al., 2016e; Lim et al., 2013).

The aim of this study is to use *Casuarina equisetifolia* cone (CEC) as an adsorbent to remove methyl violet 2B (MV) dye from aqueous solution. CEC was chosen for this purpose as it has no economical values and can be found easily on the ground in tropical and subtropical countries. Up to now, there is no research study on the use of CEC as an adsorbent; however other parts of *Casuarina equisetifolia* had been used to remove pollutants such as heavy metals (Ranganathan, 2000; Mohan and Sumitha, 2008; El

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Nemr et al., 2007) and dyes (Dahri et al., 2013; Dahri et al., 2015; Kooch et al., 2016b). MV was explored in the present study because of its vast industrial applications which include textile, paper, leather, biological staining agents, cosmetics, solar cell, rubber and inkjet (Sabnis, 2010). It is also known to possess microbial (Oros et al., 2003) and aquatic toxicity (Nishiuchi, 1984), and is also a known carcinogenic (Vachalkova et al., 1995) and mutagenic agent (Chung et al., 1981).

## 2. MATERIALS AND METHODS

### 2.1. Sample and dye preparation

CEC was collected from the campus ground and washed with distilled water prior to drying overnight in an oven at 75 °C. The dried CEC was then blended and the particle size of 355 µm was collected using a laboratory sieve. Methyl violet 2B (MV) (C<sub>24</sub>H<sub>28</sub>N<sub>3</sub>Cl; Mol. wt. 393.95 g/mol; 80% dye content) dye was purchased from Sigma-Aldrich and used without further purification. The dye stock solution was prepared by dissolving an appropriate amount of the dye in distilled water. Distilled water was used throughout the study.

### 2.2. Characterisation of sample

Fresh and dye treated CEC were subjected to Fourier transform infrared (FTIR) spectroscopy analysis for the identification of their functional groups. The sample (2 mg) was mixed with analytical grade KBr (200 mg) before the mixture was compressed into a pellet. FTIR spectra for both samples were obtained using Shimadzu Model IR Prestige-21 spectrophotometer at the range of 400 and 4000 cm<sup>-1</sup>.

Morphology of CEC's surface was investigated using scanning electron microscope (SEM) (Tescan Vega XMU). Before analysis, the sample was gold coated using SPI-MODULETM Sputter Coater at plasma current of 8 mA for 60 sec.

Point of zero charge (pH<sub>pzc</sub>) of CEC was determined using salt addition method (Mahmood et al., 2011) where the sample (0.04 g) was mixed with 0.1 mol/L NaCl. Prior to the mixing, the pH of salt solution was altered using 0.1 mol/L nitric acid (HNO<sub>3</sub>) and 0.1 mol/L sodium hydroxide (NaOH) to produce salt solution with pH of 2, 4, 6, 8 and 10. The mixtures were agitated for 24 h at 250 rpm and their pH was measured after the agitation. A plot of ΔpH (final pH - initial pH) vs. initial pH was done in order to determine the pH<sub>pzc</sub>.

### 2.3. Experimental method

The experiments were conducted using batch method whereby CEC (0.03 g) was mixed with specified concentration of MV (20.0 mL) and the mixture was agitated at 250 rpm for predetermined time. Several experimental parameters were studied such as contact time (5-180 min), dosage (0.01 – 0.06 g), pH (2 – 10), dye concentration (20 – 500 mg/L), temperature (25 – 55 °C) and ionic strength (0 – 0.8 mol/L NaCl). Each of these parameters was investigated while making the other parameters constant. The dye content was measured using UV-visible spectrophotometer (Shimadzu UV-1601PC) at wavelength 584 nm. The amount of MV adsorbed per unit mass of CEC (q<sub>e</sub>) and the percentage removal (%) were calculated using equations (1) and (2), respectively, as follows:

$$q_e \text{ (mg/g)} = \frac{(C_i - C_e)V}{m} \quad (1)$$

$$\% = \frac{(C_i - C_e) \times 100}{C_i} \quad (2)$$

Where C<sub>i</sub> is the initial MV concentration (mg/L), C<sub>e</sub> is the MV concentration at equilibrium (mg/L), V is the volume of the dye used (L) and m is the mass of CEC used (g).

### 2.4. Error analyses

Sum of absolute error (EABS) and chi- test (χ<sup>2</sup>) were used in order to determine the agreement between the experimental data and the calculated data from the kinetics and isotherm models. They can be represented as below:

$$\text{Sum of absolute error (EABS): } \sum_{i=1}^n |q_{e,exp} - q_{e,cal}| \quad (3)$$

$$\text{Chi - square test } (\chi^2): \sum_{i=1}^n \frac{(q_{e,exp} - q_{e,cal})^2}{q_{e,exp}} \quad (4)$$

where q<sub>e,exp</sub> is the q<sub>e</sub> value obtained from the experiment while q<sub>e,cal</sub> is the calculated value from the theoretical models, n is the number of data points in the experiment and p is the number of parameters of the model.

### 2.5. Regeneration study

The dye treated CEC was subjected to two washing solutions i.e. distilled water and 0.1 mol/L NaOH in

order to investigate the reusability of CEC. Fresh CEC was treated with 50 mg/L MV using the predetermined conditions and the dye treated CEC was collected and washed using distilled water in order to remove excess MV. The sample was then divided into two portions; the first portion was mixed with distilled water and the other was mixed with 0.1 mol/L NaOH, then they were agitated for 1 h. After agitation, both portions were separately washed thoroughly with distilled water until no excess MV leached out and the solution is near neutral. Both portions were then dried overnight in an oven at 75 °C. The whole procedure was repeated using the dried samples for two more cycles.

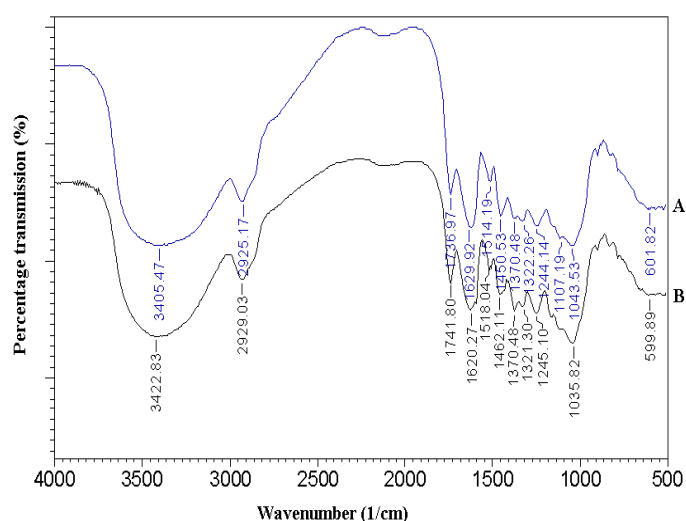
### 3. RESULTS AND DISCUSSION

#### 3.1. Characterisation of CEC using FTIR and SEM

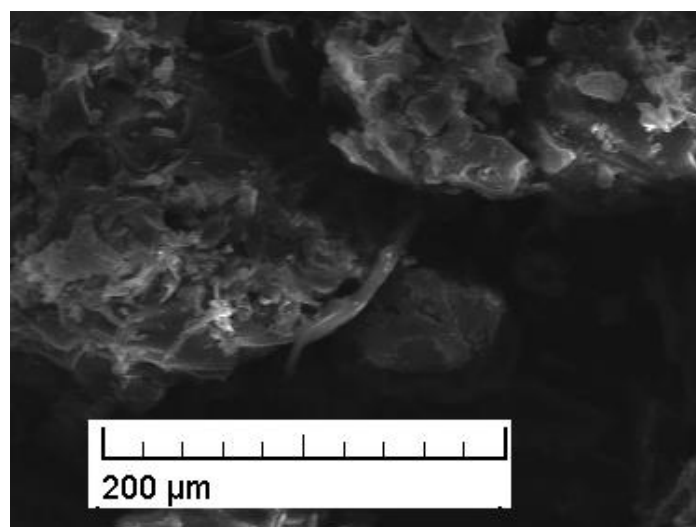
The functional groups of CEC and CEC-MV were identified using FTIR and their spectra are shown in Figure 1. In the FTIR spectrum for CEC, functional groups identified were OH and/or NH stretching ( $3405\text{ cm}^{-1}$ ),  $\text{CH}_2$  stretching ( $2925\text{ cm}^{-1}$ ), C=O stretching ( $1737\text{ cm}^{-1}$ ), C=C stretching ( $1630\text{ cm}^{-1}$ ), C=C of aromatic ring ( $1514\text{ cm}^{-1}$ ),  $\text{CH}_2$  bending ( $1450\text{ cm}^{-1}$ ), C-O-H bending ( $1370\text{ cm}^{-1}$ ) and C-O stretching ( $1244$  and  $1107\text{ cm}^{-1}$ ). After treatment with MV, shifts in the wavenumbers of these functional groups were observed, indicating the possible interaction sites for adsorption of MV. CEC surface morphology was studied using SEM image as shown in Figure 2. It can be seen that CEC has rough and irregular surface with no distinct features. The condition of the surface might provide a large surface area for the dye interaction.

#### 3.2. Effect of CEC dosage

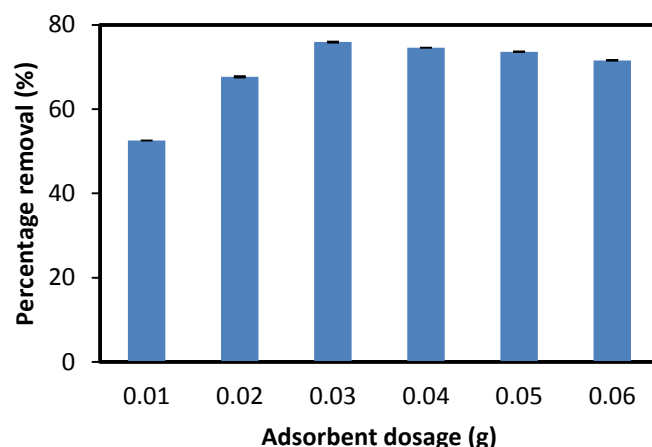
The effect of CEC dosage (0.01 – 0.06 g) on the removal of MV is shown in Figure 3. As the amount of CEC increased from 0.01 g to 0.03 g, the percentage removal of the dye increased from 53% to 76%. This could be due to the increasing amount of active sites for the dye interaction. Further increase in the dosage beyond 0.03 g did not significantly alter the percentage removal of the dye and thus, for the rest of the experiments, 0.03 g of CEC was used.



**Figure 1.** The FTIR spectra of (A) CEC and (B) MV-treated CEC.



**Figure 2.** The SEM image of CEC surface.



**Figure 3.** The percentage removal of MV by various amounts of CEC.

### 3.3. Effect of contact time and kinetics study

The removal capability of CEC towards 50, 100 and 200 mg/L MV as a function of time is presented in Figure 4A. The adsorption of these three MV concentrations followed similar trend whereby the adsorption rapidly increased in the first 60 min of agitation i.e. 16 mg/g (5 min) to 27 mg/g (60 min) for the adsorption of 50 mg/L MV. Beyond 60 min, the adsorption process started to slow down to the point where the  $q_e$  values did not change significantly i.e. 28 mg/g (180 min) for the adsorption of 50 mg/L MV. Initially, the surface of the adsorbent comprises an abundant number of active sites which contributed to the increase of adsorption and as the active sites get saturated, the adsorption process slowed down and eventually reached a plateau.

In order to investigate the mechanism of the adsorption of MV onto CEC, three kinetics models were applied to the experimental data: pseudo-first-order (Lagergren, 1898), pseudo-second-order (Ho and McKay, 1998) and Weber-Morris intraparticle diffusion (Weber and Morris, 1963) models. The pseudo-first-order model depicted a first order equation for heterogeneous system adsorption process based on solid capacity and it is expressed in equation (5) as:

$$\log (q_e - q_t) = \log q_{e,cal} - \frac{t}{2.303} k_1 \quad (5)$$

where  $q_t$  (mg/g) is the amount of MV adsorbed per unit mass of CEC at time  $t$  (min) and  $k_1$  is the rate constant (1/min). Plotting  $\log (q_e - q_t)$  vs  $t$  should yield a straight line with  $k_1/2.303$  as the slope and  $\log q_{e,cal}$  as the y-intercept.

The pseudo-second-order model is used to describe the adsorption process of a wide range of adsorbent-adsorbate system and frequently used in adsorption study. The equation is expressed in equation (6) as follows:

$$\frac{t}{q_t} = \frac{1}{q_{e,cal}^2 k_2} + \frac{t}{q_{e,cal}} \quad (6)$$

where  $k_2$  (g/mg min) is the rate constant. A straight line should be obtained from the plot of  $t/q_t$  vs  $t$  with  $1/q_{e,cal}$  as the slope and  $1/q_{e,cal}^2 k_2$  as the y-intercept.

Unlike the previous two models, the Weber-Morris intraparticle diffusion model can be used to describe the diffusion of the adsorbate to the adsorbent. If the rate depends on the movement of particle to the surface, then the process can be said to be diffusion

controlled (Kavitha, 2016). The model is expressed in equation (7) as follows:

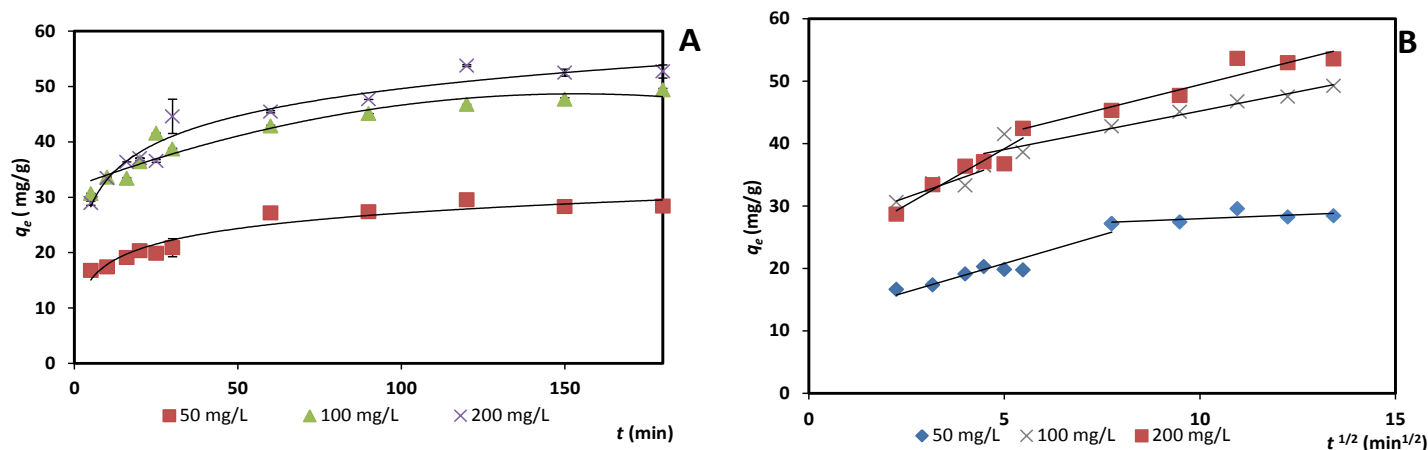
$$q_t = k_3 t^{1/2} + C \quad (7)$$

where  $k_3$  (mg/g min<sup>1/2</sup>) is the rate constant and the slope while  $C$  is the y-intercept and also represents the boundary layer thickness i.e. the larger the  $C$  value, the bigger the boundary layer.

**Table 1.** The kinetics parameters for the adsorption of 50, 100 and 200 mg/L MV onto CEC.

	Pseudo-first-order model		
$C_1$ (mg/L)	50	100	200
$q_{e,cal}$ (mg/g)	12.2	17.2	32.7
$q_{e,exp}$ (mg/g)	29.5	49.2	53.6
$k_1$ (1/min)	0.015	0.016	0.028
$R^2$	0.896	0.962	0.939
$\chi^2$	129.7	258.2	124.8
EABS	168.6	317.5	218.4
	Pseudo-second-order model		
$q_{e,cal}$ (mg/g)	30.2	50.0	56.0
$q_{e,exp}$ (mg/g)	29.5	49.2	53.6
$k_2$ (g/ mg min)	0.004	0.003	0.002
$R^2$	0.996	0.998	0.997
$\chi^2$	18.0	15.0	23.5
EABS	49.4	66.3	83.4
	Weber-Morris intraparticle diffusion model		
$k_3$ (mg/g min <sup>1/2</sup> )	1.8	2.2	3.6
$C$	11.6	25.8	21.2
$R^2$	0.894	0.812	0.903

The pseudo-first-order and pseudo-second-order were compared in order to evaluate their suitability in describing the experimental data. As seen in Table 1, the pseudo-first-order model gave coefficient of determination ( $R^2$ ) values between 0.896 to 0.962 across the three concentrations of MV while the pseudo-second-order model yielded better  $R^2$  values of >0.99 for all the three concentrations. This clearly indicates that the pseudo-second-order is better fitted to the experimental data than the pseudo-first-order model. This was further supported by the lower



**Figure 4.** (A) the effect of contact time (B) the Weber-Morris plots

EABS and  $\chi^2$  values of the pseudo-second-order model as well as the close agreement between the model  $q_{e,cal}$  and the experimental  $q_{e,exp}$ .

An adsorption process is considered to be controlled by intraparticle diffusion if the Weber-Morris plot of  $q_t$  vs  $t^{1/2}$  gives a straight line that passes through the origin. If the plot displays multi linear behaviour, it indicates that the adsorption process is influenced by more than one mechanism. In the multi linear plot, usually three portions are observed. The first portion represents film diffusion, a fast phase that takes place at the beginning of the agitation and not depicted in the plot. The second portion represents the intraparticle diffusion while the third represents the equilibrium phase. As shown in Figure 4B, the Weber-Morris plots for all the three concentrations showed multi linear lines, indicating more than one mechanism is involved. In addition to that, all the first linear lines of these plots did not pass through the origin (Table 1) suggesting that intraparticle diffusion is not rate limiting step of the adsorption process of MV onto CEC.

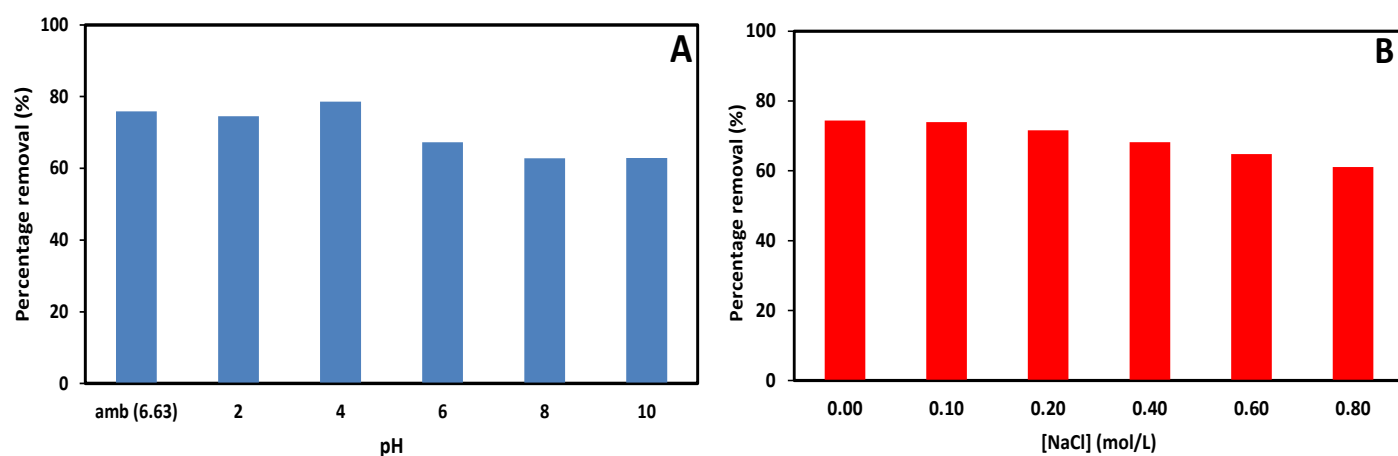
### 3.4. Effects of pH and ionic strength

The  $pH_{pzc}$  value or the pH at which the CEC surface is neutral was determined as 3.75. Theoretically, when an adsorbent is subjected to aqueous medium with pH lower than the  $pH_{pzc}$  value, then the adsorbent's functional groups such as amino group will be protonated and thus making the surface to be predominately positive in charge. Likewise, higher medium pH would cause the functional groups such as carboxyl group to be deprotonated and the surface would be predominately negative in charge.

The pH parameter is important as it can significantly affect the surface charge of the adsorbent

depending on the adsorbent's  $pH_{pzc}$  value and it can also affect the solubility of the heavy metals. Thus, it is imperative to investigate the effect of pH on the adsorption process as the wastewaters have different values of pH. Basic dyes such as MV dissolve in water to form positively charged molecules and in theory would be attracted to a negatively charged surface (electrostatic interaction). Therefore, it is expected that high removal of MV would be achieved at pH higher than the CEC  $pH_{pzc}$  (3.75) and low removal below this value. However, this is not the case as seen in Figure 5A whereby an opposite trend was observed. The removal at pH 2, 4, 6, 6.63 (ambient pH), 8 and 10 were 75%, 79%, 67%, 76%, 63% and 63%, respectively. This deviation can be caused by several reasons and one of them might be due to the various interactions involved such as hydrogen bonding and hydrophobic interaction instead of just electrostatic interaction (Dahri et al., 2014).

The wastewater from the industries generally comprise of variable amount of salts and thus, altering the effluent ionic strength. The presence of salts can affect the adsorption process via electrostatic and hydrophobic interactions between the adsorbate and the adsorbent (Hu et al., 2013). Figure 5B displays the removal of MV by CEC at various concentrations of NaCl. It can be seen that the removal steadily decreased as the salt concentration was increased i.e. 74% without NaCl and 61% at 0.8 mol/L NaCl. This decrease is contributed by the suppression of electrostatic interaction by  $Na^+$  ions. The cations can compete with the dye molecules for the active sites on CEC and create surplus of positive charge on the surface which can repel the positively charged dye molecules. In the adsorbent-dye system where electrostatic interaction plays a major role, the removal of the dye would be greatly reduced (Hu et al., 2013); however in



**Figure 5.** The effect of (A) pH and (B) ionic strength on the adsorption of 50 mg/L MV onto CEC.

this study, the removal of was still fairly high despite the high salt concentration used. This suggested that electrostatic interaction was not the major force in the adsorption process which is in agreement with the pH experimental result.

### 3.5. Effect of temperature and thermodynamics study

Temperature can have profound effects on the adsorption process where it can increase the activity of the adsorbate and thus, increasing the probability of the adsorbate to interact with the adsorbent's active sites. Adsorption of 50 mg/L MV onto CEC at 25, 35, 45 and 55 °C was found to be 24.9, 25.5, 26.7 and 27.7 mg/g, respectively. Albeit the small changes in the  $q_e$  values, it can be said that the adsorption increased as the temperature was increased.

Thermodynamics study was performed by fitting the experimental data into van't Hoff equation where it is expressed as:

$$\Delta G^0 = -RT \ln k \quad (8)$$

$$k = \frac{C_s}{C_e} \quad (9)$$

$$C_s = C_i - C_e \quad (10)$$

$$\ln k = \frac{\Delta S^0}{R} - \frac{\Delta H^0}{RT} \quad (11)$$

where T is the temperature in Kelvin (K),  $\Delta G^0$  is the Gibbs free energy (kJ/mol),  $\Delta S^0$  is the change in entropy (J/mol K),  $\Delta H^0$  is the change in enthalpy (kJ/mol), k is the equilibrium constant,  $C_s$  is the amount of

the adsorbed by the adsorbent (mg/L), and R is the gas constant (8.314 J/mol K).

The parameter  $\Delta G^0$  can be calculated from equation 8 while  $\Delta S^0$  and  $\Delta H^0$  were calculated from the straight line plot of  $\ln k$  vs  $1/T$  (equation 11) whereby  $\Delta S^0/R$  is the y-intercept and  $\Delta H^0/R$  is the slope. Negative values of  $\Delta G^0$  of -2.6, -3.3, -3.7 and -4.2 kJ/mol were obtained for 25, 35, 45, and 55 °C, respectively. Increasing negative values of  $\Delta G^0$  with increasing temperature indicates the spontaneous behavior of the adsorption process. Positive  $\Delta H^0$  value of 10.7 kJ/mol indicates the endothermic nature of the adsorption process, while positive  $\Delta S^0$  value of 50.0 J/mol K suggests the system has increased in randomness at the solid/solution interface.

### 3.6. Effect of dye concentration and isotherm modeling

Figure 6 shows the effect of dye concentration on the adsorption process. It can be observed that there was a rapid increase in  $q_e$  values from 9 mg/g (20 mg/L) to 60 mg/g (200 mg/L). As the dye concentration increases, the driving force due to concentration gradient also increases and thus, the observed increase in  $q_e$  values. However, beyond 200 mg/L, no significant changes on the  $q_e$  was observed due to the saturation of CEC active sites and the system has achieved equilibrium state.

The data obtained from isotherm experiment was described using three isotherm models and their applications were explained in the literature (Foo and Hameed, 2010). These three isotherm models were compared based on their  $R^2$ , EABS and  $\chi^2$  values in order to investigate their acceptability and suitability to the experimental data. The Langmuir (Langmuir, 1918) isotherm model is represented as:



$$\frac{C_e}{q_e} = \frac{1}{K_L q_m} + \frac{C_e}{q_m} \quad (12)$$

$$R_L = \frac{1}{(1+K_L C_i)} \quad (13)$$

where  $q_m$  (mg/g) is the maximum adsorption capacity and  $K_L$  (L/mg) is the Langmuir constant.  $R_L$  is a dimensionless parameter which uses the Langmuir constant in order to determine the favourability of the adsorption process whereby value between 0 and 1 indicated favourable adsorption; > 1 indicates unfavourable; equals to 1 means linear and equals to zero suggests an irreversible reaction.

The Freundlich (Freundlich, 1906) isotherm model is expressed as:

$$\ln q_e = \frac{1}{n_F} \ln C_e + \ln K_F \quad (14)$$

where  $K_F$  ((mg/g)(L/mg)<sup>1/n<sub>F</sub></sup>) is the adsorption capacity of the adsorbent and  $n_F$  value indicates favourability of the adsorption process.

Finally, the Dubinin-Radushkevich (D-R) (Dubinin and Radushkevich, 1947) isotherm model equation is shown as:

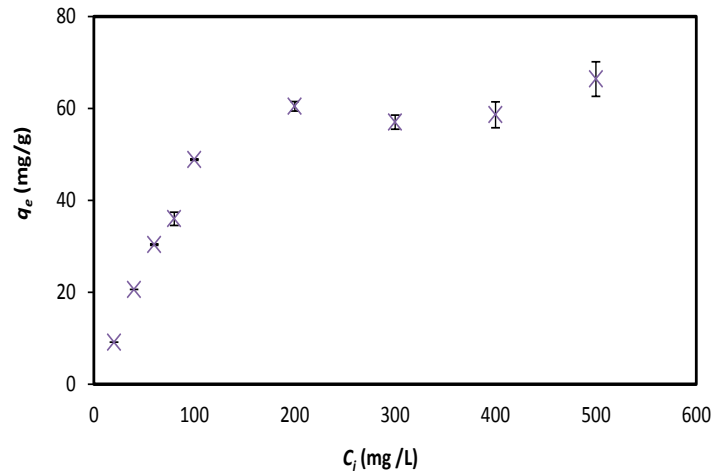
$$\ln q_e = \ln q_m - K_{DR} [RT \left(1 + \frac{1}{C_e}\right)]^2 \quad (15)$$

$$E = \frac{1}{\sqrt{2K_{DR}}} \quad (16)$$

where  $K_{DR}$  (mol<sup>2</sup>/kJ<sup>2</sup>) is D-R constant, R (8.314 J/mol K) is the gas constant, T (K) is the absolute temperature and E (kJ/mol) is the mean free energy.

The plots of  $C_e/q_e$  vs  $C_e$ ,  $\ln q_e$  vs  $\ln C_e$  and  $\ln q_e$  vs  $[RT(1+ 1/C_e)]^2$  were done in order to calculate the parameters for the Langmuir, Freundlich and D-R models, respectively. Their parameters are displayed in Table 2. The Langmuir model has the highest R<sup>2</sup> value amongst the isotherm models while the D-R model exhibited the lowest values for both EABS and  $\chi^2$ . In this case, the Langmuir can be considered as the best model as it has higher R<sup>2</sup> value than D-R with considerable low values for both EABS and  $\chi^2$ .  $R_L$  and  $n_F$  indicate that the adsorption of MV onto CEC was a favourable process with  $q_m$  value of 63.12 mg/g. Comparing between CEC and *Casuarina equisetifolia* needle, the latter has a higher adsorption capacity of 165 mg/g (Dahri et al., 2013). However, adsorption capacity of CEC is higher than rich husk char (48 mg/g) (Xu et al., 2011), orange peel (11.5 mg/g) (Annadurai et al., 2002) and banana

peel (12.2 mg/g) (Annadurai et al., 2002) but lower when compared to other adsorbents such as granular activated carbon (95 mg/g) (Azizian et al., 2009), soya bean (Kooch et al., 2016c) (181 mg/g) and duckweed (332.5 mg/g) (Lim et al., 2014).



**Figure 6.** The effect of increasing the MV concentration on the adsorption process.

**Table 2.** Isotherm model parameters for the adsorption of MV onto CEC.

Langmuir isotherm	
$q_m$ (mg/g)	63.1
$K_L$ (L/mg)	0.06
$R_L$	0.03
$R^2$	0.99
$\chi^2$	17.6
EABS	53.4
Freundlich isotherm	
$K_F$ ((mg/g)(L/mg) <sup>1/n<sub>F</sub></sup> )	12.4
$n_F$	3.5
$R^2$	0.62
$\chi^2$	33.0
EABS	84.0
Dubinin-Radushkevich isotherm	
$q_m$ (mg/g)	59.8
$K_{DR}$ (mol <sup>2</sup> /kJ)	11.3
$E$ (kJ/mol)	0.21
$R^2$	0.85
$\chi^2$	13.1
EABS	50.1

### 3.7. Regeneration study

For regeneration studies, the MV loaded CEC was subjected to washing using distilled water and 0.1 mol/L NaOH for three cycles. Initially, the removal of 50 mg/L MV by CEC was 76% and with distilled water washing the removal increased to 96% for the 1st cycle but deteriorated in the 2nd (59%) and 3rd (52%) cycles. On the other hand, washing with the base yielded removal of 99%, 85% and 82% for the first, second and third cycle, respectively. This shows that the spent CEC can be reused effectively when it was subjected to 0.1 mol/L NaOH washing, adding value to CEC as a potential adsorbent.

## 4. CONCLUSIONS

This study shows that CEC was determined as a good material to be used as an adsorbent to remove MV from aqueous solution. Optimal adsorption can be achieved using 0.03 g of CEC and at ambient pH (6.63). Increasing the ionic strength slightly decreased CEC's removal capability by 13%. Increasing the temperature provides a small increase in the adsorption. CEC was able to be regenerated and reused for three consecutive cycles using 0.1 mol/L NaOH as the desorbent, proving the advantage of using the adsorbent in real life applications. The kinetics mechanism followed the pseudo-second-order model and intraparticle diffusion model was not the rate limiting step of the reaction. The Langmuir isotherm model best fitted the experimental data with  $q_m$  value of 63 mg/g. From the thermodynamics study, the adsorption process was found to be favourable, spontaneous and endothermic in nature.

### ACKNOWLEDGEMENTS

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