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Effect of preparation conditions of activated carbon from bamboo waste for real textile wastewater

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ABSTRACT

This study deals with the use of activated carbon prepared from bamboo waste (BMAC), as an adsorbent for the removal of chemical oxygen demand (COD) and color of cotton textile mill wastewater. Bamboo waste was used to prepare activated carbon by chemical activation using phosphoric acid (H_3PO_4) as chemical agent. The effects of three preparation variables activation temperature, activation time and H_3PO_4:precursor (wt%) impregnation ratio on the color and COD removal were investigated. Based on the central composite design (CCD) and quadratic models were developed to correlate the preparation variables to the color and COD. From the analysis of variance (ANOVA), the most influential factor on each experimental design response was identified. The optimum condition was obtained by using temperature of 556 °C, activation time of 2.33 h and chemical impregnation ratio of 5.24, which resulted in 93.08% of color and 73.98% of COD.

1. Introduction

Textile wastewater includes a large variety of dyes and chemical additions that make the environmental challenge for textile industry not only as liquid waste but also in its chemical composition [1]. Biological methods such as biodegradation have been proposed. However, due to the low biodegradability of dyes, conventional biological wastewater treatment processes are not very efficient for the treatment of dyeing wastes [2].

In the case of cotton textile industry of woven polyester and cotton blended fabric, the textile main processes started from fiber production in the case of synthetic fiber followed by spinning to convert the fiber to yarns. Yarns are then strengthened with sizing chemicals like starch, polyvinyl alcohol and wax so that they can withstand vigorous movements when the yarns are weaved into fabric in high speed weaving looms. After weaving, weaved fabric must be pretreated before they can be dyed, printed and finished. During the pretreatment there are various chemicals, which scoured using sodium hydroxide and detergents. Bleaching is done normally by using hydrogen peroxide to remove the natural color of the fabric white. Fabric is then mercerized using high concentration sodium hydroxide to stabilize the fabric. During dyeing and printing, many types of dyes are used e.g. disperse, reactive, vat, dyeing auxiliaries and chemicals [3]. The combination of the processes and products makes the wastewater from textile plant containing many types of pollutants. This pollution contributed to high suspended solids (SS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), heat, color, acidity, basicity and other soluble substances [4].

There are two processes for the preparation of activated carbon: chemical activation and physical activation. Chemical activation is known as a single step method of preparation of activated carbon in the presence of chemical agents. Physical activation involves carbonization of a carbonaceous materials followed by activation of the resulting char in the presence of activating agents such as carbon dioxide (CO_2) or steam [5]. The chemical activation usually takes place at a temperature lower than that used in physical activation, therefore it can improve the pore development in the carbon structure because the effect of chemicals [6]. The carbon yields of chemical activation are higher than physical one [7]. Therefore, in this work, activated carbon was prepared from bamboo waste (lignocelluloses materials) by phosphoric acid activation at different conditions.

Experimental design technique is a very useful tool for this purpose as it provides statistical models which help in understanding the interactions among the parameters that have been optimized [8]. Response surface methodology (RSM) is a statistical technique for designing experiment, building models, evaluating the effects of several factors and searching optimum conditions for desirable responses and reducing number of experiments [9]. RSM uses an experimental design such as the central composite design (CCD) to fit a model by least squares technique [10]. Adequacy of the proposed model is then revealed using the diagnostic checking tests provided by analysis of variance (ANOVA). The response surface

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plots can be employed to study the surfaces and locate the optimum. Statistical experimental design has been applied by Bacaoui et al. [11] to optimize the preparation of activated carbons for use in water treatment. As reported recently, RSM was applied in preparation of activated carbons using precursors such as olive-waste cakes [12], Luscar char [13] and Turkish lignite [14].

The objective of this work was to optimize the preparation conditions of BMAC for removal color and COD from a real cotton textile mill wastewater. A central composite design (CCD) was selected to study simultaneously the effects of three variables: activation temperature, activation time and chemical impregnation ratio on the removal of color and COD from cotton textile mill wastewater.

2. Materials and methods

2.1. Cotton textile wastewater

Textile wastewater (final effluent after biological treatment) samples were collected from the outlet point of setting tank of activated sludge treatment plant of a nearby cotton textile mill in Penang, Malaysia. The COD and color of the wastewater were 200–260 mg l^{-1} and 450–650 P_t–C_o, respectively. The sample was stored at >5 °C to avoid any change in their physico-chemical characteristics before use.

2.2. Preparation and characterization of activated carbon

Bamboo waste used for the preparation of activated carbon was obtained from local furniture factory, Penang, Malaysia. It was washed with hot distilled water to remove dust like impurities, dried at 105 °C for 24 h, ground and sieved to discrete sizes (200–300 μm). Chemical activation method using phosphoric acid (purity 85% Merck, Germany) was used to activate the precursor (raw bamboo waste). 40 g of precursor was impregnated by certain amount of 40 wt% concentration phosphoric acid with occasional stirring. The amount of phosphoric acid solution used was adjusted to give a certain impregnation ratio (weight of activating agent:weight of precursor) of 3:1, 4:1, 5:1, and 6:1. The impregnation ratio is given by:

$$\text{impregnation ratio (IR)} = (\text{weight of } H_3PO_4 \text{ in solution}) : (\text{weight of precursor}) \quad (1)$$

After impregnation, the solution was filtered to take the residual acid. Subsequently, impregnated samples were air dried under sunlight for 3 days. Activation of phosphoric acid impregnated raw materials was carried out at different temperatures 400–600 °C and time 1–3 h under nitrogen flow 150 cm^3 g^{-1} at a heating rate of 10 °C min^{-1}. After activation, the samples were cooled down under nitrogen flow and were washed sequentially several times with hot distilled water (70 °C) until the pH of the washing solution reached 6–7. Finally samples were dried in an oven at 110 °C for 24 h and then stored in plastic containers.

2.3. Experimental design

The parameters used for prepared activated carbon from bamboo waste were studied with standard response surface methodology (RSM) design called a central composite design (CCD). The CCD was chosen as the experimental design. This method is suitable for fitting a quadratic surface and it helps to optimize the effective parameters with a minimum number of experiments, and also to analyze the interaction between the parameters [13]. The ranges and the levels of the variables investigated are given in Table 1. The variables studied were temperature (X_1), activation time (X_2) and chemical impregnation ratio (X_3). These three variables together with their respective ranges were chosen based on the literature and our preliminary studies. Activation temperature, activation time and chemical impregnation ratio were found to be important parameters affecting the characteristics of the activated carbons produced [15–18]. The experimental sequence was randomized in order to minimize the effects of the uncontrolled factors. The CCD consists of a 2^n factorial runs with $2n$ axial runs and nc center runs. For each categorical variable, a 2^3 full factorial CCD for the three variables, consisting of 8 factorial points, 6 axial points and 6 replicates at the center points were employed. The total number of experiments with three variables was 20 ($=2^n + 2n + 6$), where n is the number of independent variables. The center points are used to determine the experimental error and the reproducibility of the data. The independent variables are coded to the (−1, 1) interval where the low and high levels are coded as −1 and +1, respectively. The axial points are located at ($\pm\alpha$, 0, 0), (0, $\pm\alpha$, 0) and (0, 0, $\pm\alpha$) where α is the distance of the axial point from center and makes the design rotatable. In this study, α value was fixed at 1.682 (rotatable). The responses were percentage removal on color (Y_1) and COD (Y_2). The complete design matrixes of the experiments carried out, together with the results obtained, are shown in Table 2. Each response was used to develop an empirical model that correlated the response to the activated carbon preparation variables using a second-degree polynomial equation as given by Eq. (2) [19]:

$$Y = b_0 + \sum_{i=1}^{n} b_i x_i + \left(\sum_{i=1}^{n} b_{ii} x_i\right)^2 + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} b_{ij} x_i x_j \quad (2)$$

where Y is the predicted response, b_0 the constant coefficient, b_i the linear coefficients, b_{ij} the interaction coefficients, b_{ii} the quadratic coefficients and x_i, x_j are the coded values of the activated carbon preparation variables.

The mathematical model and evaluate the subsequent regression analyses, analyses of variance (ANOVA) and response surfaces contours were done using Design-Expert software (version 6.0.6, Stat-Ease, Inc., Minneapolis, USA).

Table 1
Independent variables and their coded levels for the central composite design.

Variables	Code	Units	Coded variable levels				
			$-\alpha$	−1	0	+1	$+\alpha$
Temperature	X_1	(°C)	331.82	400	500	600	668.18
Activation time	X_2	(h)	0.32	1	2	3	3.68
Impregnation ratio	X_3	–	1.98	1:3	1:4.5	1:6	7.02

2.4. Activated carbon yield

The activated carbon yield was calculated based on Eq. (3):

$$\text{yield}\,(\%) = \frac{w_c}{w_o} \times 100 \quad (3)$$

where w_c (g) is the dry weight of final activated carbon and w_o (g) is the dry weight of precursor.

2.5. Batch equilibrium studies

Batch adsorption was performed in 20 flasks of 250 ml Erlenmeyer flasks where 100 ml of cotton textile mill wastewater solution with initial color concentration 486.87 P_t/C_o and initial COD concentration 251.65 mg l^{-1} was placed in each flask. 0.30 g of each of the prepared activated carbon, with particle size of 200–300 μm, was added to each flask and kept in an isothermal shaker of 120 rpm at 30 °C until equilibrium was reached. Aqueous samples were taken from the solutions and the concentrations were analyzed. The concentrations of color and COD in the

Table 2
Experimental factors in coded units and experimental responses.

Run no.	X_1: temp. (°C)	X_2: time (h)	X_3: IR	Color removal Y_1 (%)	COD removal Y_2 (%)
1	331.82 (−1.682)	2.00 (0)	4.50 (0)	36.97	17.76
2	500.00 (0)	2.00 (0)	4.50 (0)	93.76	72.43
3	400.00(−1)	3.00 (1)	6.00 (1)	53.43	48.56
4	500.00(0)	3.68 (1.682)	4.50 (0)	71.91	46.98
5	500.00 (0)	2.00 (0)	4.50 (0)	90.43	69.65
6	400.00 (−1)	1.00 (−1)	3.00 (−1)	51.91	32.31
7	500.00 (0)	2.00 (0)	1.989 (−1.682)	38.56	22.94
8	500.00 (0)	2.00 (0)	4.50 (0)	88.43	66.05
9	668.18 (1.682)	2.00 (0)	4.50 (0)	71.43	51.76
10	600.00 (1)	1.00 (−1)	6.00 (1)	76.34	61.34
11	500.00 (0)	2.00 (0)	7.02 (1.682)	64.84	47.93
12	500.00 (0)	2.00 (0)	4.50 (0)	93.03	73.98
13	500.00 (0)	2.00 (0)	4.50 (0)	91.87	75.98
14	400.00 (−1)	1.00 (−1)	6.00 (1)	66.93	38.86
15	500.00 (0)	2.00 (0)	4.50 (0)	89.54	65.83
16	600.00 (1)	3.00 (1)	6.00 (1)	91.98	73.98
17	600.00 (1)	3.00 (1)	3.00 (−1)	46.93	49.96
18	400.00 (−1)	3.00 (1)	3.00 (−1)	42.93	29.65
19	500.00 (0)	0.32 (−1.682)	4.50 (0)	48.03	38.43
20	600.00 (1)	1.00 (−1)	3.00 (−1)	51.98	44.98

supernatant solutions before and after adsorption were determined using DR2800 spectrophotometer (CECIL 1000 series, Cambridge, UK) at its maximum wavelength of 455 and 660 nm, respectively. The removal of percentage can be calculated as follows:

$$\text{removal of percentage} = \frac{C_o - C_e}{C_o} \times 100 \quad (4)$$

where C_o and C_e (mg l^{-1}) are the liquid-phase concentrations at initial and equilibrium, respectively.

2.6. BET and SEM of the prepared activated carbon

The specific surface area, pore volume and pore size distribution properties were measured by nitrogen adsorption isotherm at 77 K using an ASAP 2020 Micromeritics instrument by Brunauer–Emmett–Teller (BET) method. Scanning electron microscopy (SEM) analysis was carried out on the activated carbon prepared under optimum conditions, to study its surface texture and the development of porosity.

3. Results and discussion

3.1. Model development

The complete design matrix together with the values of both the responses obtained from the experimental works is given in Table 2. For both responses of color and COD removal, the quadratic model was selected, as suggested by the software. By using multiple regression analysis, the responses (color and COD removal) were correlated with the three variables studied using the second-order polynomial as represented by Eq. (2). The coefficients of the model equation and their statistical significance were evaluated using Design-Expert 6.0.6 software. The quadratic regression model for the color (Y_1) and COD (Y_2) removal in terms of coded factors are given by Eqs. (5) and (6), respectively:

$$\%\text{colour removal, } Y_1 = 90.94 + 8.05X_1 + 2.07X_2 + 10.19X_3 - 11.56X_1^2 - 9.52X_2^2 - 12.44X_3^2 + 4.13X_1X_2 + 5.49X_1X_3 + 2.02X_2X_3 \quad (5)$$

$$\%\text{COD removal, } Y_2 = 70.27 + 10.11X_1 + 2.86X_2 + 7.90X_3 - 10.19X_1^2 - 7.39X_2^2 - 9.96X_3^2 + 1.32X_1X_2 + 1.87X_1X_3 + 2.50X_2X_3 \quad (6)$$

Table 3
Statistical parameters obtained from the ANOVA for the reduced models.

Variables	Color removal (%)	COD removal (%)
Standard deviation, S.D.	0.0782	0.735
Mean	6.806	5.147
Coefficient of variation, CV	1.149	1.428
R-squared (R^2)	0.923	0.912
R^2 adjusted	0.8541	0.8319

where X_1, X_2 and X_3 are the coded values of the process variables temperature, activation time and chemical impregnation ratio, respectively. Positive sign in front of the terms indicates synergistic effect, whereas negative sign indicates antagonistic effect. The quality of the model developed was evaluated based on the correlation coefficient R-squared (R^2), standard deviation values, R^2 adjusted and coefficient of variation (CV) are presented in Table 3. The R^2 coefficient gives the proportion of the total variation in the response predicted by the model, indicating ratio of sum of squares due to regression (SSR) to total sum of squares (SST) [20]. A high R^2 coefficient ensures a satisfactory adjustment of the quadratic model to the experimental data. The CV as the ratio of the standard error of estimate to the mean value of the observed response (as a percentage) is a measure of reproducibility of the model and as a general rule a model can be considered reasonably reproducible if its CV is not greater than 10% [21]. The CV values obtained for all responses studied are relatively small with none of them exceeding 2% as given in Table 3. The present study ensured a satisfactory adjusted R^2 ranged from 0.854 (for color removal) to 0.831 (for COD removal) of the quadratic model to the experimental data and all the three variables studied were found to have synergistic effects on the color and COD removal of the activated carbons prepared. The quality of the fit of polynomial model was expressed by the coefficient of determination R^2, and its statistical significance was checked by the F-test in the same program.

3.2. Statistical analysis

The results of the second-order response surface model fitting in the form of analysis of variance (ANOVA) are given in Tables 4 and 5 for color and COD removal, respectively. ANOVA is required to test the significance and adequacy of the model. The mean squares were obtained by dividing the sum of the squares of each of the two sources of variation, the model and the error variance, by the respective degrees of freedom. The ANOVA for the quadratic

Table 4
Analysis of variance (ANOVA) for response surface quadratic model for color removal.

Source of data	Sum of squares	Degree of freedom (DF)	Mean square	*F*-value	Prob. > *F*	Comment
Model	7344.62	9	816.07	13.36	0.0002	Significant
X_1	885.75	1	885.75	14.50	0.0034	
X_2	58.52	1	58.52	0.96	0.3508	
X_3	1417.34	1	1417.34	23.20	0.0007	
X_1^2	1924.44	1	1924.44	31.49	0.0002	
X_2^2	1304.96	1	1304.96	21.36	0.0009	
X_3^2	2230.10	1	2230.10	36.50	0.0001	
X_1X_2	136.70	1	136.70	2.24	0.1656	
X_1X_3	240.79	1	240.79	3.94	0.0752	
X_2X_3	32.68	1	32.68	0.53	0.4813	
Residual	611.04	10	61.10	–	–	
Lack of fit	589.67	5	117.93	27.59	0.0012	Significant
Pure error	21.37	5	4.27	–	–	

Table 5
Analysis of variance (ANOVA) for response surface quadratic model for COD removal.

Source of data	Sum of squares	Degree of freedom (DF)	Mean square	*F*-value	Prob. > *F*	Comment
Model	5567.95	9	618.66	11.45	0.0004	Significant
X_1	1395.70	1	1395.70	25.82	0.0005	
X_2	111.60	1	111.60	2.06	0.1813	
X_3	851.99	1	851.99	15.76	0.0026	
X_1^2	1497.86	1	1497.86	27.71	0.0004	
X_2^2	786.17	1	786.17	14.55	0.0034	
X_3^2	1428.55	1	1428.55	26.43	0.0004	
X_1X_2	13.99	1	13.99	0.26	0.6219	
X_1X_3	27.83	1	27.83	0.51	0.4895	
X_2X_3	50.10	1	50.10	0.93	0.3584	
Residual	540.47	10	54.05	–	–	
Lack of fit	452.41	5	90.48	5.14	0.0484	Significant
Pure error	88.06	5	17.61	–	–	

model for color removal is listed in Table 4. From the ANOVA for response surface quadratic model for color removal, the model *F*-value of 13.36 implied that the model was significant. Values of probability > *F* less than 0.05 indicated that the model terms were significant. In this case, X_1, X_3, X_1^2, X_2^2 and X_3^2 were all significant model terms whereas X_2, X_1X_2, X_1X_3 and X_2X_3 were insignificant to the response.

From the ANOVA for response surface quadratic model for COD removal (Table 5), the model *F*-value of 11.45 implied that the model was significant as well. In this case, X_1, X_3, X_1^2, X_2^2 and X_3^2 were significant model terms whereas X_2, X_1X_2, X_1X_3 and X_2X_3 were insignificant to the response.

Lack of fit (LOF) is a special diagnostic test for adequacy of a model that compares the pure error, based on the replicate measurements, and other the LOF, based on the model performance [20]. *F*-Value, calculated as the ratio between the lack of fit mean square and the pure error mean square, is the statistic parameter used to determine whether the LOF is significant or not, at a significance level α. In the two studied systems, prob. > *F*-values were 0.0012 and 0.0484, respectively revealing an undesirable significant LOF.

The plot of predicted values versus experimental values for color and COD removal (figure not shown), respectively were quite close, indicating that the models developed were successful in capturing the correlation between the activated carbon preparation variables to the color and COD removal.

3.3. Response surface contours

For the graphical interpretation of the interactions, the use of three-dimensional plots of the regression model is highly recommended [22]. Therefore, the three-dimensional response surface curves were plotted by statistically significant model to understand the interaction of the medium components. The graphical representations of the models (Eqs. (5) and (6)) facilitate an examination of the effects of the experimental factors on the responses, 3D surface graphs and contour plots between the factors are presented in Figs. 1 and 2 cir. The plots are approximately sym-

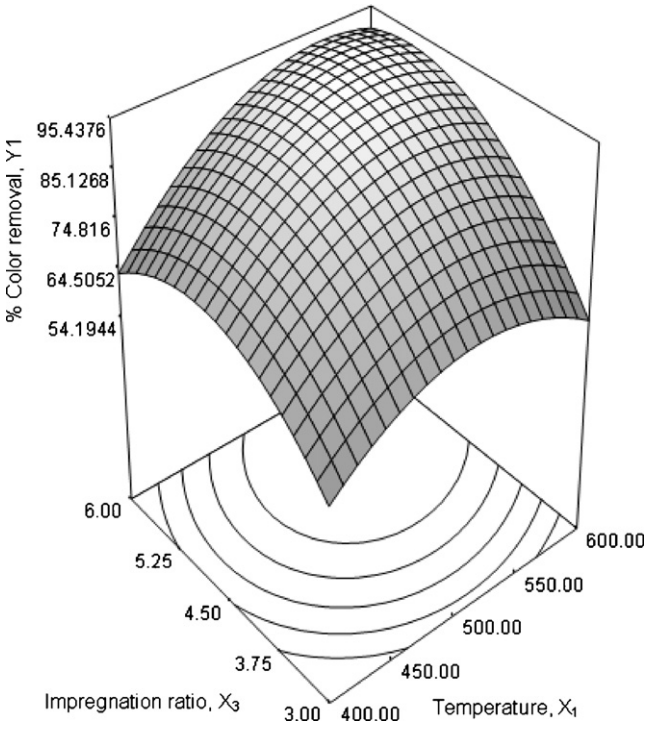

Fig. 1. Contour and three-dimensional response surface plot of color removal (effect of activation temperature and chemical impregnation ratio, t = 2 h).

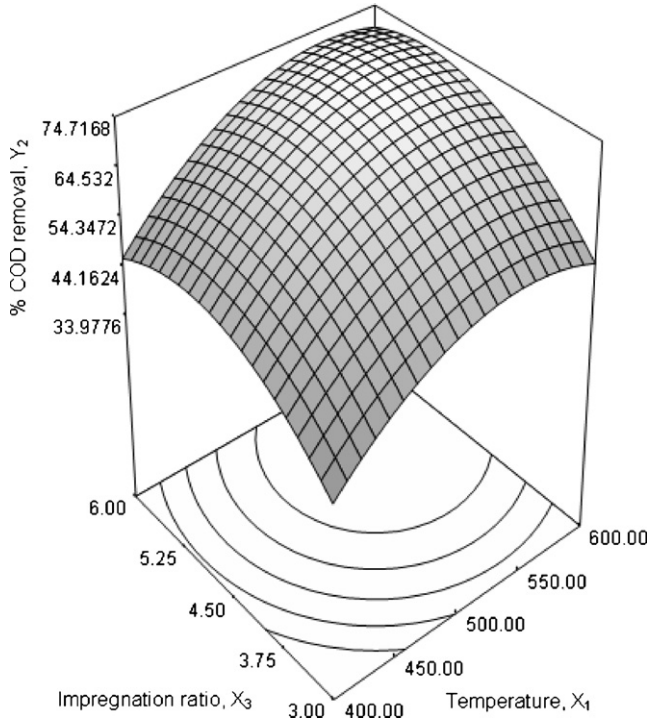

Fig. 2. Contour and three-dimensional response surface plot of COD removal (effect of chemical impregnation ratio and activation temperature, $t = 2$ h).

metrical in shape with circular contours. The response plots show clear peaks, implying for maximum values of the responses are attributed to temperature (X_1) and impregnation ratio (X_3) in the design space. The two-dimensional representation of the responses on the temperature and impregnation ratio plane (contour plot) show concentrically closed curves whose centers represent the maximum values. Based on the *F*-values (Table 4), chemical impregnation ratio (X_3) showed the largest *F*-value of 23.20, activation temperature (X_1) of 14.50 while activation time (X_2) of 0.96. The chemical impregnation ratio and activation temperature had the significant effect on the color removal for the prepared activated carbon, compared to activation time (X_2). Fig. 1 shows the three-dimensional response surfaces which was constructed to show the interaction effects of the activated carbon preparation variables (activation temperature and chemical impregnation ratio) on the color removal (Y_1). For this plot, the activation time was fixed at zero level ($t = 2$ h). As can be seen from Fig. 1, the color removal generally increases with increase in activation temperature and chemical impregnation ratio.

For COD (Y_2) in the other hand, activation temperature (X_1) was found to have the greatest effect on it, with the highest *F*-value (Table 5) of 25.82 and the chemical impregnation ratio (X_3) of 15.76 while activation time (X_2) of 2.06 is a lower effect on the response, which were less significant compared to activation temperature and chemical impregnation ratio. The quadratic effect of activation temperature and impregnation ratio on COD removal were also larger compared to activation time. Fig. 2 shows the three-dimensional response surfaces which was constructed to show the effects of the activated carbon preparation variables (activation temperature and chemical impregnation ratio) on the COD removal (Y_2). The effects of activation temperature and chemical impregnation ratio were studied as they were found to have significant effects on the response. The activation time was fixed at zero level ($t = 2$ h). As can be seen from Fig. 2, COD removal increases with increase in activation temperature and chemical impregnation ratio. In this work, all the three variables studied were found to have synergistic effects on the color and COD removal of the activated carbons prepared. The results obtained agreed with the works by Sudaryanto et al. [7] which reported that activation time gave no significant effect on the pore structure of activated carbon produced from cassava peel, and the pore characteristics changed significantly with the activation temperature and also the KOH impregnation ratio. Sentorun-Shalaby et al. [23] also found that activation time did not show much effect on the surface area obtained for activated carbons prepared from apricot stones using steam activation.

3.4. Verification of the model and optimum conditions

Response surface methodology has been used successfully to optimize the parameters affecting the color and COD removal. However, to optimize both of these responses under the same condition is difficult because the interest regions of factors are different. Fig. 3 shows desirability ramp for numerical optimization. The numerical optimization was selected the desired goal for each factor and response from the menu. The goals may apply to either factors or responses. The possible goals are maximize, minimize, target, within range, none (for responses only) and set to an exact value (factors only). A minimum and a maximum level must be provided for each parameter included in the optimization. The obtained value of desirability (0.996) shows that the estimated function may represent the experimental model and desired conditions. The activated carbon was prepared under the experimental conditions listed in Table 6, together with the predicted and experimental values for color and COD removal. The optimum activated carbon was obtained using preparation condition as: 556 °C activation temperature, 5.24 impregnation ratio and 2.33 h time, which experimentally resulted in 93.08% of color and 73.98% of COD removal. It was observed that the experimental values obtained were in good agreement with the values predicted from the models, with relatively small errors between the predicted and the actual values, which was only 2.414 and 2.031%, respectively for color and COD removal. This result agrees with the work done by Amina et al. [24].

3.5. BET and SEM of activated carbon prepared under optimum conditions

The BET surface area, Langmuir surface area, total pore volume and average pore diameter of the prepared activated carbon were 988.24, 1561.16 $m^2\,g^{-1}$, 0.69 $cm^3\,g^{-1}$ and 2.82 nm, respectively. The maximum value of activated carbon yield was found to be 30.21%. Besides, the average pore diameter of the activated carbon was found to be 2.82 nm, indicated that the activated carbon pre-

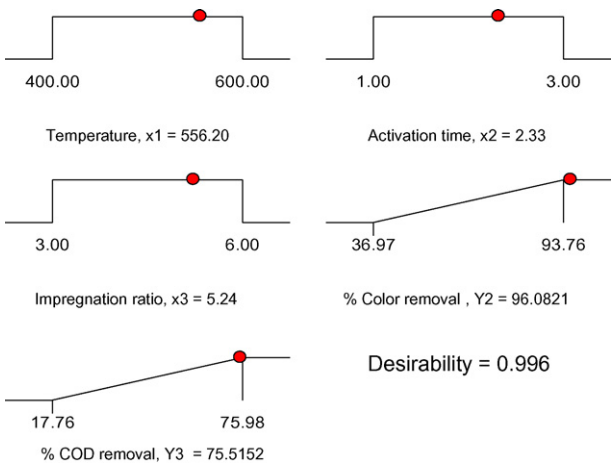

Fig. 3. Desirability ramp for numerical optimization.

Table 6
Verification of experimental and predicted values of prepared activated carbon under the optimum conditions predicted by RSM.

X_1: temp. (°C)	X_2: time (h)	X_3: IR	Color removal (%)		Error (%)	COD removal (%)		Error (%)	Desirability
			Experimental	Predicted		Experimental	Predicted		
556	2.33	5.24	93.761	96.082	2.414	73.981	75.515	2.031	0.996

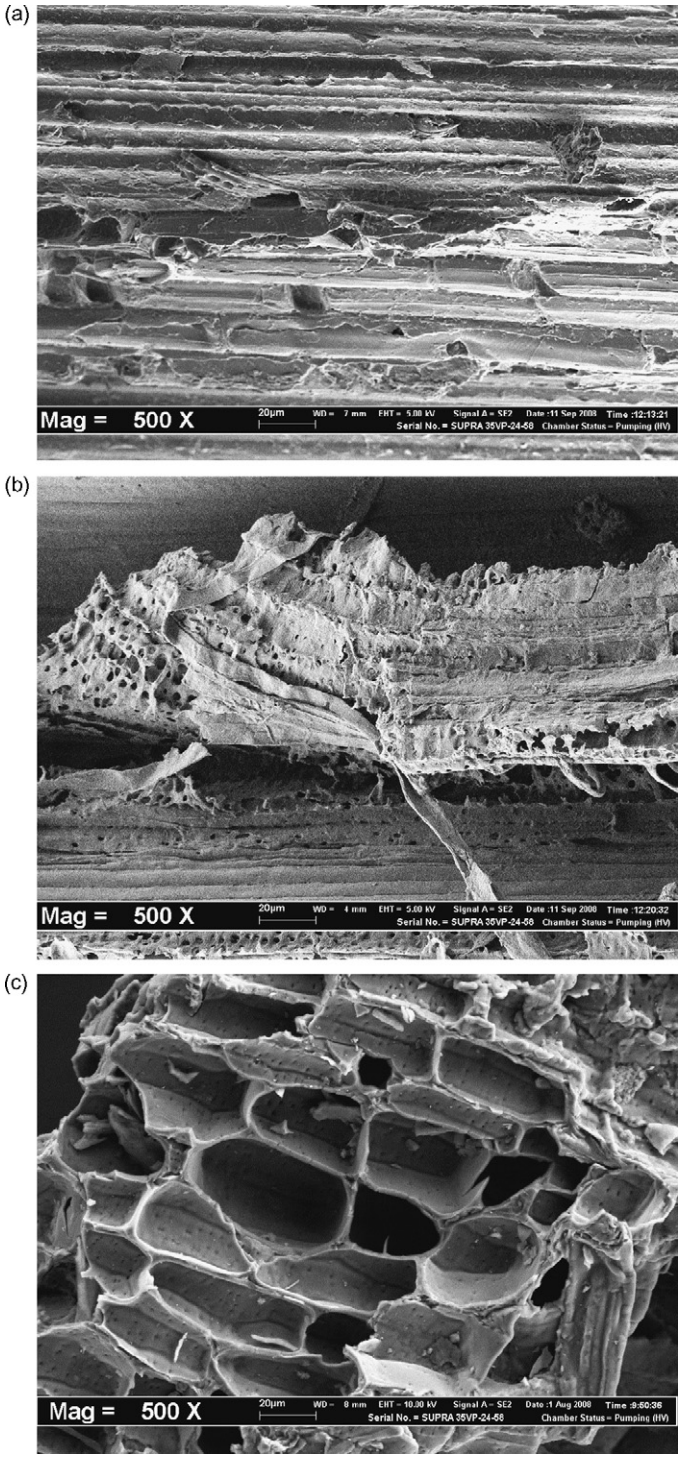

Fig. 4. Scanning electron micrograph: (a) Precursor, (b) H_3PO_4 impregnation ratio (1:5.24), and (c) BMAC (magnifications: 500×).

pared was in the mesopores region according to the International Union of Pure and Applied Chemistry (IUPAC), pores are classified as micropores (<2 nm diameter), mesopores (2–50 nm diameter) and macropores (>50 nm diameter) [25]. The activated carbon derived from bamboo waste contained relatively large surface area and total pore volume compared to commercially available activated carbons such as BDH from Merck, F100 and BPL from Calgon Corporation with BET surface area of 1118, 957 and 972 $m^2\,g^{-1}$ as well as total pore volume of 0.618, 0.526 and 0.525 $cm^3\,g^{-1}$, respectively [26]. The high BET surface area, total pore volume and pore developments of the prepared activated carbon were due to the activation process using H_3PO_4 as chemical activating agent. The chemical agent is dehydrating agent that penetrate deep into the structure of the carbon causing pores to develop [27].

Fig. 4(a)–(c) shows the SEM images of the precursor, precursor impregnated with H_3PO_4 and the derived activated carbon, respectively. Large and well-developed pores were clearly found on the surface of the activated carbon, compared to the original precursor. The H_3PO_4 and activation process were effective in creating well-developed pores on the surfaces of the BMAC, hence leading to large surface area activated carbon with good porous structure (mesopores). Similar observations were reported by other researchers in their works of preparing activated carbons from jute and coconut fibers [28], apricot stones [23] and pistachio-nut shells [29].

4. Conclusion

The present investigation showed that the activated carbon prepared from bamboo waste by chemical activation with H_3PO_4 was a promising for treatment of textile industry wastewater. The surface area of the MBAC was considered relatively high besides having mesopores, hence it was suitable to be applied in liquid-phase adsorption. CCD was conducted to study the effects of three activated carbon preparation variables, which were the temperature, chemical impregnation ratio and activation time, on color and COD removal. Quadratic models were developed to correlate the preparation variables to the two responses. Through analysis of the response surfaces derived from the models, activation temperature and chemical impregnation ratio was found to have the most significant effect on color and COD removal. Process optimization was carried out and the experimental values obtained for the color and COD removal were found to agree satisfactorily with the values predicted by the models. The optimal activated carbon was obtained using 556 °C activation temperature, 5.24 chemical impregnation ratio and 2.33 h activation time, which experimentally resulted in 93.08% of color and 73.98% of COD.

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