Removal of colour using banana stem adsorbent in textile wastewater

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Abstract. The potential use of banana stem adsorbent has been investigated via batch adsorption experiment. A series of batch experiment was carried out to determine the effect of various adsorbent dosage (0.2 – 1.4 g) and various contact time (15 – 120 minutes). Analysis on adsorption isotherm was done using Langmuir and Freundlich model. In addition to it, the behaviour and mechanism of adsorption was analysed using kinetic model, namely Pseudo-first order and pseudo second order kinetic. The result shows that more than 90% of colour was removed at optimum dosage of 1 g of banana stem adsorbent in 100 mL synthetic dye at optimum contact time of 90 minutes. Analysis of isotherm models showed that the adsorption of colour by banana stem adsorbent was fitted to Freundlich with coefficient of determination, $r^2$ of 0.917. Adsorption kinetics of colour showed that Pseudo-second order fit better ($r^2 = 0.99$) than Pseudo-first order ($r^2 = 0.94$) kinetic model. From the result, it was indicated that the adsorption of colour occurred by multilayer on a heterogeneous surface of the banana stem through the chemical reaction process. As a conclusion, the use of banana stem adsorbent has good potential for colour removal in textile wastewater treatment because of low cost of the media. Thus, it is an alternative to overcome problems related to an excessive of colour in dye wastewater treatment plant.

1. Introduction
Textile industry is one of the industries that produce great income to economic growth in several countries around the world. In Malaysia, the textile industry became the country's 11th largest export income in 2017, which contribute about RM15.3 billion (1.6%) of Malaysia's total manufactured exports. In 2017, RM428.8 million investment in 12 projects has been approved in the textile and textile industry [1]. However, the wastewater generated contains high organic and inorganic contaminants which exceeds the standard effluent of industrial wastewater by Department of Environment. Untreated textile effluent consists of high pH, temperature, detergents, oil, suspended and dissolved solids, toxic and non-biodegradable matter, color, chemical oxygen demand (COD), and alkalinity [2]. In fact, the textile dyeing consumes large quantity of water and produces large volumes of wastewater from different steps in the dyeing and finishing process [3]. There are more than 100,000 commercially available dyes with 700,000 tons of dye production each year and about 10% of these dyes used in the industry have been lost in industrial effluents [3]. The extensively used of textile
dyes in several manufacturing process have been proved to be harmful to the human health as well as to the environment [4].

Several treatment methods had been used such as physical, chemical, and biological methods or suitable combinations of them are available for the treatment of textile wastewater before safely discharged into the environment. Among them, adsorption process has been proven superior compared to other techniques in terms of its simplicity of design, high removal efficiency and ease operation, [4]. Recently, activated carbon is widely used in adsorption process due to porous structure with large surface area and high adsorption capacity. Although it is advantageous as adsorbent media, the high cost of activated carbon caused researchers to find a cheaper alternative. Application of an agricultural waste as adsorbent media has gained attention by researchers to explore the potential of the adsorbent media in solving textile wastewater problem. Some of agricultural waste adsorbents such as pink guava waste[3], rambutan peel [5], orange peel[6], groundnut shell waste[7], garlic peel[8], pineapple leaf powder[9], coconut husk waste[10] and banana peel[11] used to remove various type of dyes in wastewater treatment.

Banana stem is an agriculture plant waste which is among the most popular fruit grown in Asia particularly India, Thailand, China, Indonesia, and Malaysia [12]. A few tons per hectare of the banana stem has been estimated annually and this can lead to disposal issues [13]. Several studies on activated banana stem [12;13;14] and banana peel adsorbent [11; 15] have been conducted by the previous researchers. However, the study on agricultural waste using natural banana stem is still limited and need to be explored as an alternative to remove colour in textile wastewater.

The aim of this study was to investigate the potential use of banana stem as adsorbent media for the removal of colour from Methylene Blue (MB) synthetic dye solution. The effect of various adsorbent dosage and contact time were evaluated.

2. Methodology

2.1. Preparation of synthetic solution

1 L of textile wastewater was collected from selected batik factory in Kelantan. The concentration of color in the actual sample was tested using spectrometer DR2800 (Model: HACH, 127181-D). The analysis was conducted in Makmal Alam Sekitar 1, UiTM Pulau Pinang. In this study, the color concentration of synthetic MB solution was simulated close to the effluent from batik factory. 0.02g of MB powder was dissolved in 1000mL of distilled water in a volumetric flask. The initial concentration of color was tested using spectrometer (APHA Method 2120).

2.2. Adsorbent preparation

The banana stem was peeled layer by layer and washed each layer using tap water to remove dirt. Then, it was cut into small particle size in the range of 5 - 7 cm. The banana stem was washed several times with hot water until no color released by the media. After that, the sample was dried in an oven for 105°C. Lastly, the adsorbent was sieved to pass through an aperture size of 1.18 mm and retain in 2 mm size.

2.3. Batch adsorption experiment

Batch adsorption experiment was conducted to determine the adsorption capacity and removal efficiency of colour. In this study, the effects of various dosage and various contact time were analysed and optimised. The adsorption capacity at equilibrium, \( q_e \) (mg/g) can be determine by using Eq. (1).

\[
q_e = \frac{(C_0 - C_e)}{m} \times V
\]
where $C_0$ and $C_e$ (mg/L) are the liquid phase concentration of solute at initial and at equilibrium, respectively. The $V$ represent the volume of the solution (L) and $m$ is the mass of dry adsorbent use (g).

2.3.1. The effect of varied dosage. The effect of varied dosage experiment was investigated to determine the optimum dosage and adsorption mechanism of adsorption process. In this experiment, the dosage of banana stem was varied from 0.2 to 1.4g in 100mL of synthetic sample. The conical flasks were agitated at 200 rpm of shaking speed using orbital shaker for 90 minutes. After shaking process, the samples were allowed to settle for 60 minutes. Approximately, 10 mL of samples were drawn and analysed using spectrometer.

2.3.2. The effect of varied contact time. In this study, the effect of varied contact time was conducted to determine the optimum contact time and adsorption kinetic between solute and solid surface. The varied contact time applied in this experiment is 15, 30, 45, 60, 90 and 120 min. The optimum dose of banana stem adsorbent obtained from section 2.3.1 were adopted in this experiment. This experiment was conducted with previous operating condition obtained from Section 2.3.1.

3. Result and discussion

3.1. The effect of varied dosage

Figure 1 shows the effect of varied dosage on the removal of colour in the synthetic sample. It can be observed that the removal of colour increased significantly when the dosage from 0.2 to 1 g. Increase in adsorption of colour with the banana stem adsorbent dose can attributed to increase surface area of adsorbent and the availability of active site increase. Based on Figure 1, the optimum removal of colour was 91.12 % at 1.0 g of banana stem adsorbent in 100 mL of synthetic sample. After this, the removal of colour slightly decreases to 88.5%. As the dose of banana stem adsorbent increases, not much change in adsorption is observed. This phenomenon indicated that active sites were fully occupies, due to the limited capacity of banana stem adsorbent to adsorb high amount of colour [17].

![Figure 1. The effect of varied adsorbent dosage](image)

3.2. The effect of varied contact time

Figure 2 shows a plot of percentage removal versus time. From the graph, the percentage removal of colour sharply increases to 83.33% in the first 15 minutes. Then the removal was increased gradually
to the maximum removal of 91.05% at optimum 90 minutes. After 90 minutes, the removal of colour was decreased to 84.26% because the banana stem adsorbent surface was saturated. An equilibrium adsorption time of 90 minutes was reported for MB adsorption onto garlic from aqueous solution [8].

![Figure 2. The effect of varied contact time](image)

### 3.3. Adsorption isotherm model

The adsorption isotherm is a mathematical modelling describe the interaction between solid and liquid related to the homogeneous and heterogeneous of the solid surface. In this study, two linearized adsorption isotherm model of colour known as Langmuir and Freundlich model were investigated to analyse the adsorption process. Langmuir can be expressed as:

\[
\frac{C_e}{Q_e} = \frac{1}{Q_0b} + \frac{C_e}{Q_0}
\]  

Where \( Q_e \) the amount of solute adsorbed, per unit weight of adsorbent (mg/g). \( C_e \) (mg/L) is equilibrium concentration of the solute, \( Q_0 \) amount of solute adsorbed per unit weight of adsorbent required for monolayer coverage of the surface, also called monolayer capacity and \( b \) (L/mg) is a constant related to the heat of adsorption. For generalization of the data, \( C_e/Q_e \) is plotted against \( C_e \) and the straight line. \( Q_o \) and \( b \) were measured by the slope and intercept of the plotting graph.

The empirical Freundlich isotherm is given by Equation 3.

\[
\log Q_e = \frac{1}{n} \log C_e + \log K_f
\]

where \( K_f \) is Freundlich isotherm constant (mg/g), \( n \) is the adsorption intensity, \( C_e \) is the equilibrium concentration of adsorbate (mg/L) and \( Q_e \) is the amount of adsorbed of the adsorbent at equilibrium (mg/g). From the experimental data, \( \log Q_e \) is plotted versus \( \log C_e \) is plotted to obtain the value of \( \frac{1}{n} \), and \( K_f \) from slope and intercept of the graph.

Table 1 shows the summary results of the constant parameters and coefficient of determination, \( R^2 \) of colour adsorption onto banana stem adsorbent for Langmuir and Freundlich isotherm in this research. From Table 1, it shows that the adsorption of colour onto banana stem adsorbent followed Freundlich model \((R^2 = 0.917)\) rather that Langmuir model \((R^2 = 0.775)\). The highest value of \( R^2 \) indicates the goodness of the adsorption isotherm model. In the Freundlich model, the value of \( K_f \) for colour adsorption onto banana stem adsorbent was 0.105.
Table 1.: Langmuir and Freundlich parameter for the adsorption of colour onto banana stem.

| Method | Langmuir | Freundlich |
|--------|----------|------------|
|        | constant | R² | Q₀ | b | R_L | R² | K_f | N |
| value  |          | 0.775 | 33.784 | -4.2×10⁻³ | 0.439 | 0.917 | 5.7×10⁻³ | 0.401 |

While, for Freundlich Isotherm constant, N that represent adsorption intensity for this study is 0.4013. The value of N obtained for adsorption process that is lower than 1 show high adsorptive capacity at optimum concentrations [18]. The Freundlich model assumes a heterogenous surface with a non-uniform distribution of colour sorption over the banana stem adsorbent surface, and the adsorption might be occurred as multiple-layer [16].

3.4. Kinetic model
The adsorption kinetic analysis used to evaluate the performance and describe the mechanism of adsorption using banana stem adsorbent. The result as shown in Table 2 presented that the R² value for Pseudo-second order (R² > 0.99) was higher than Pseudo-first order (R² > 0.94). The best adsorption kinetic model was assessed by comparing the adsorption capacity between experiment and calculated data. The adsorption capacity of the experiment, q_exp (29.50 mg/g) is very close to the calculated value, q_cal (27.85 mg/g) which indicates good fitting kinetic model. As referred to the previous study, adsorption of colour using different adsorbents such as rambutan peel, orange peel, pineapple leaf powder and banana peel probably followed pseudo-second order model. Thus, it can be concluded that the Pseudo-second order more satisfy to describe kinetic mechanism for this research and the chemisorption process involved in the adsorption of colour onto natural banana stem adsorbent.

Table 2.: Coefficient of determination and constants values for Pseudo-first and second order models

| Model       | Pseudo-first order | Pseudo-second order |
|-------------|--------------------|---------------------|
|             | R² | qₑ (mg/g) | k₁ | R² | qₑ (mg/g) | k₂ |
| value       | 0.949 | 3.819 | 0.033 | 0.996 | 27.855 | 0.186 |

4. Conclusion
Banana stem adsorbent has the capability to remove colour for textile wastewater. The adsorbent removed 91.12% of colour at optimum dosage of 1.0 g in 100 mL synthetic sample within 90 minutes contact time. This study found that the adsorption process of colour fitted to the Freundlich model rather than Langmuir model. Furthermore, adsorption kinetic of colour showed that pseudo-second order fit better than pseudo first order kinetic model. This indicates that chemisorption is the adsorption mechanism which contributed to colour removal from textile wastewater sample. Thus, the banana stem was found to be very effective and as alternative to remove colour for industrial wastewater due to low cost of media and solving agricultural abundance.

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