Carbonized chilli stalk adsorbent to remove methylene blue dye from aqueous solution: Equilibrium and kinetics studies

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Abstract. The fast growth of textile industry has led to afflictive water pollution problems. The discharge of dyes into the environment poses health threats to the ecosystem due to their carcinogenicity and mutagenicity. Adsorption process is among the most utilized approach in treating textile wastewater. Chilli stalk which is abundantly available as agrowaste was transformed into adsorbent through carbonization process at various temperatures for the adsorption of methylene blue (MB). Dye batch adsorption studies were conducted to evaluate the effects of initial dye concentration (25 – 300 mg/L), contact time (0 – 24 hours) and carbonization temperature (350 - 400 °C). The surface characteristics, proximate and elemental analyses, surface morphology and chemistry were studied on both chilli stalk (CS) and carbonized chilli stalk adsorbent (CCSA). The maximum MB dye removal was 97.04% at 400 °C of carbonization temperature. The data fitted Freundlich isotherm model and pseudo-second-order kinetic model for adsorption equilibrium and kinetic studies, respectively.
1. Introduction
The fashion and textile industries have expanded widely to serve one of the human needs, clothes. Textile industry is growing in a fast pace since 1980s, which mainly based in the east coast, as it is a big contribution to the national economic growth, employment and worldwide trade. The demand for textile and clothing is expected to increase further as the increasing demand in the global market for high quality textile and clothing from Malaysia. More than 7 × 10^5 tons of synthetic dyes to be produced worldwide annually, as tons of industries synthesize various types of colourants and pigments [1]. Dyes are materials which emit colour after application to a medium. The two main components of dye are chromophore and auxochrome to impart and deepen the colour. In textile, colour fastness is vital in measuring how well the dye can be absorbed by the fabric or substrate, where indanthrenes were invented for faster colouring and brighter colour. However, due to escalating annual production of the textiles, our environment has been affected largely by these activities mainly from the dyeing process. In addition, this recalcitrant dye compounds are also found relatively resistant to biodegradation, thus negatively impact the aquatic lives [2]. Therefore, it is vital to treat dyes from the wastewater before they could pose more harmful impact on the environment.

Physical, chemical and biological treatment methods are being practiced to treat contaminated wastewater. Among these treatment techniques, adsorption which employs physicochemical principles appears to be a highly potential treatment technique due to its relatively simple preparation, requires very minimal energy consumption, and capable of effectively adsorb multiple contaminants. Physical adsorption embraces the Van der Waals’ attraction force, while chemical adsorption embraces the attraction force between the adsorbate and adsorbent with the help of a chemical compound to aid the adsorption. The synergy effect of these physical and chemical forces would double the efficiency of contaminant particles adsorption onto the surface of the adsorbent.

The highly porous structure material is the most preferable adsorbent in the adsorption studies for treating wastewater. The porous structure of the adsorbent is to ensure the dye particles are efficiently adsorbed from the wastewater. High surface area can be achieved with more pores presence on the surface or inside the adsorbent, to have high adsorption capacity. The only disadvantage of the adsorption method is that the cost of the adsorbent [3]. If the adsorbent is abundant in nature and requires less processing, it is weighed as low cost adsorbent [4]. Aiming for a low cost process, numerous published studies are available on the utilization of low cost materials as the adsorbent precursors [5]. The low cost materials which are generally made up from agricultural biomass, include coconut and palm shells, sawdust, paddy husk and straws, and many more.

In this study, a discarded waste of chilli stalks (CS) has been selected to be converted into carbonized adsorbent for methylene blue (MB) adsorption. As one of the most planted plants in Malaysia, CS is seemed to be an ideal low-cost material for the dye wastewater treatment owing to its abundance and throughout-the-year availability. Various carbonization temperatures, dye initial concentrations and contact time were applied for dye adsorption studies by carbonized chilli stalk adsorbent (CCSA). The surface characteristics, proximate and elemental analyses, surface morphology and chemistry were studied on both CS and CCSA to confirm the adsorption capability of chilli stalk based adsorbent. With the adsorption isotherms and kinetics values of CCSA, we hypothesize that the CS based adsorbent is an effective adsorption precursor in removing the dye from wastewater.

2. Methodology
2.1 Materials and CCSA preparation
Chilli stalk (CS) was collected from food stalls near Universiti Sains Malaysia, Nibong Tebal, Penang. The chilli stalk was washed with deionized water and dried in the oven at 100 °C for 24 hours. Then, the samples were cut into small pieces of 1 – 2 cm followed by carbonization step at 350 °C, 370 °C and 400 °C under purified nitrogen (99.995 %) flow of 150 mL/min for 10 °C/min in a reactor shown in Figure 1. Then, the stalks were soaked in deionized water for 24 hours to remove chlorophyll content.
and dried for another 24 hours at 100 °C. The samples were then cooled to room temperature before proceeding with the batch adsorption of methylene blue (MB) dye (Sigma Aldrich Sdn. Bhd.).

2.2 Surface characteristics and proximate analyses

The volumetric adsorption analyzer Micromeritics ASAP 2020 was used to determine the surface area, pore volume and average pore diameter of the samples. Using Brunauer-Emmett-Teller equation, the BET surface area was analyzed from the adsorption isotherm. The gross pore volume was guesstimated as the liquid volume of nitrogen at 0.98 of a relative pressure. With the aid of a scanning electron microscope (SEM) (Quanta 450 FEG, Netherland), the surface morphology of the samples was assessed. By using a simultaneous thermal analyzer (Perkin Elmer STA 6000, USA), the proximate analysis of the samples was achieved. Elemental analyzer (EA) (Model Perkin Elmer Series II 2400, USA) was used to deliberate the elemental composition of the samples. An FT-IR spectrometer (IR Prestige 21 Shimadzu, Japan) was used to analyze the surface characteristic of the samples.

2.3 Batch equilibrium, isotherms, kinetics and mechanism studies

To test for the adsorption behaviour of MB on CCSA, batch equilibrium was carried out. 0.20 g CCSA were transferred into test tubes consisting 20 ml of dye solutions of varying MB initial concentrations (50 mg/L to 300 mg/L). Then, the sealed test tubes were arranged in an isothermal water bath shaker (Protech Malaysia) at the temperature of 30°C and agitation speed of 60 rpm. For the collection of dye solution samples, a 3-mL disposable syringe was used to analyse concentrations using UV-Vis spectrometer at the fixed time interval. Repetition of the steps were done until a steady state adsorption has reached over 24 hour. The amount of adsorption at equilibrium, \( q_e \), can be calculated by using the following equation:

\[
q_e = \frac{(C_0-C_e) W}{W} 
\]

where, \( q_e \), \( C_0 \), \( C_e \), \( V \) and \( W \) represent the amount of adsorbate adsorbed at equilibrium (mg/g), the liquid-phase dye concentrations at initial stage (mg/L), the liquid-phase concentrations of dye at equilibrium stage (mg/L), the volume of dye solution (L), and mass of adsorbent used (g), respectively. The percentage of dye removal, \( \% C \) (Equation 2) can be calculated with the equation expressed below with \( C_i \) as liquid-phase dye concentrations at time.
\[
\% C = \left( \frac{C_o - C_t}{C_o} \right) \times 100
\]

The experimental results were then tested to determine the optimal match on the Langmuir, Freundlich and Temkin isotherm models. The \( R^2 \) value of the correlation coefficient will determine the best fitted isotherm, with the value being the closest to unity. Kinetics studies were performed, by calculating the amount of adsorption at time \( t \), \( q_t \) (mg/g) with the equation below:

\[
q_t = \frac{(C_o - C_t)V}{W}
\]

where \( q_t \), \( C_o \), \( C_t \), \( V \) and \( W \) represent the amount of adsorbate adsorbed at time \( t \) (mg/g), the liquid phase dye concentrations at initial stage (mg/L), liquid-phase concentrations of dye at equilibrium stage (mg/L), volume of dye solution (L) and mass of adsorbent used (g), respectively. For the study of adsorption kinetic, pseudo-first-order and pseudo-second-order models were employed. With both kinetic models applied, the correlation coefficient, \( R^2 \) value can be obtained. The intra-particle diffusion model (Equation 4) was used to determine the adsorption rate in relation to the diffusion mechanism for the adsorption of MB dye onto CCSA. The \( k_{pi} \), \( t^{1/2} \) and \( c_i \) are defined as the intra-particle diffusion rate constant (mg/g.h\(^{1/2}\)), the half-adsorption time (g/h.mg) and the intercept from \( q_t \) vs. \( t^{1/2} \) linear plot, respectively.

\[
q_t = k_{pi} t^{1/2} + c_i
\]

3. Results and discussion

3.1 The effect of contact time and initial concentrations

The effect of contact time and initial concentrations of MB dye (25 – 300 mg/L) were examined for batch equilibrium study. Figure 2 (a) shows uptakes of MB dye adsorption on CCSA against adsorption time, while Figure 2 (b) shows the percentage of MB removal against adsorption time. MB dye adsorption consists of two phases: the rapid adsorption phase and the incremental adsorption phase [6]. The first phase is also known as the initial rapid phase of fast adsorption occurrence and the second phase is slower where the MB adsorption is relatively small, and the MB uptake will eventually enter equilibrium phase.

It is observed that the increasing amount of dye uptake is linear towards the increasing contact time at all initial dye concentrations and then remained constant after equilibrium time. CCSA’s adsorption capacity increased rapidly in the first 2 hours (Figure 2 a) and a gradual rise in adsorption ability can be observed until the 20th hour. The adsorption has reached equilibrium over 20th hour. Many active sites of CCSA were vacant and accessible at an early stage, and as the adsorption time increased, the active sites were occupied and the adsorption process slowed [7]. When the initial concentration of MB dye increased the adsorption capability increased. Adsorption process is enhanced at higher initial dye concentration, as the concentration serves as the driving force preventing the dye’s mass transfer resistance from the aqueous phase to the solid phase [8]. The MB dye % removal, however, showed the opposite pattern, where it decreased as the initial concentration of MB dye increased (Figure 2 b). Increasing the initial concentration of dye from 25 mg/L to 300 mg/L reduced the % removal from 99.68 % to 97.04 %.
3.2 The effect of carbonization temperature
The maximum removal was observed by the adsorption on CCSA at 400°C. Carbonization was conducted at the variation of temperature on the precursor; 350 °C, 370 °C and 400 °C for initial dye concentrations ranging from 50 to 300 mg/L. From Figure 3, the quantity of MB dye adsorbed increased from 4.82 mg/g to 28.00 mg/g (350 °C), 4.96 mg/g to 29.16 mg/g (370 °C) and 4.98 mg/g to 29.38 mg/g (400 °C) for the initial MB dye concentrations of 50 – 300 mg/L, respectively. However, no significant difference of $q_e$ values were observed among the three temperatures. But, Johari et al. [9] found that the adsorption capacity is enhanced significantly with the increasing carbonization temperatures. The treated MB dye solutions by CCSA at 400 °C have clearer colour and most assured aesthetics to be used for drinking purpose. The treated dye-bearing solutions by the adsorption of CCSA at 350 °C still have hints of blue colour, indicating that the adsorption of MB dye has reached the maximum capacity.
3.3 Isotherm study

The critical factors for adsorbent efficiency are the adsorption capacity based on the interaction of adsorbate-adsorbent [10]. The experimental results were fitted into three adsorption isotherms; Langmuir, Freundlich and Temkin isotherm models. Figure 4 shows the plots for linearized equation isotherm parameters for MB dye removal at 350 °C, 370 °C and 400 °C. Table 1 summarizes the values parameters involved; the maximum adsorbed quantity ($q_m$), the correlation coefficient ($R^2$), and others constants for all the isotherms applied for the adsorption process. The adsorption behaviour between the adsorbate and the adsorbent can be observed. Langmuir isotherm model describes the irreversible monolayer adsorption on a homogeneous adsorbent surface. Freundlich isotherm model depicts the reversible multilayer adsorption onto heterogeneous adsorbent surface. Temkin isotherm model assumes the interactions of adsorbent-adsorbate through the adsorption heat of all molecules in the layer [11].

The maximum adsorption capacity, $q_m$ obtained for Langmuir isotherm was 45.68 mg/g and the $R^2$ value was 0.919. These demonstrate good fit of the Langmuir isotherm to the experimental data. The obtained values of nF and 1/nF for Freundlich isotherm were 1.47 and 0.68 respectively. The $R^2$ value obtained to describe Freundlich isotherm’s best fit with the experimental data was 0.971, which is the closest to unity. The constant B value for Temkin isotherm, which is related to the heat of adsorption, was 9.0287. The endothermic process is proven by positive value of the constant B. The fit to the experimental data, obtained value $R^2$ was 0.96, which is larger than 0.91 indicating the favourability of the adsorption.

From the analysis of all the isotherms, with respect to $R^2$, the isotherms are arranged to describe the experimental behaviour of the interactions between the MB dye and the CCSA adsorption system. In descending order, it is possible to observe Freundlich > Temkin > Langmuir, which is applied to the range of carbonization temperature studied. Similar results were recorded from various works for the adsorption of MB dye from aqueous solution onto rice husk adsorbent [12], raw and modified waste ash [13] and jute stick charcoal [14].
Figure 4. Graphs of (a) Langmuir, (b) Freundlich, (c) Temkin Isotherms for MB dye adsorption on CCSA.

From Table 1, as the carbonization temperature increased, the $k_F$ values increased suggesting that the adsorption favours at high temperatures [11]. The adsorption process favourability can be determined from the separation factor $R_L$ values obtained in Langmuir isotherm. The $R_L$ value decides the isotherm type; isotherm is favourable ($R_L<1$) or unfavourable ($R_L>1$) [15]. From the analysis, the average $R_L$ value is 0.1002 at the concentration range studied, this proved the favourable adsorption system of MB dye onto the CCSA surface. Figure 5 shows that when the initial dye concentration in the solutions increases, the $R_L$ values decrease, indicating that the adsorption was favoured the high concentration of MB dye.

Table 1. Isotherm values for adsorption of MB dyes by CCSA at 350 °C, 370 °C and 400 °C.

| Isotherm | Temperature (°C) | Constants | $R^2$ |
|----------|------------------|-----------|-------|
| Langmuir | 350              | 45.6775   | 0.0699 | 0.9196 |
|          | 370              | 41.8949   | 0.1844 | 0.6710 |
|          | 400              | 36.4102   | 0.2971 | 0.5880 |
|          | $k_F$            |           |       |
| Freundlich| 350              | 3.7072    | 1.4681 | 0.9707 |
|          | 370              | 7.6966    | 1.7986 | 0.9377 |
|          | 400              | 10.1378   | 2.3302 | 0.8786 |
|          | $n_F$            |           |       |
| Temkin   | 350              | 0.8659    | 9.0287 | 0.9611 |
|          | 370              | 3.4934    | 7.0873 | 0.7980 |
|          | 400              | 10.8693   | 5.2708 | 0.6851 |
3.4 Kinetic study

The applied pseudo-first-order and pseudo-second-order equations aimed at determining the kinetics of MB dye adsorption onto CCSA. The goal of the kinetic study is to optimize the adsorption process of dye on adsorbents [15]. Figure 6 (a) and (b) display the linearized plots for MB dye adsorption onto CCSA at 400 °C. Table 2 summarizes the parameters of the kinetic models as measured, and their constant values.

![Figure 5](image1.png)

**Figure 5.** Separation factor against initial dye concentration at different temperatures.

![Figure 6](image2.png)

**Figure 6.** Linearized plots of (a) pseudo-first-order and (b) pseudo-second-order for MB dye adsorption onto CCSA at 400 °C.
Table 2. Kinetic model parameters for the MB-CCSA adsorption system at 400 °C.

| Initial dye concentration, C_o (mg/L) | q_e, exp. (mg/g) | q_e, calc (mg/g) | k_1 | R^2 | q_e, calc. (mg/g) | k_2 | R^2 |
|--------------------------------------|------------------|------------------|-----|-----|------------------|-----|-----|
| 50                                   | 4.9856           | 2.1193           | 0.9104 | 5.1416 | 1.9499           | 0.9971 |
| 100                                  | 9.7977           | 2.9176           | 0.9661 | 9.7586 | 0.9564           | 0.9998 |
| 150                                  | 14.6217          | 4.1525           | 0.9382 | 14.2414 | 0.7119           | 0.9999 |
| 200                                  | 19.5748          | 7.5839           | 0.9901 | 18.8825 | 0.3440           | 0.9985 |
| 250                                  | 24.3871          | 8.9643           | 0.9649 | 23.2890 | 0.3076           | 0.9994 |
| 300                                  | 29.3812          | 12.2052          | 0.9650 | 28.2293 | 0.2085           | 0.9992 |

The R^2 for the pseudo-second order is higher and closest to unity, compared to that of the first order. Thus, the pseudo-second-order kinetic model suits better with the experimental data. Different findings have been reported for the adsorption of MB from aqueous solution onto pineapple leaf powder [16], carbonized green tea dredge [17], kenaf core fibres [11], and raw and modified waste ash [13]. It is also observed that the coefficient rate, k_2 of the pseudo-second-order value decreased with the increasing initial dye concentration. There will be greater competition for the spots on the adsorbent at higher initial concentration, and reduced electrostatic interaction as the initial dye concentration increases [15]. Thus, it can be deduced that the dye affinity was reduced towards the adsorbent.

3.5 Mechanism study

The kinetic mechanism of MB dye adsorption could be described by the intra-particle diffusion model. Factors include diffusion of the solute from the solution to the film, diffusion from the film to the surface of the particles, diffusion from the surface to the internal sites and uptake involving adsorption mechanism [17]. Figure 7 displays the multi-linearity of the intra-particle diffusion model plots at various initial dye concentrations at 400 °C.

![Figure 7. Graph of intra-particle diffusion model for MB adsorption by CCSA.](image)

The dotted line in the figure signify three distinct stages of adsorption mechanism; first stage is characterized by a sharper region at the first 0.25 h, followed by the second stage which is from 0.5 h to 1 h and the third stage of adsorption is around 4.9 h onwards. The first stage suggests a rapid adsorption due to a strong electrostatic attraction between MB dye and CCSA’s outer [18]. A gradual adsorption in the second stage indicates that the intra-particle diffusion of MB dye molecules through CCSA pores. The third stage is the final equilibrium stage which describes the slowed down adsorption process due to less adsorption sites available.
In each stage, the slope of the plotted lines is defined as the rate parameters; \( k_{p,1} \), \( k_{p,2} \) and \( k_{p,3} \) [19]. Table 3 lists the constants for the intra-particle diffusion model. It is observed that as the initial concentration of MB dye increased, the rate parameter values for the three stages increased, indicating an increase in the rate of MB dye diffusion. The intercept values of the plotted lines; \( c_1 \), \( c_2 \) and \( c_3 \) increased for the three stages with the increasing MB dye initial concentration range, suggesting thickening of the boundary layer [20]. The boundary layer gets thicker and then reduces the external mass transfer, but will increase the internal mass transfer [15].

### Table 3. Intra-particle diffusion model constants for MB adsorption by CCSA.

| MB initial concentration | \( k_{p,1} \) | \( k_{p,2} \) | \( k_{p,3} \) | \( c_1 \) | \( c_2 \) | \( c_3 \) | \( R^2_{1} \) | \( R^2_{2} \) | \( R^2_{3} \) |
|------------------------|----------------|----------------|----------------|--------|--------|--------|----------|----------|----------|
| 50                     | 8.3167         | 0.5194         | 0.007          | 0      | 3.9592 | 4.951  | 1        | 0.9976   | 0.9975   |
| 100                    | 14.211         | 2.7065         | 0.1506         | 0      | 6.0765 | 9.0792 | 1        | 0.9995   | 0.9956   |
| 150                    | 21.079         | 3.7144         | 0.2956         | 0      | 9.2189 | 13.192 | 1        | 0.9971   | 0.9962   |
| 200                    | 25.695         | 6.1732         | 0.5683         | 0      | 9.8988 | 16.914 | 1        | 0.9997   | 0.9796   |
| 250                    | 31.918         | 7.7483         | 0.7504         | 0      | 12.521 | 20.859 | 1        | 0.9976   | 0.9847   |
| 300                    | 36.147         | 11.511         | 0.9649         | 0      | 12.519 | 24.822 | 1        | 0.9959   | 0.9829   |

*\( k_p \) is in mg/gh\(^{1/2} \) and MB initial concentration is in mg/L.

#### 3.6 Characterization of CCSA

##### 3.6.1 Surface area and pore characteristics

The summary of the characteristics on surface area and pore, BET surface area, mesopores surface area, total pore volume and average pore diameter of chilli stalk and CCSA is tabulated in Table 4. The chilli stalk has a small BET surface area of 1.104 m\(^2\)/g. The increase of the surface area and total pore volume can be observed because of the removal of water and volatile matter from the chilli stalk after being carbonized with the absence of oxygen at the temperature of 400 °C. The properties were significantly improved with the elevated temperature of carbonization [21]. Meanwhile, the porosity and BET surface area increased with carbonization temperatures. The enhanced BET surface area and porosity can be observed on the carbonized chilli stalk adsorbent, as washing process with deionized water was performed to extract inorganic matter after carbonization.

### Table 4. Surface area and pore characteristics of the samples.

| Sample | BET surface area (m\(^2\)/g) | Mesopore surface area (m\(^2\)/g) | Total pore volume (cm\(^3\)/g) | Average pore diameter (nm) |
|--------|-----------------------------|----------------------------------|-------------------------------|-------------------------|
| CS     | 1.104                       | 0.628                            | 0.0001                        | 3.14                   |
| CCSA   | 171.8                       | 97.2                             | 0.138                         | 3.67                   |

##### 3.6.2 Proximate and elemental analysis

Table 5 shows the results of moisture content, volatile content, fixed carbon and ash content. Moisture and volatile matter concentrate the precursors, chilli stalks. Volatile content indicates the combustible non-carbon components that is released due to heating at elevated temperature [21]. High volatile content defines the material to be highly combustible and vice versa. After carbonization at 400 °C, the moisture and volatile content were decreased whereas the fixed carbon content increased. Organic substances became unstable due to the heat applied during carbonization, causing the bonds and linkages of molecules to break [17]. Owing to the pyrolytic effect, the degradation and discharge of organic substances into gas and liquid tar left the material with high carbon purity [22]. The small amount of ash content in both precursors and carbonized CS indicates the suitability of chilli stalks as the adsorbents.

Table 5 also lists the elemental contents in both chilli stalk and CCSA. The elemental carbon and nitrogen contents increased and accompanied by the decreased of elemental H content. The
carbonization temperature was responsible for the increment in the elemental carbon content. Due to the carbonization process, the hydrogen content reduced with the rupture of organic molecular chains [22].

**Table 5.** Proximate and elemental analysis of the samples.

| Sample | Proximate analysis (%) | Elemental analysis (%) |
|--------|------------------------|------------------------|
|        | Moisture | Volatile | Fixed Carbon | Ash | C   | H   | S   | (N+O)* |
| CS     | 21.6     | 65.8     | 11.2         | 1.4 | 41.6 | 4.2  | 0.1 | 54.1   |
| CCSA   | 14.2     | 16.1     | 68.6         | 1.1 | 71.5 | 2.1  | 0.1 | 26.3   |

*Estimated by difference

3.6.3 Surface morphology and chemistry. The SEM images of the CS and CCSA at 400 °C are shown in Figure 8 (a) and (b), respectively. The structural variations in particles are provided by the surface morphology, with the objective to compare the morphological changes in the pore structure between the precursors and the carbonized samples [23]. The precursors were observed to have rough and uneven surface textures. Upon the process of carbonization, the escape of volatile content led to the reduction in pore size, appearance of internal pores and increment of porosity. The irregular holes and pores evolvement on the CCSA surface were also led by the breakdown of lignocellulosic material due to the high carbonization temperature prior to the evaporation of volatile matters [17].

![SEM micrographs of (a) chilli stalk and (b) CCSA (magnification 1000x).](image)

The adsorption bands for CCSA’s FTIR spectrum as shown in Figure 9 indicates the different functional groups available. These spectra disclosed for the further reduction, disappearance or broadening of the peaks upon the application of carbonization temperature [17]. The strong and broad peak at 3414.00 cm\(^{-1}\) for chilli stalk spectra defines the presence of an O-H group (alcohols). In addition, there are peaks at 2555.58 cm\(^{-1}\), 1587.47 and 1568.13 cm\(^{-1}\), 1431.18 cm\(^{-1}\) and 1037.70 cm\(^{-1}\) to reflect the presence of aromatic ring (C=C), O-H group (carboxylic acid) and C-O (ester). In addition, O-H group and C-O group (ester) were also present at 3446.79 cm\(^{-1}\), 1413.82, 1330.88 cm\(^{-1}\)and 1049.28 cm\(^{-1}\), respectively.
4. Conclusion

Chilli stalks have been transformed into an adsorbent by carbonization process. Carbonization temperature of 400 °C has been proven to be effective for the maximum removal of MB dye (97%) at high initial concentration of MB dye (300 mg/L). The experimental data matched best with the Freundlich isotherm model. It is found that the pseudo-second-order kinetic model suits the adsorption data well and the adsorption mechanism was regulated by the film diffusion model. A well-developed porous structure could be observed through SEM image, with the BET surface area, total pore volume and total fixed carbon content of 171.8 m²/g, 0.138 cm³/g 68.6 %, respectively. This study has proven that cheaply available chilli stalk has the potential as the effective precursor for the preparation of CCSA in order to optimally remove the MB dye.

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