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Evaluation of the efficacy of papaya seed-based natural adsorbent for synthetic textile wastewater treatment

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Abstract. This study explored the application of papaya seed-based activated carbon for removing methylene blue dye from synthetic textile effluent. Batch experiments are used in the study to investigate the adsorption potential of activated carbon. The results demonstrate that papaya seeds derived from activated carbon have the greatest potential for methylene blue adsorption, with an average removal effectiveness of 89.4%. The effects of several parameters such as pH, contact time, adsorbent dose, adsorbent-adsorbate temperature, and starting dye amount or concentration were examined to optimize the adsorption conditions. Maximum dye removal was achieved after 60 minutes of contact time at pH 6.5. The carbon dosage and pH of the solution were discovered to have the greatest influence on the adsorption process. Based on the experimental data, the Langmuir and Freundlich models were identified as the most appropriate fits for the adsorption investigation. In conclusion, activated carbon derived from papaya seeds is a viable and natural bio-adsorbent for removing methylene blue from synthetic textile wastewater.

1 Introduction

Natural water conservation is crucial due to increasing human population, farming changes, and environmental pressures [1]. This leads to water asset reduction and pollution of natural resources, with businesses producing dyed wastewater [2]. Dyeing wastewater harms humans and the environment, necessitating eco-friendly and efficient wastewater treatment systems [3]. Textile manufacturing uses significant amounts of dyes and chemicals, including cleaners, acids, salts, and colors which aggravates the situation leading to a harmful concoction of the ingredients in the wastewater [4]. Manufacturing processes involve

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extensive water usage for cleaning, washing, and coloring, resulting in wastewater containing hazardous and toxic substances [5]. The Environmental (Protection) Rules of 1986 state that the maximum limits for various pollution parameters that are notified for textile mills are as follows: pH-6.5 to 8.5; Suspended Solids (TSS)-100 mg/l; Color (PCU-Pt-Co Hazen scale)-150; BOD (three days to 270C)- 30mg/l; Oil & Grease-10mg/l; COD-250mg/l; Total Chromium as 'Cr'-2.0; Total Sulphide as 'S'-2.0; Phenolic Compounds as (C_2H_5OH) -1 mg/l; Total Dissolved Solids (TDS)-2100mg/l; Sodium Absorption Ratio (SAR)- 26 Ammoniacal Nitrogen (as N)-50mg/l, Methylene Blue-1(https://scclmines.com/env/Linkfile2.htm) (IS: 2296-1982).

Textile industry wastewater contains toxic dyes, causing cancer and preventing sunlight penetration for photosynthesis, posing a threat to humans and aquatic life and also promulgating the increase of the nutrients in the wastewater leading to algal growth in waterways [6]. The use of methylene blue dye in textile industries is crucial for environmental protection due to its long history as a coloring agent for fiber [7]. Methylene blue, a chemical structure (Figure 1) used in various applications, can be toxic when ingested with water or absorbed through the skin in large amounts.

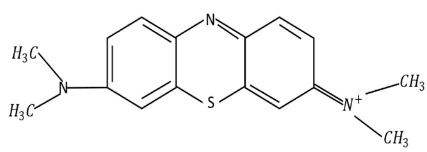

Fig. 1. Chemical structure of Methylene Blue.

The methods used include biological techniques, advanced oxidation processes (AOP), coagulation-flocculation processes, ion exchange, and adsorption [8]. The phenomenon of a substance's molecules being attracted to and retained by a liquid or solid's surface, resulting in hazardous sludge, has been designated as scheduled waste [9]. Different types of plants and agricultural wastes are abundantly available in the natural environment [10]. In the adsorption process, different agricultural wastes such as banana peel, corncob, jojoba seed, and vertebrate living animals have been used by many researchers [11]. Papaya, a globally recognized fruit primarily found in tropical or subtropical climates, experienced a significant international trade worth $200 million in 2009 [12]. Consumption of papaya fruits contributes to a significant volume of food waste, notably the disposal of papaya peels and seeds, which collectively represent 15-20% of the fruit's total weight [13].

2 Materials and method

2.1 Preparation of materials

For the purpose of preparation of the adsorbent, *Carica papaya* seed (CPS) fruit was collected from nearby fruit markets and shops in Rajkot, Gujarat.

The papaya fruit is washed multiple times with tap water, then dissected and separated into seeds. The seeds are dried in an oven at 105^0C for an hour and treated with phosphoric acid. The seeds are then ground and weighed. The powder is ignited in a muffle furnace at 300^0C for a maximum of 1.5 hours. The charcoal is then washed with water to remove the acid. Papaya seed powder's porous structure effectively adsorbs impurities, while synthetic wastewater simulates Methylene blue dye-containing characteristics. Carbon was kept at ambient temperature for study.

2.2 Batch adsorption experiment

The research study utilizes activated carbon made from *Carica papaya* (CP) seeds as an adsorbent in the investigation of methylene blue adsorption from synthetic textile wastewater. It was carried out using different parameters for the operation of adsorption. The examination of methylene blue's adsorption onto activated carbon of papaya seed encompassed a range of experimental conditions, incorporating initial methylene blue concentrations of 40–200 mg/l, initial pH solutions of 3.0–11.0, and quantities of 0.4–2.4 g/l, respectively.

In an experiment, activated carbon from papaya seeds and methylene blue solution were added to a 200 mL Erlenmeyer flask and shaken until equilibrium was reached [14]. various effects of parameters were analysed and studied while finding the adsorption potential of the adsorbent. Adsorbent dose, adsorbate concentration, pH, adsorbent-adsorbate temperature, contact time, and adsorption rate are only a few of the variables that have a substantial impact on the performance and behaviour of adsorbents and adsorbates [15]. The dye removal in percentage, methylene blue adsorbed at equilibrium and at a time t (min), was calculated by using Equation 1.

$$\text{Percentage dye removal} = (C_0 - Cf/ C_0) * 100\% \quad (1)$$

The quantity of dye adsorption at equilibrium (Q) is calculated using Equation 2.

$$qe = (C_0 - Cf/W) * V \quad (2)$$

The quantity of dye adsorbed at equilibrium (q_t) is calculated using the Equation 3

$$qe = (Ce - Ct/W) * V \quad (3)$$

Where; $C0$ = concentration of dye before treatment; Cf= the concentration of dye after treatment; Ct = concentration of dye at time t (mg); W = weight of adsorbent in grams. qt & qe In (mg/g) is the adsorbed methylene blue amount per carbon dosage at time t and equilibrium time, respectively; $V(l)$, the quantity of methylene blue solution used.

3 Results and discussion

3.1. Isotherm studies

Adsorption isotherms, such as Langmuir and Freundlich, are widely used to understand interactions between adsorbent and adsorbate at liquid and solid surfaces. The Langmuir model suggests monolayer adsorption, while the Freundlich model characterizes multilayer adsorption on heterogeneous surfaces [15]. These models are used to simulate equilibrium values for methylene blue on papaya seed carbon. The Langmuir isotherm was used to estimate molecule adsorption on a solid surface, considering fixed accessible sites, reversible adsorption, one-time adsorption, and no interaction between adsorbates [16]. The Equations 4 and 5 show the Langmuir isotherm:

$$Ce/qe=1/KlQmax+Ce/Qmax \quad (4)$$
$$Rl=1/(1+KaCo) \quad (5)$$

Where;Ce (mg L−1) = the adsorbate concentration at equilibrium; qe (mg g−1) = the amount of adsorbate, that is absorbed; Q max (mg/g) = related to maximum adsorption capacity; Rl (l/mg).

Table 1 shows that the value of the Langmuir constant is Ka, and the greatest initial adsorbate concentration is C_0. The isotherm's form is either irreversible or favorable, determined by the value of Rl. Methylene blue adsorption onto papaya seed-based activated carbon is favorable, with an Rl value of 0.413. The linearized Freundlich isotherm form was used to investigate equilibrium data, with excellent linearity demonstrated by an R2 value of 0.9927 (Figure 2).

Table 1. Isotherm parameter for adsorption utilizing activated carbon from papaya seeds.

Isotherm		Parameters	Values
Freundlich		n	2.6413
		Kf	3.5267
		$R2$	0.9073
Langmuir		qm (mg/g)	135
		Kl (L/mg)	0.0109
		$R2$	0.9927

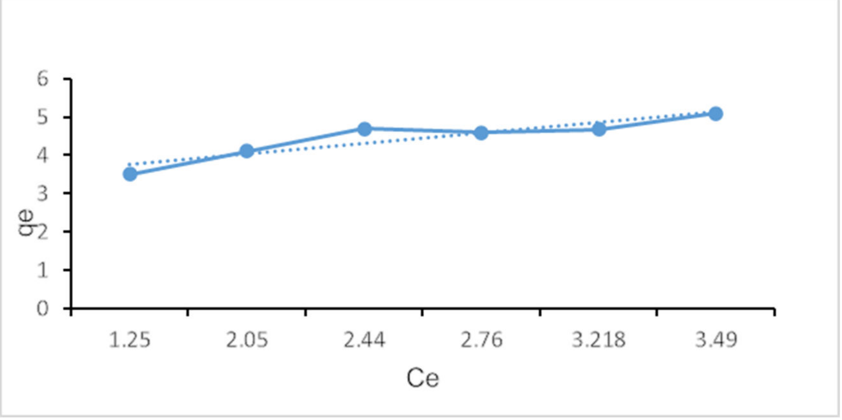

Fig. 2. Freundlich isotherm model.

In (Figure 3), the linear plot of 1/qe versus 1/Ce shows the adsorption process following the Langmuir model. The Langmuir constants qm and Ka are calculated from the graph's slope and intercept. A high correlation coefficient (R^2 = 0.9927) indicates a good fit, and the dimensionless separation factor Rl (Equation 6) characterizes the Langmuir isotherm.

$$Rl = 1/1+KaCo \tag{6}$$

The Langmuir constant is Ka, with the maximum initial adsorbate concentration being C_0. The isotherm's form can be irréversible, advantageous, linear, or unfavorable.

The Freundlich isotherm is an empirical formula for nonideal sorption, represented by heterogeneous sorption, as illustrated by Equation 7.

$$In\ qe = InKF + 1/n * In\ Ce \tag{7}$$

The equation qe represents the adsorbate's equilibrium amount, Ce represents its concentration, KF is the Freundlich adsorption constant, and n indicates its adsorption intensity and heterogeneity.

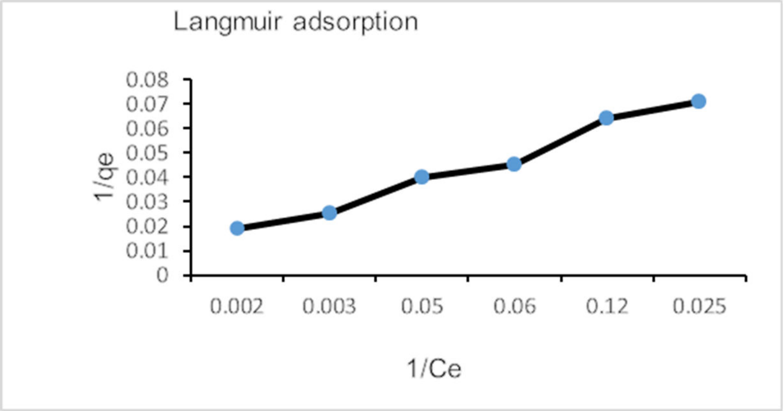

Fig. 3. The Langmuir isotherm model.

3.2. Effect of dosage and carbonation time

The study reveals that higher carbonization temperatures increase the removal capacity of methylene blue dye, reaching 92.1% at 70 minutes and slightly decreasing to around 90.0% at 80 minutes. Papaya seed carbons can be produced at low activation temperatures, but their adsorption effectiveness is unsatisfactory [17]. The carbon removal effectiveness in papaya seed improved from 42.5% to 92.1% after elongating the burning process from 20 to 90 minutes, with slightly reduced performance for longer periods (Figure 4a, 4b).

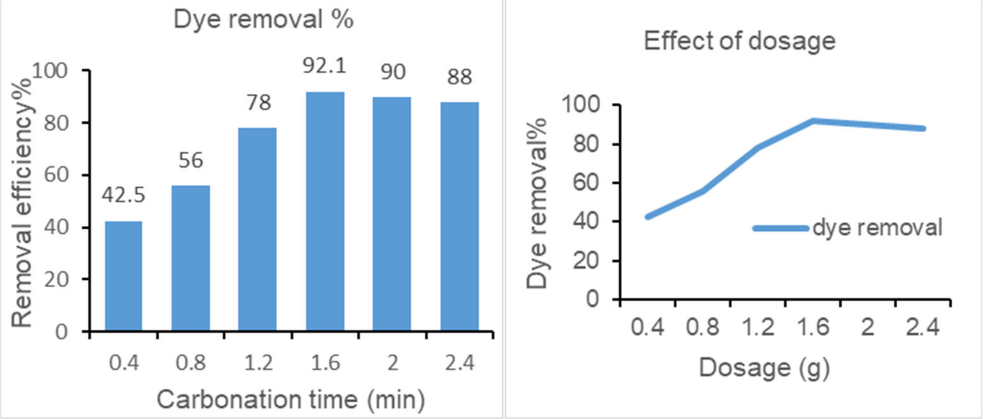

Fig. 4. (a) Carbonation time and **(b)** dosage on removal efficiency.

The study investigated the adsorption of methylene blue dye on papaya seed-based activated carbon. The adsorbent dosage was adjusted for 40 mg/l of dye concentration, and the maximum removal was reached at 1.6 g.

3.3. Effect of pH and contact time

The study reveals that pH significantly affects the adsorption of Methylene Blue from synthetic dye wastewater, with a maximum of 78.4% adsorption achieved at pH 6.5. This is due to the electrostatic interaction between papaya seed-activated carbon and dye. The study also found that the time of contact increased the adsorption capacity of the activated carbon, resulting in a maximum of 98.8% dye uptake in 90 minutes (Figure 5a, 5b).

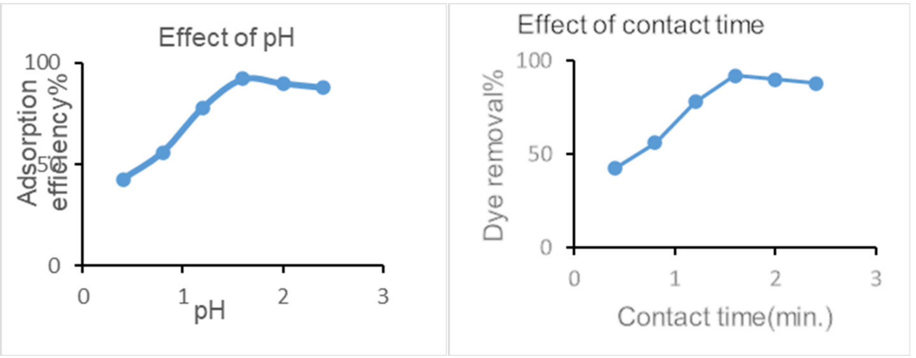

Fig. 5. (a) The effect of pH, and **(b)** contact time on adsorption of methylene blue dye.

4. Conclusion and future scope

The study investigated the potential use of papaya seeds as a natural adsorbent in conjunction with activated carbon to remove methylene blue from synthetic textile wastewater. The findings indicated that activated carbon demonstrated significant efficiency, achieving an 87.2% removal rate. The research suggests that activated carbon derived from papaya is an economical solution for the treatment of textile wastewater. Furthermore, it recommends exploring comparative studies between papaya seed-activated carbon and other adsorbents for future research.

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