Methylene Blue Removal Using Chitosan Encapsulated Strychnos Potatorum (Igini) Seeds Activated Carbon: Isotherm and Kinetic Study

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1 Introduction

The need for effective, sustainable, and economically viable water purification technologies has become a curious topic. Methylene Blue (MB) is commonly used in industries such as textile rubber, plastics, paper and etc. The effluents of these industries contain dye residues and can result in several issues such as increase in toxicity [1]. *Strychnos potatorum* is also known as the clearing nut tree, due to the purification ability of its seeds on water. The presence of –COOH and free –OH surface groups in these seeds is the main factor responsible for this purification ability. Furthermore, the nontoxicity of these seeds is crucial for their use as a water purification agent [2]. However, the adsorption abilities of the activated carbons derived from *Strychnos potatorum* seeds are higher than those of the seeds themselves, seed powder, and charcoal of *Strychnos potatorum*, owing to their high porosity [3]. Utilizing activated carbons directly for water purification leads to increased filtration expenses because it induces the formation of cloudy solutions [4]. Therefore, encapsulation techniques enable the creation of composite particles, often featuring a core material surrounded by a secondary material [5]. Chitosan, the deacetylated product of chitin, is abundantly found in nature. As a biopolymer, it possesses biodegradable, eco-friendly, and non-toxic properties. Its molecular structure comprises D-glucosamine (GlcN) and N-acetyl-D-glucosamine (GlcNac), connected by β-(1,4)-glycosidic bonds [6]. Recently, chitosan has found application as a wall material for encapsulating core ingredients. The activated carbon of *Strychnos potatorum* seeds have been encapsulated in chitosan. The SEM and FTIR analysis prove the adsorption capacities of the novel material due to availability of functional groups responsible for adsorption and high nano porosity [4]. Therefore, this study aims to study the Methylene Blue removal efficiency of novel encapsulated *Strychnos Potatorum* (Igini) seeds activated carbon and investigate the isotherm and kinetics mechanisms of the adsorption.

2 Methodology

2.1 Preparation of Chitosan Encapsulated *Strychnos Potatorum* (Igini) Seeds Activated Carbon

The dried *Strychnos potatorum* seeds (SPS) were subjected to heating at 300°C for 45 minutes in a muffle furnace. A chemical activating agent, sulfuric acid (H_2SO4), was then incorporated into the carbonized material and thoroughly mixed. The resulting dried activated carbon from *Strychnos potatorum* was crushed and sieved using a 250 µm sieve.

For the preparation of activated chitosan-encapsulated *Strychnos Potatorum* (Igini) Seeds Activated Carbon, a quantity of 0.75 g of chitosan powder was mixed with 10 ml of 0.1 M acetic acid in a 1 dm^3 solution, to which 0.25 g of activated carbon was added and thoroughly dispersed. The mixture was vigorously shaken for 5 minutes in a shaker. The resultant suspension was injected via a 3 mm injector into 50 ml of 3 M NaOH. Deionized water was used to wash the beads until a neutral solution was reached. The beads were then dried at 50°C for 24 hours and stored for further studies.

2.2 Batch Experiments for MB Removal

In this study, batch adsorption experiments were carried out by shaking 5 g/L of adsorbent in 200 mg/L of MB solution mixture of pH 8.5 on a shaking incubator at 200 rpm for 2.5 hours at room temperature (30±1°C). The effect of contact time (30 –240 min), initial concentration (50 – 40 mg/L) and adsorbent dosage (2–10 g/L) were investigated in this study. The MB concentrations were analyzed using UV-Spectrophotometer at 663 nm. All experiments were carried out in duplicate, and the average value was taken for data analysis.

2.3 Isotherm and Kinetic Experiments

Isotherm and kinetics experiments were carried out using 5 g/L of adsorbent in MB solution at pH 8.5 by shaking at 200 rpm in room temperature (30±1°C). The kinetic study was carried out at time intervals of 30, 60, 90, 120, 150, 180 and 240 min, and the MB concentration was 200 mg/L. Furthermore, in the isotherm experiments, the concentration range for MB was 50–400 mg/L and the equilibrium time was 150 min.

3 Results and Discussion

3.1 Characterization of the Adsorbent

The characterization of the chitosan encapsulated *Strychnos Potatorum* (Igini) seeds activated carbon was done in our previous study. FTIR analysis reveals the presence of various functional groups responsible for adsorption. Moreover, novel encapsulated activated carbons feature nanoporous surfaces with dense porosity. These nanoporous surfaces act as barriers, preventing the activated carbons from escaping while enabling the adsorption of small ions or molecules onto their surfaces. Consequently, this encapsulation method offers a solution to filtration challenges.

3.2 Effect of Contact Time, Concentration and Adsorbent Dosage

It was observed that the adsorption of MB has intensified with prolonged contact time. Moreover, the adsorption reached equilibrium within 2.5 hours. However, extending the contact time of 2.5 hours did not notably enhance the removal of MB from the solution and the adsorption rate has decreased over time. The quantity of unoccupied surface sites within an adsorbent is constant. The rate of adsorption decreases as active sites become scarce during the adsorption [3],[6].

The impact of initial concentrations of MB on removal efficiency was examined while maintaining a constant adsorbent dosage of 5 g/L. Variations in the adsorption capacity (q_e) was observed with different initial concentrations of MB. Notably, the adsorption capacity for MB increased with higher initial concentrations. This study explored initial concentrations up to 400 mg/L of MB, beyond which the adsorption capacity of the prepared adsorbents did not reach a constant value.

Different adsorbent dosages ranging from 2 g/L to 10 g/L were examined while maintaining constant concentrations of MB. Results indicate a progressive increase in adsorption percentage with higher dosages of the adsorbent, owing to the heightened availability of active sites [7]. Optimal removal rates for all parameters were observed at a dosage of 5 g/L. Beyond this threshold, the removal of MB reached a constant value, likely due to the diminishing concentration gradients between the solution and the adsorbent surface [8].

Furthermore, the MB adsorption capacity of the prepared novel adsorbent is 39.06 mg/g at optimized conditions.

3.3 Isotherms and Kinetics of MB on Adsorbent

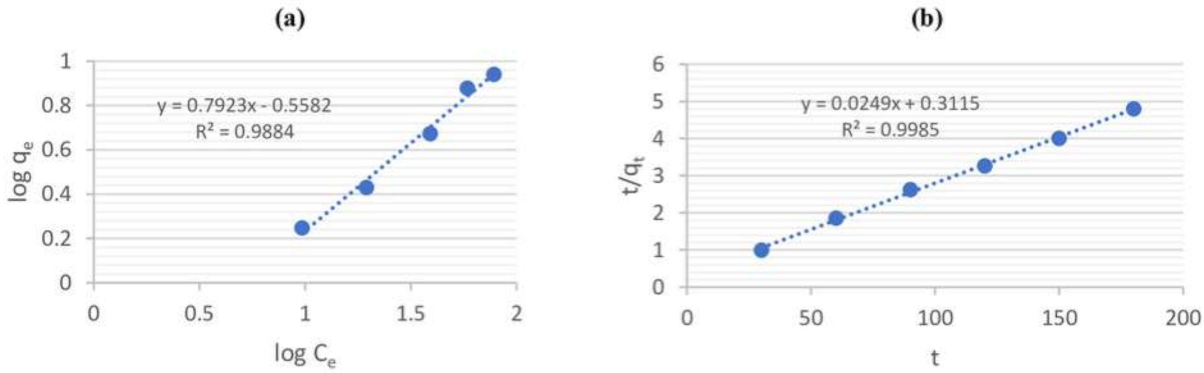

Fig. 1: (a) Freundlich adsorption isotherm for the MB adsorption onto the adsorbent (b) Pseudo-second-order kinetic model for the MB adsorption onto the adsorbent

The obtained results were well fitted to the Freundlich isotherm model with $R^2 = 0.9884$ (Fig 1). Freundlich isotherm model describes multilayer adsorption, over a heterogeneous surface [3]. Freundlich isotherm constant (1/n) for the adsorbent is less than 1 (0.7923) and that indicates that the adsorption process is favorable under the experimental conditions. Moreover, data were best fitted with a pseudo-second-order model ($R^2 = 0.9985$) and the adsorption of MB onto the adsorbent followed the pseudo-second-order kinetic model.

Conclusion

This study revealed that novel chitosan encapsulated *Strychnos Potatorum* (Igini) seeds activated carbon exhibits efficient removal capabilities for MB. Removal efficacy was influenced by contact time, adsorbate concentration, and adsorbent dosage. The adsorbent achieved adsorption equilibrium within 150 minutes. Moreover, the adsorption data exhibited good fitting to the Freundlich isotherm and the pseudo-second-order kinetic models, suggesting that adsorption occurred on heterogeneous and amorphous surfaces rather than being restricted to monolayer adsorption. Since the value of $1/n$ (0.7923) is less than one, the adsorption process can be deemed favorable. This adsorbent provides a solution to the drawbacks associated with the direct use of activated carbon for water purification. According to the FTIR analysis of the adsorbent, various functional groups that are potentially responsible for the adsorption are identified. Furthermore, SEM analysis of this novel adsorbent suggests the practical ability to use it as an effective adsorbent. And also, this effective adsorbent can be further tested to investigate the removal efficiencies of other pollutants.

Keywords: *Strychnos potatorum* Seeds, Chitosan, Encapsulation, Methylene Blue, Water Treatment

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