



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

IJRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 12, Issue 10, October 2023

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 8.423

9940 572 462

6381 907 438

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Experimental Investigation of Wastewater Treatment via Sugarcane Bagasse Pulp

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ABSTRACT: Textile wastewater effluents yield tons of dyes that are toxic and need to be removed before the water is discharge into the aquatic life. Methylene blue has a low degradation rate and causes severe harmful effect to the environment. Adsorption is an effective method of getting rid of these dyes. In this study sugarcane bagasse pulp, which is a waste resulting from the sugar extraction process, is examined as an adsorbent for the removal of methylene blue from textile wastewater. The experiments are carried out to determine the efficiency of the adsorption of methylene blue . Seven different parameters including the adsorbent dose, temperature, initial dye concentration, contact time, pH, and adsorbent particle size are studied to determine their effect on the adsorption process; characterization of the adsorbent is also carried out. Artificial neural network is used to determine the optimum conditions that give maximum efficiency. The results of this study showed that bagasse pulp is an effective adsorbent material for methylene blue removal with a maximum adsorption efficiency of 90%.

KEYWORDS: Adsorption, Agricultural waste, Artificial neural network, characterization, Methylene blue, Sugarcane bagasse pulp, Waste water treatment.

I. INTRODUCTION

A large quantity of industrial waste is released into aqua systems without treatment, creating major issues that seriously threaten both the environment and human health.

Methylene Blue dye (MB) is one of the dyes that are discharged in aqueous systems (Turhan et al. 2012). This dye is a water-soluble azo dye that has a very deep colour and low degradation rate. The most common wastewater treatments are using physical, biological, and chemical methods. Usually, photocatalysis, ion exchange, synthetic membrane separation, advanced oxidation processes and adsorption are highly efficient methods for treating wastewater. Adsorption offers benefits over other technologies because of its simple design and potential for minimal initial investment and land requirements. However, the selection of an appropriate adsorbent is a remarkable challenge, whereas the model adsorbent should have various features involving large surface area, high adsorption capacity, cost- effectiveness, eco-friendly, recyclability, and high selectivity for dye pollutants .

Agricultural wastes are promising raw materials for adsorbents in wastewater treatment. These wastes contain valuable components such as cellulose, protein, tannin, lignin, resin, and other available compounds that could be used in diverse beneficial wastewater treatment applications.. Moreover, they increase at a rate of 5% to 10% every year and represent a remarkable source of environmental pollution since their safe disposal is very expensive, and they are commonly burned to be disposed of releasing harmful gases to the environment. As a result, using them as a raw material for adsorbents won't only valorize these wastes but also avoid the consequences of their disposal.

Our study examines the sugarcane bagasse pulp efficiency as an adsorbent for MB removal. Its functional groups and surface morphology are characterized. Parameters including adsorbent dose, temperature, contact time, pH, initial dye concentration, shaking speed, and particle size effect on adsorption are examined. Artificial neural network (ANN) modelling has received a lot of attention in recent years from researchers looking to resolve environmental challenges because of its capability in capturing the nonlinear patterns in the data (Husien et al. 2022). It can be applied to resolve issues for which traditional statistical techniques are ineffective. Using ANN is the primary goal of this work to assess the effectiveness of sugarcane bagasse pulp in removing MB by adsorption process.

II. MATERIAL AND METHODS

Sugarcane cane bagasse pulp is purchased from a sugar company. MB with an empirical formula of $C_{16}H_{18}ClN_3S_3H_2O$, a molecular mass of 373.8 g mol^{-1} , and a pure grade of 98.5% is used in the adsorption process. NaOH (98%) and HCl (37%) are used in adjusting the pH of the solution. All required chemicals are purchased. A 500 mg/L stock solution of MB is prepared by dissolving 0.5 g of MB in 1000 ml distilled water in a volumetric flask. MB solutions of different concentrations of 25,50,100 and 200 mg/L are prepared by serial dilution from a stock solution according to the following equation.

$$C_o \times V_o = C_d \times V_d$$

Where, C_o is the stock solution's concentration, V_o is the volume of stock solution being diluted, C_d is the dilute solution's concentration, and V_d is the volume of the dilute solution. After each experiment, the dye solution is filtered by using Whatman (number 541) filter paper and the filtrate is then analyzed to get the MB concentration after adsorption. The concentration of MB in the filtrate is determined by using a dual-beam UV-Visible spectrophotometer (Shimadzu Brand UV-3000) where the absorbance of MB is measured at 665 nm. All determinations are performed in a total of three replicates per experiment, and the average values are reported. The removal efficiency is then calculated by using the following equation.

$$\text{Removal efficiency(\%)} = (2) (C_o - C_e) / C_o \times 100$$

Where, C_o is the initial concentration (mg/L) and C_e is the residual concentration (mg/L) of the MB being studied.

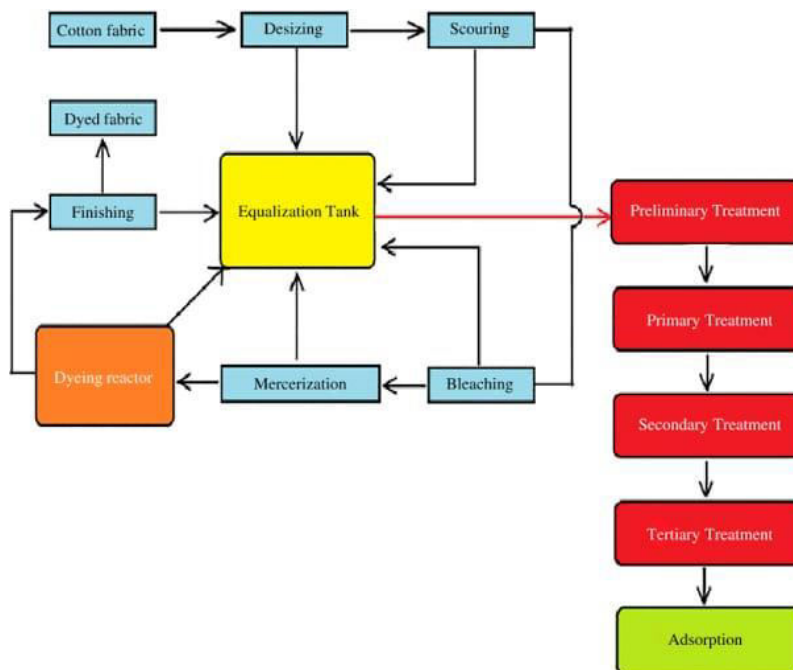


Fig 1 Treatment process

III. CHARACTERIZATION TECHNIQUES

- **Fourier transformation infra radiation FTIR**

FTIR is carried on the sugarcane bagasse pulp powder to determine the functional groups and chemical bonds present. Attenuated total reflectance (ATR) mid-infrared spectra are acquired using a Tensor 27 (Bruker Optics). The spectrometer is equipped with A deuterated triglycine sulphate (DTGS) detector and a heated single reflectance diamond ATR accessory (Grase by Specac) with a sealed sapphire anvil. Spectra with 128 scans at 4 cm⁻¹ resolution are selected for both samples at room temperature. The spectra are vector normalized over the entire wavelength range of 400–40 cm⁻¹.

- **X-ray diffraction XRD**

XRD is utilized to determine and analyze the degree of crystallinity and physical properties of bagasse pulp powder. The spectra of the samples are collected using a Siemens D500 X-ray diffractometer using Cu k-alpha X-rays at 4 kV and 25 mA.

- **SEM scanning electron microscopy**

SEM is used to study the morphological properties, homogeneity, and voids present in the bagasse powder. The Small particles of bagasse pulp are glued into a holder using Tissue Tek O.C.T compound and brought down to solid nitrogen temperature under vacuum, and then, they are fractured by a blade from the side brought up to 90 °C and platinum-coated and then imaged.

- **Adsorption study**

A beaker containing 50 mL of MB solution is used in the experiments. The effect of adsorbent dose, temperature, initial concentration, contact time, shaking speed, pH, and particle size is examined. The experimental procedures start with a temperature equal to 25 °C, at pH equal to 7, adsorbent dose equal to 20 g/L, initial dye concentration equal to 100 mg/L, at a shaking speed of 130 rpm, adsorbent particle size equal to 500 µm and take place as follows.

- **Examining the effect of pH**

The effect of pH is studied by performing the experiments at H 4,7,9,10,12 while keeping all the other parameters constant. The pH is adjusted by using an HCl (chloride acid) purity of 37% (0.1 M) and NaOH (sodium hydroxide) purity of 98% (0.1 M).

- **Examining effect of adsorbent dose**

MB solution is divided into 6 beakers. Each beaker contains 50 ml of MB prepared solution. Different doses of sugarcane bagasse pulp adsorbent are added as follows (4, 8, 10, 20, 30, 40) g/L. The optimum adsorbent dose is chosen for continuing the study.

- **Examining the effect of dye initial concentration**

Five different initial concentrations of MB are prepared by dissolving 25, 50, 100, 200, and 300 mg of dye solution in a 1000-mL beaker keeping all the other parameters constant at their initial values, dose, pH, and temperature at their optimum values.

- **Examining the effect of contact time**

The chosen dose of sugarcane bagasse pulp is added to the solution prepared at the optimum initial concentration to experience different contact times (15, 30, 60, 120, and 180) minutes. The experiments are carried out at the chosen dose, temperature, and pH. Particle size=500 µm and shaking speed equals 130 rpm.

- **Examining the effect of shaking speed**

Different shaking speeds (80, 100, 130, 200, and 300) rpm are examined while keeping all the other parameters constant at their optimum values.

- **Examining the effect of particle size**

Finally, the effect of adsorbent particle size is investigated at (200, 500, and 1000 (µm)), where all the other factors remain constant as shown at their optimum conditions.

I. RESULT

Parameters effect

- **Effect of temperature**

The temperature directly affects the rate of adsorption. The results show an increase in efficiency as the temperature rises from 25 to 60 °C. This is contributed to the fact that as the temperature increases, the rate of diffusion of the adsorbate

molecules across the external boundary layer and internal pores of adsorbent particles increases. Moreover, an increased number of molecules may obtain sufficient energy to interact with active sites at the surface of the adsorbent. Hence, the amount of dye removal increases. Results show no great difference between the 78% efficiency obtained at 45 °C and the 82.54% efficiency obtained at 60 °C. Since there is no great rise in removal efficiency between 78% and 82.54% at temperatures equal to 45 and 60 °C, respectively, the temperature for continuing the study is chosen to be 45 °C for saving energy.

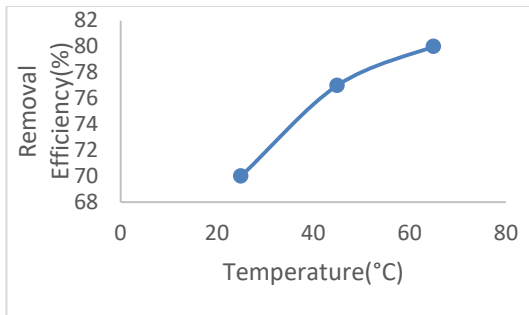


Fig 2 Effect of different temperatures on MB removal Efficiency

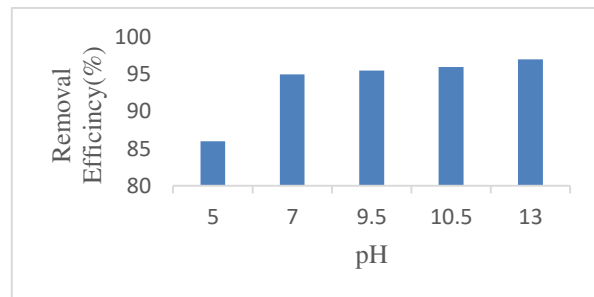


Fig 3 Effect of solution pH on removal efficiency

- **Effect of pH**

pH is an important parameter in the adsorption process, and it affects the adsorption capacity. The degree of its adsorption onto the adsorbent surface is influenced by the surface charge on the adsorbent which in turn is influenced by the solution pH. MB shows a very small adsorption value of 85.52% in an acidic solution at pH 3.0. MB is a cationic dye, which exists in an aqueous solution in form of positively charged ions. At low pH, the number of negatively charged adsorbent sites decreases, and the positively charged surface sites increase which will not favour the adsorption of cationic dyes due to electrostatic repulsion which will occur between the adsorbent surface and the MB ions. On the other hand, the results show increasing the dye removal efficiency with increasing system pH till it reaches 93.85% at pH = 12. The negatively charged adsorbent sites increased, which enhanced the adsorption of positively charged dye cations through electrostatic forces of attraction. Due to the slight difference in the adsorption capacity at pH from 7 to 12.0, pH 7 is used as the optimum pH for continuing the study.

- **Effect of adsorbent dose**

The adsorbent dose has a major role in the dye removal process. Fig 4 shows the effect of the adsorbent dose on the adsorption efficiency. The removal efficiency increases from 42.85 to 95.135% as the adsorbent dose increases from 4 to 40 g/L. The results also show that after reaching the adsorbent dose equal to 20 g/L, an extra increase in adsorbent does not appreciably change MB removal. This is attributed to the fact that the adsorption sites are efficiently saturated at a lower adsorbent dose. To continue the study, the optimum adsorbent dose is chosen to be 20 g/L with an elimination percentage equal to 93.54%. The chosen amount minimizes the consumption of the amount of the dose to half compared to 20 g/L with a percentage of 95.135% close to that of 40 g/L.

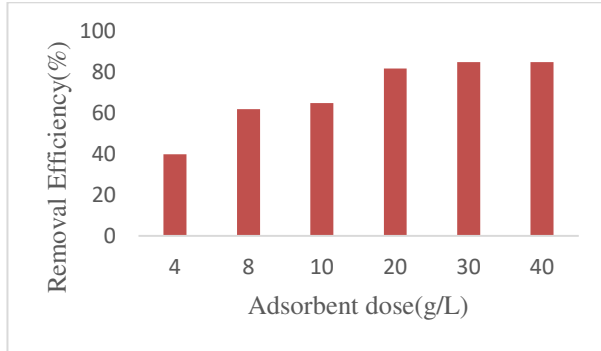


Fig 4 Effect of adsorbent dose on MB removal Efficiency

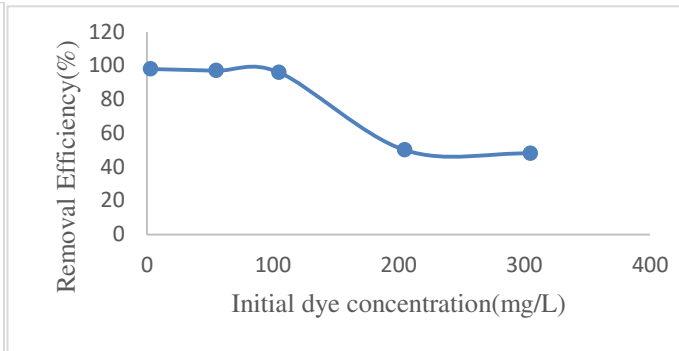


Fig 5 Effect of initial MB concentration on removal efficiency

- **Effect of initial dye concentration**

Choosing the optimum adsorbent dose to be 20 g/L and the temperature of adsorption to be 40 °C, the effect of the initial concentration of MB on the removal efficiency is studied at different initial concentrations, ranging from 25 to 300 mg/L while keeping all the other parameters constant. The percentage of MB removal is high for low initial concentrations and then decreases from 94 to 54% as the initial concentration of the dye increases from 25 to 300 mg/L.

However, as the concentration increases, the total available adsorption sites are limited, which may result in a reduction in the percentage removal of contaminants (Gamoudi and Srasra 2019). For continuing the study, solution with a concentration of 25 mg/L is chosen.

- **Effect of contact time on MB adsorption**

The contact time effect has been studied by varying the contact time from 15 to 180 min while keeping all the other parameters constant. The dye adsorption is rapid at first with a high dye removal efficiency in the first 15 min reaching 94%. The removal efficiency then begins to decrease at a slow rate as the contact time increases from 15 to 180 min reaching a removal efficiency equal to 88%.

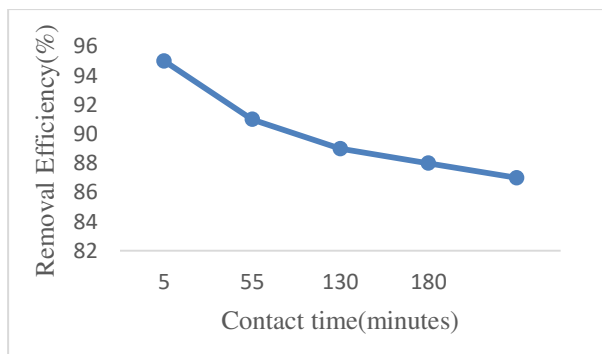


Fig 6 Effect of contact time on MB dye removal efficiency

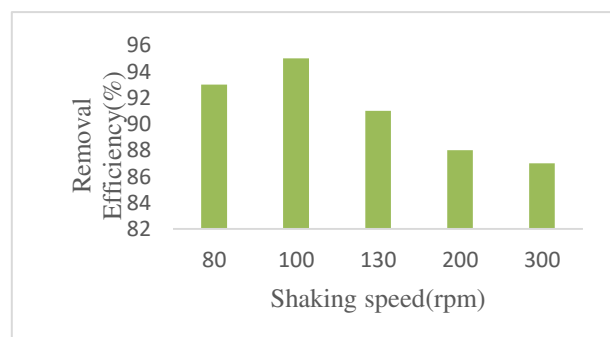


Fig 7 Effect of varying shaking speed on MB removal efficiency

This result is obtained because sugarcane bagasse pulp's active sites are accessible for adsorption during the first 15 min, and afterward, the active sites become gradually occupied reducing the amount being adsorbed, since repulsion action takes place between bulk phases and the sugarcane bagasse pulp adsorbed molecules. The optimum contact time for continuing the study is chosen to be 15 min.

- **Effect of shaking speed**

The study is conducted on a magnetic stirrer. The effect of shaking speed is studied by varying it from 80 to 300 rpm at contact time equals 15 min. The results, shown in Fig 7, indicate that the removal efficiency increases with increasing magnetic stirrer shaking speed. This is contributed to the fact that the increase in shaking speed results in an increase in the kinetic energy of both dyes molecules and adsorbent particles. Therefore, more adsorbent particles get the chance to react with more dye molecules and more bonds are formed. However, a further increase in the shaking speed results in excess kinetic energy than the required one. Therefore, collision starts resulting in breaking the formed bonds and detaching the adsorbed molecules. Thus, the efficiency decreases from 94.73 at 100 to 86.84% at 300 rpm. The optimum shaking speed is chosen to be 100 rpm for continuing the study.

- **Effect of particle size**

The effect of particle size is studied by examining 3 different particle sizes 200, 500, and 1000 μm . The results show that the increase in particle size will increase the removal efficiency to a maximum value, and then, the efficiency will be decreased again with further particle size increase. This is explained by the fact that at very small particle sizes the adsorbent particles will be carried on the surface of the solution. Therefore, a large part of the active sites will be missed, while increasing the particle size over a certain value will result in declining the accessibility of the dye to the adsorbent pores. Therefore, the efficiency decreases again. The optimum particle size is then chosen to be 500 μm .

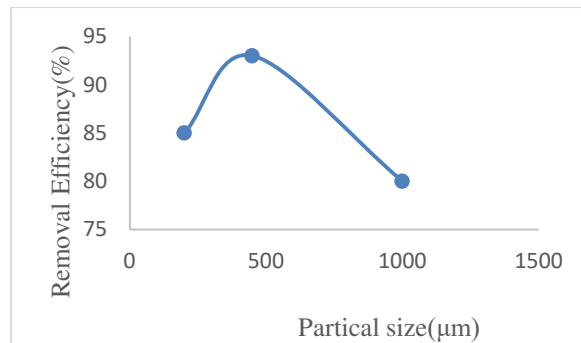


Fig 8 Effect of particle size on MB removal efficiency

IV. CONCLUSION

In this study, sugarcane bagasse pulp is examined as an adsorbent for MB removal, the FTIR analysis of the surface shows the presence of OH, C=O, and CO groups which are responsible for Mb removal, XRD analysis proves its cellulosic structure, while SEM image shows no agglomeration in its fibres.

Removal efficiency of 90% is achieved under these conditions. Therefore, the study findings demonstrate that employing sugarcane bagasse pulp is an effective method for removing dyes from aqueous solutions. Moreover, it is suggested that it can be used to prepare activated carbon physically or chemically for further increase in the removal efficiency with a low amount of adsorbent dose. Parameters affecting the adsorption are studied. As temperature increases, removal efficiency increases showing an optimum temperature value equal to 40 °C. MB adsorption is found to favour the alkaline medium. The removal efficiency increases with increasing the adsorbent dose and reaches saturation at the adsorbent dose equal to 20 g/L. Removal efficiency is found to be decreasing with increasing both contact time and the initial dye concentration.

Table 1 Experimental data for the adsorption by bagasse pulp and ANN results

Adsorbent dose (g/L)	Temperature (°C)	Dye concentration (mg/L)	Time (min)	Shaking Speed (rpm)	pH	Particle size (µm)	Volume (ml)	Experimental %	ANN%
20	25	100	60	130	7	500	50	71.36512	72.3705
20	40	100	60	130	7	500	50	79.04594	78.0463
20	55	100	60	130	7	500	50	80.54258	74.9762
20	40	100	60	130	4	500	50	85.52636	85.6656
20	40	100	60	130	7	500	50	91.22506	93.1548
20	40	100	60	130	9	500	50	91.66668	92.0006
20	40	100	60	130	10	500	50	92.54385	92.3495
20	40	25	60	130	12	500	50	92.85965	93.7585
4	40	100	60	130	7	500	50	75.37512	85.9762
8	40	100	60	130	7	500	50	69.84839	65.7939
10	40	100	60	130	7	500	50	42.89378	46.8589
20	40	100	60	130	7	500	50	93.54548	90.5952
30	40	100	60	130	7	500	50	94.48082	94.5803
40	40	100	60	130	7	500	50	94.13564	95.1522
20	40	25	60	130	7	500	50	94.30088	90.6639
20	40	50	60	130	7	500	50	92.15667	91.9542
20	40	100	60	130	7	500	50	89.77765	91.6052
20	40	200	60	130	7	500	50	56.96266	56.8301
20	40	300	60	130	7	500	50	54.96266	53.9301
20	40	25	60	80	7	500	50	93.65035	98.3062
20	40	25	60	100	7	500	50	94.83684	90.1577
20	40	25	60	130	7	500	50	91.24807	90.7739
20	40	25	60	200	7	500	50	90.03509	98.7819
20	40	25	60	300	7	500	50	88.84211	86.8734
20	40	25	15	100	7	500	50	94.09895	93.1948
20	40	25	30	100	7	500	50	91.65567	92.2903
20	40	25	60	100	7	500	50	90.36088	92.1477
20	40	25	120	100	7	500	50	89.50368	90.3746
20	40	25	180	100	7	500	50	88.56949	88.6001
20	40	25	15	100	7	500	50	94.98543	95.1313
20	40	25	15	100	7	212	50	87.84211	79.8575
20	40	25	15	100	7	1000	50	92.22807	92.2790

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