



Pine needle biochar as a low cost adsorbent for removal of malachite green dye from wastewater

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Pine needle biochar (PNB) has been examined as a promising cost-effective adsorbent using batch method for mitigation of Malachite green (MG) dye from synthetic wastewater. The effects of time of equilibration, equilibrium pH, dye concentration and temperature have been studied on adsorption of malachite green. Adsorption kinetics of MG onto PNB conformed to pseudo-first-order reaction. Adsorption of the dye onto PNB fitted well to Freundlich isotherm model indicating that multilayer adsorption and adsorption capacities (K_F) are the highest (6837.40 mg/kg) at pH 7.0, intermediate (4073.61 mg/kg) at pH 9.0 and minimum (1196.05 mg/kg) at pH 4.6. Adsorption of malachite green regularly increased with increase in temperature. The evaluation of thermodynamic parameters indicate that adsorption of MG onto PNB was a spontaneous and endothermic reaction with increase in the disorderliness of the system. Fourier transformed infra-red spectroscopy (FTIR) studies indicate involvement of H-bonding and electron exchange between aromatic nuclei and electron donor groups onto PNB.

Keywords: Adsorption, Biochar, Buffer, Malachite Green dye, Synthetic wastewater

Introduction

Water is considered as an extremely essential and scarce commodity in all the countries around the world. However, with rapid industrialisation, there has been an increase in the production of different types of chemicals which are both a necessity and an obligation to mankind. Synthetic dyes belong to the group of chemicals which are prepared from organic molecules that give them a specific consistency. Though these dyes provide long-lasting colouring effect, but it is actually at the cost of highly stable and persistent organic structures having inert properties. Dyes are extensively used in textile, leather, paper, food, pigments, plastics, and cosmetic industries to colour the final products. They are perceived to be the most important hazardous material found in textile effluents which need to be removed because they cause many undesirable changes to the ecological system leading to deterioration of both flora and fauna's normal function. This creates a lot of havoc to the ground water resources too^{1,2} as there is reduction in the reoxygenation capacity of the water bodies due to increasing BOD. The colour of dyes also acts as a shield, preventing the penetration of sunlight by reducing the water transparency, thereby reducing the

photosynthetic activity in aquatic organisms and algae³.

Malachite Green (MG) or Brilliant Green (BG) is a cationic triphenyl methane dye which is lustrous green in colour and is used in dyeing wool, silk, jute, leather, cotton, paper and acrylic industries. It is also used as a fungicide, antiparasitic, antibacterial and antiseptic in aquaculture and commercial fish hatchery industries to control fish parasites and diseases⁴. Though, MG is not approved for use on any aquatic species by the U.S. Food and Drug Administration (FDA) or the U.S. Environmental Protection Agency yet it has been routinely used in aquaculture since the early 1930s and is considered by many in the fish industry as the most efficacious agent for combating fungal infections⁵. Most importantly, MG dye has toxic properties which can cause carcinogenesis and mutagenesis⁶. The environmental quality standard limits the concentration of MG in water to 0.5-100 $\mu\text{g/L}$ ⁷. Therefore, in order to meet the current regulations, it becomes extremely crucial to treat the effluent containing this dye prior to discharge, thus, preventing the devastation caused by it. Some methods employed for removal of dyes are typically classified as physical, chemical and

biological treatments⁸. Since synthetic dyes possess high solubility and low biodegradability, so conventional physicochemical techniques are not suitable for synthetic dye removal. However, adsorption of dyes using different adsorbents has proved to be an effective technique for the treatment of synthetic dye wastes^{9,10}. Biochar is one such adsorbent which is a C-rich solid obtained from pyrolysis or carbonization of biomass under limited oxygen conditions^{11,12}. Various degrees of carbonization produce an infinite variety of biochars for use as fuel and adsorbents¹³. Biochar is porous in nature with a very high specific surface area and due to this it possesses excellent adsorbent capability. Biochars have been reported to adsorb hydrocarbons, several different types of organics including dyes and some inorganic metal ions too^{14,15}.

In this study, an attempt has been made to use pine needle biochar, as a novel nonconventional low-cost adsorbent for the removal of MG from synthetic wastewater. The effects of contact time, initial dye concentration, pH and temperature on the adsorption capacity were investigated to optimize the conditions leading to maximum mitigation efficiency. Equilibrium isotherm data were fitted to different equations for determining constants of isotherm equations and different kinetic models were used to analyze the adsorption kinetics.

Experimental Section

Adsorbate

MG dye (adsorbate) was procured from Molychem, India having physicochemical properties and chemical structure as depicted in Table 1. Three stock solutions each of 100 ppm concentration were prepared by dissolving accurately weighed amount of dye in the buffer solutions of pH 4.6, 7.0 and 9.0 in 100 ml volumetric flasks. The working test solutions were prepared by dilution of the stock solution with desired buffers to obtain appropriate concentrations.

All the other reagents used in this work were of analytical grade and highest purity. Double distilled water used throughout the study was prepared in quartz double distillation assembly.

Biochar preparation

Dry pine needle litters were collected and washed five times with tap water to remove dust. Biochar was produced via pyrolyzing biomass at 450°C under limited oxygen conditions. It was washed ten times using double distilled water followed by washing with

10% HCl, then hot water and finally with cold distilled water to remove any residual acid till complete removal of Cl⁻ ion as tested by a negative test (no cloudy appearance) using 1 percent AgNO₃ solution. The pine needle biochar (PNB) was then kept in an electric oven at 75°C for 48 h to remove the moisture content. The dried PNB was finally ground using a mortar and pestle and was stored in air-tight plastic bags for further experimental use. The powdered PNB was characterised for its physicochemical properties (Table 2).

Analytical method

The concentration of MG dye was measured spectrophotometrically using a double beam UV-VIS spectrophotometer (Genesys 10S UV-VIS spectrophotometer, Thermo Fisher Scientific) by plotting calibration curves of different known

Table 1 — Description of Malachite Green (MG) dye

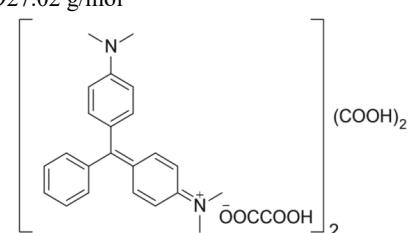
Dye names	Malachite Green, Brilliant Green, Basic Green 4, Victoria Green B, Diamond Green B, Fast Green, Aniline Green
IUPAC Name	[4-[[4-(dimethylamino) phenyl]-phenylmethylidene] cyclohexa-2,5-dien-1-ylidene]-dimethylazanium,2-hydroxy-2-oxoacetate, oxalic acid
CAS Number	2437-29-8
C.I. Number	42000
Molecular Formula	C ₅₂ H ₅₄ N ₄ O ₁₂
Molecular Weight	927.02 g/mol
Molecular Structure	
Melting Point	164°C
Appearance	Dark green, crystalline powder
λ _{max}	618 nm.
Solubility in water	60 g/L
LD ₅₀ (median dose)	80 mg/kg (oral, mouse)

Table 2 — General properties of pine needle biochar (PNB)

Properties	Numerical Value
Carbon (g/kg)	604.6
Hydrogen (g/kg)	37.5
Oxygen (g/kg)	343.4
Nitrogen (g/kg)	15.4
Phosphorus (g/kg)	9.1
pH (1:10)	7.36
Electrical Conductivity (dSm ⁻¹ at 25°C)	128.48

concentrations of MG dye (0-50 mg MG L⁻¹) in buffer solutions of pH 4.6, 7.0 and 9.0 at a wavelength corresponding to the maximum absorption for the dye solution ($\lambda_{\max} = 618$ nm).

Study on kinetics of adsorption of MG dye

Batch equilibrium studies were conducted by taking 0.1g of PNB in each of the sixteen conical flasks and 1 mL of 100 mg MG dye L⁻¹ solution prepared in a buffer solution of pH 7.0. The total volume was made to 10 mL by adding 9 mL buffer solution of pH 7.0. The flasks were then shaken in an incubator shaker for different time intervals viz. 0.25, 0.5, 1, 2, 4, 6, 12 and 24 h at room temperature (25°C) at a speed of 120 rpm in duplicate. The flasks were covered with aluminium foil to avoid the fluctuation of pH due to the exchange of gases during the experiment. After respective duration of shaking time, the flasks were taken out and solutions were centrifuged at 9000 rpm for 15 min. After centrifugation, the supernatant solution was decanted into glass vials (10 ml) by using a funnel. Supernatant was passed through a PTFE (poly tetra fluoro ethylene) membrane filter and the absorbance was measured at 618 nm (λ_{\max}) using a UV-Vis Spectrophotometer. The amount of dye adsorbed by PNB at different time intervals { Q_t (mg/kg)} and the removal efficiency, RE (%), was computed using equation 1 and 2

$$Q_t = \frac{C_i - C_e}{m} \times V \quad \dots(1)$$

$$RE(\%) = \frac{C_i - C_e}{C_i} \times 100 \quad \dots(2)$$

where, C_i is the initial dye concentration (mg L⁻¹), C_e is the equilibrium dye concentration (mg L⁻¹), V is the volume of the solution (mL) and m is the mass of pine biochar (g).

A similar procedure was followed with the two other buffers (pH 4.6 and 9.0) solutions too. It was observed that 12 h shaking time was enough to reach the state of quasi-steady state equilibrium for MG dye adsorption in the presence of buffers of all three pH values.

Study on effect of concentration on adsorption

For the adsorption study, 0.1g PNB was taken in twelve conical flasks and 0, 1.0, 2.0, 3.0, 4.0 and 5 mL solution of MG dye prepared in buffer solution of pH 7.0 were added to conical flasks in duplicate. The total volume was maintained to 10 mL by adding the requisite volume of buffer solution of pH 7.0. The

flasks were covered with aluminium foil and were shaken for 12 h (equilibration time) in the shaker incubator at 120 rpm at a constant temperature of 25°C. After equilibration, the flasks were removed and the suspensions were centrifuged and the concentration of MG dye in the supernatants was determined as described in the preceding section.

Adsorption studies of the MG dye on PNB were also conducted at the above mentioned concentrations in buffer solutions of pH 4.6 and 9.0 too.

Study on effect of temperature on adsorption

For this study, 0.1g PNB was taken in six conical flasks and 1 mL of 100 mg MG dye L⁻¹ solution prepared in buffer solution of pH 4.6, 7.0 and 9.0 was added to them making the total volume to 10 mL by adding 9 mL of respective buffer solution of pH 4.6, 7.0 and 9.0. All the flasks were plugged with aluminium foil and kept in a shaker incubator at 120 rpm for 12 h shaking at 15°C. After equilibration, the flasks were removed, suspensions were centrifuged and the concentration of MG dye in equilibrium solution was determined as described in the preceding section.

Adsorption studies of MG dye on PNB were also performed at 25 and 35°C temperatures following the details mentioned above. The observations on effect of temperature on adsorption of MG dye onto PNB were used to calculate the thermodynamic parameters such as equilibrium constant ($K_c = (Q_e/C_e)$), standard Gibbs free energy change (ΔG°), standard enthalpy change (ΔH°), and standard entropy change (ΔS°). The standard Gibbs free energy change (ΔG°) for adsorption of MG onto PNB was estimated as $\Delta G^\circ = -RT \ln K_c$ where, K_c is equilibrium constant for adsorption, R gas constant, T temperature (K). Standard enthalpy change (ΔH°) and entropy changes (ΔS°) were computed as intercept and slope, respectively from the graphical plots drawn between ΔG° and T (°K).

Fourier Transformed Infra-red spectroscopic analysis

To study the involvement of functional groups on the adsorption of MG dye onto biochar, FTIR analysis of MG dye, untreated PNB (pH 7.0) and MG dye sorbed on PNB (pH 7.0) was done on Bruker FTIR spectrophotometer (alpha model, Germany) in Department of Environmental Science, College of Basic Sciences & Humanities of the University.

Results and Discussion

Determination of Equilibration time

The data on the sorbed amount of MG dye on PNB at different time intervals are presented in Fig. 1.

The adsorption of MG dye onto PNB increased with increase in contact time reaching to the state of quasi-steady state equilibrium at 12 h. After 12 h, there was a negligible increase in adsorbed amount of MG onto PNB so 12 h of equilibration was considered as an optimum time for equilibration in further studies.

Kinetic studies

The kinetics of adsorption describes the uptake rate of adsorbate on the adsorbent. The kinetic parameters are also helpful for the prediction of adsorption rate,

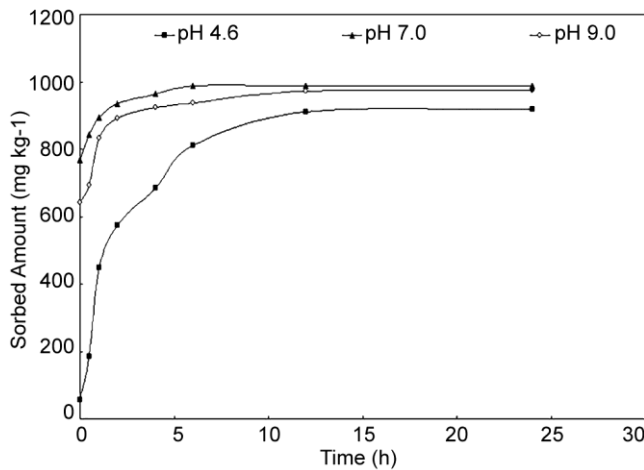


Fig. 1 — Effect of time on adsorption of MG dye onto PNB at different equilibrium pH values

which gives important information for designing the reactor and modelling the processes¹⁶. Therefore, the data on adsorbed amount of MG dye onto PNB at different time intervals were fitted to the following different kinetic equations to know the order of this adsorption reaction.

Zero order $Q_t = Q_0 + k_0 t$... (3)

Pseudo-first order model $\ln(Q_e - Q_t) = \ln Q_e - k_{01} t$... (4)

First order model $\ln Q_t = \ln Q_0 - k_1 t$... (5)

Pseudo-second order model $t/Q_t = (1 / k_{02} Q_e^2) + t/Q_e$... (6)

Second order model $1/Q_t = 1/Q_0 - k_2 t$... (7)

where, Q_0 , Q_t and Q_e indicated the quantity of adsorbate (mg kg^{-1}) at 0, t and equilibrium time in hours, respectively. The constants represented by k_0 , k_{01} , k_1 , k_{02} and k_2 are indicating the rate constants for zero-, pseudo-first-, first-, pseudo-second- and second- order models, respectively. The goodness of data fit to a model was examined by linear coefficient of determination (R^2) and standard error of estimate ($S.E_{\text{est}}$). The constants for the different kinetic models along with the R^2 -values and $S.E_{\text{est}}$ are presented in Table 3.

The data contained in Table 3 explicitly shows that out of all the five models, pseudo-second order model

Table 3 — Values of Kinetic Constants for MG dye sorption on PNB at different equilibrium pH values

Equilibrium pH	Reaction order	Sorbed amount (mg/kg) ± S.E.	Rate constant(k) ± S.E.	R ² value	S.E. _{est.}
4.6	Zero	390.93±105.85	29.44 ± 10.74	0.556*	233.04
	Pseudo-first	835.41±1.09	0.370 ± 0.017	0.990**	55.83
	First	281.97±1.48	0.069 ± 0.040	0.340	361.96
	Pseudo-Second	967.99±30.01	0.837 ± 0.214	0.994**	444.41
	Second	172.41±75.96	29.09x10 ⁻⁵ ± 25.93x10 ⁻⁵	0.173	580.04
7.0	Zero	881.86 ± 30.41	6.29 ± 3.08	0.409	66.94
	Pseudo-first	131.44 ± 1.55	0.403 ± 0.082	0.829**	44.08
	First	878.89 ± 1.04	0.007 ± 0.004	0.390	66.05
	Pseudo-Second	993.76 ± 1.56	10.092 ± 1.689	0.999**	10751.34
	Second	875.73 ± 31.11	7.70x10 ⁻⁶ ± 4.10x10 ⁻⁶	0.371	69.63
9.0	Zero	794.26 ± 46.38	10.28 ± 4.70	0.443	102.12
	Pseudo-first	462.41 ± 1.60	0.565 ± 0.048	0.959**	82.68
	First	786.47 ± 1.06	0.012 ± 0.006	0.409	105.57
	Pseudo-Second	983.69 ± 2.59	4.500 ± 0.562	0.999**	4122.61
	Second	778.49 ± 47.17	1.50x10 ⁻⁵ ± 0.80x10 ⁻⁵	0.378	111.55

*Significant at $p \leq 0.05$

**Significant at $p \leq 0.01$

SE_{est.}: Standard Error of estimate

gave the highest R^2 -values (0.994-0.999; all significant at $p \leq 0.01$) for adsorption kinetic data for all the three equilibrium pH values and also gave the highest value of $S.E._{est.}$ (444.41-10751.34) while the pseudo-first order model yielded significantly higher R^2 -values (0.829-0.990; all significant at $p \leq 0.01$) along with the lowest value of $S.E._{est.}$ (44.08-82.68) for all the three equilibrium pH values. Hence, pseudo-first order model appeared to be more suitable to account adsorption kinetics of MG dye onto PNB at all the three pH values. The best accountability of the pseudo-first-order model suggested that rate of MG dye adsorption was governed by adsorbate concentration only owing to the excess of concentration of sorption sites on the adsorbate. Other investigators have reported the best fit of pseudo-second order kinetics to the adsorption data of MG dye onto rice husk¹⁷ and sulphuric acid treated coffee husk¹⁸ possibly considering the coefficient of determination (R^2 -value) as the only criteria for judging the best fit of sorption data of MG dye on natural sorbents. However, Sartape et al. (2017) noted that the pseudo-first order kinetic model best accounted the sorption of MG dye on wood apple shell¹⁹.

Effect of concentration

The data on adsorption of MG dye onto PNB at varying concentrations are presented in Fig. 2 which clearly depicts that the amount of MG dye adsorbed at equilibrium increased with increasing concentration of MG in equilibrium solution but beyond adsorption density of 3684.5, 3938.5 and 3897.1 mg MG dye kg^{-1} PNB for equilibrium pH 4.6, 7.0 and 9.0, respectively

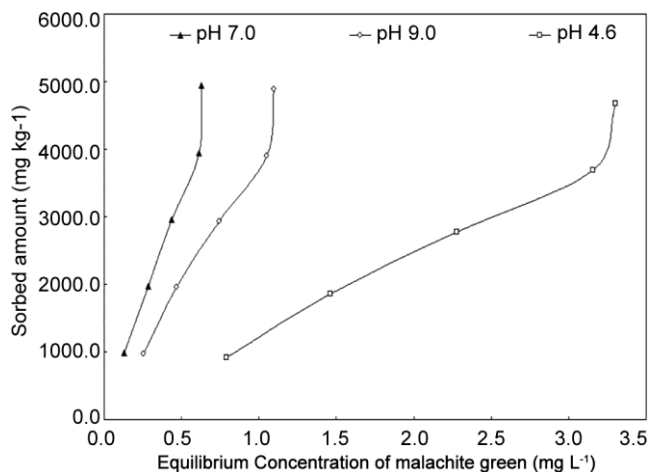


Fig. 2 — Effect of different concentrations on adsorption of MG dye onto PNB at different equilibrium pH values

there was a spectacular increase in adsorption of MG by PNB at all the three equilibrium pH values possibly indicating a transition from adsorption of monomolecular to multi-molecular layer of MG dye onto PNB. At the highest initially taken concentration of MG dye (50 mg MG L^{-1}), the observed adsorption of MG dye onto PNB was 4669.9, 4936.9 and 4890.5 mg MG dye kg^{-1} PNB at equilibrium pH 4.6, 7.0 and 9.0, respectively. According to Srivastava *et al.* (2006) the initial dye concentration provides the necessary driving force to overcome the resistances to the mass transfer of MG dye between the aqueous and solid phases²⁰. Sharma *et al.* (2019) also reported that the variation in MG uptake with changes in initial concentrations and adsorption occurred very fast at lower concentrations of the dye due to high ratio of biochar active site to MG molecules⁴.

The adsorption data of MG were fitted to Langmuir and Freundlich adsorption isotherms using the following linear equations:

$$\text{Langmuir equation: } C_e/x/m = (1/K_L Q_m) + (C_e/Q_m) \quad \dots(8)$$

$$\text{Freundlich equation: } \ln x/m = \ln K_f + 1/n \ln C_e \quad \dots(9)$$

where, C_e is the equilibrium concentration of dye, x = quantity of MG dye adsorbed, m = mass of PNB, K_L = constant related to bonding energy ($L \text{ mg}^{-1}$), Q_m = adsorption maximum (mg kg^{-1}), K_f = adsorption capacity and $1/n$ = intensity of adsorption.

The adsorption data of MG dye onto PNB at different equilibrium pH values did not conform to Langmuir adsorption isotherm as the values of coefficients of determination (R^2) were statistically not significant (0.026-0.191 at $p \leq 0.05$) (the data pertaining to Langmuir adsorption isotherm are not presented here). On the other hand, adsorption data of

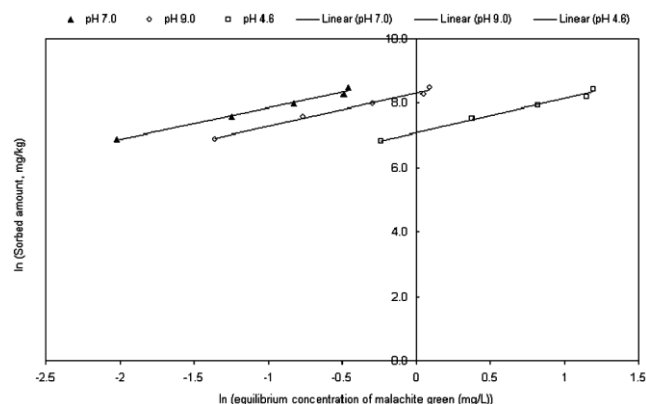


Fig. 3 — Freundlich adsorption isotherms of MG on PNB at different equilibrium pH values

Table 4 — Freundlich adsorption parameters for MG dye sorption onto PNB at different equilibrium pH

Equilibrium pH	$\ln K \pm SE$	$1/n \pm SE$	Coefficient of determination (R^2)	S.E. _{est.}
4.6	7.0868 ± 0.0585	1.0594 ± 0.0688	0.988**	329.25
7.0	8.8302 ± 0.0806	0.9707 ± 0.0693	0.985**	384.32
9.0	8.3123 ± 0.0487	1.0345 ± 0.0684	0.987**	335.30

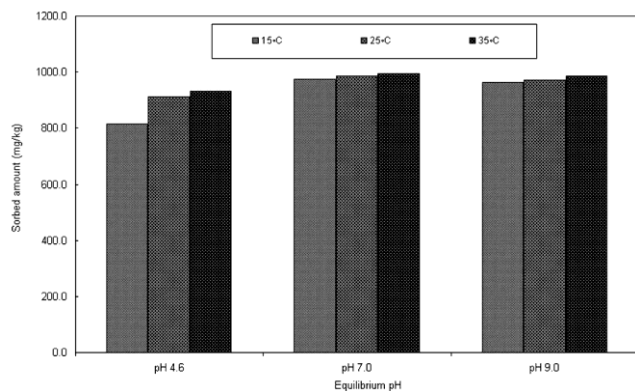
S.E._{est.}: Standard Error of estimate** Significant at $p \leq 0.01$ 

Fig. 4 — Effect of temperature on adsorption of MG dye onto PNB at different equilibrium pH values

MG dye onto PNB at all three equilibrium pH conformed well to Freundlich adsorption isotherm (R^2 values- 0.985-0.988; all significant at $p \leq 0.01$) (Fig.3). The values of Freundlich isotherm constants ($1/n$ and K) and coefficient of determination (R^2) at different pH are shown in Table 4 which clearly indicated that Freundlich adsorption isotherm adequately accounted the adsorption of MG onto PNB. The highest adsorption capacity of MG dye was observed at equilibrium pH 7.0 followed by those at pH 9.0 and 4.6. The values of intensity of adsorption ($1/n$) close to unity indicated the involvement of high energy bonding sites of the adsorbent in the adsorption of MG dye.

Effect of temperature

The data on the adsorption of MG dye by PNB at different temperatures (15, 25 and 35°C) and at different equilibrium pH values are presented in Fig. 4. The extent of adsorption was found to increase with increase in temperature and the increase in adsorption with increasing temperature was quite significant at pH 4.6 followed by pH 7.0 and 9.0, respectively. This difference in the extent of adsorption at varying equilibrium pH values could be attributed to increase in the number of active surface sites available for adsorption onto PNB, which led to increase in the rate of diffusion of the adsorbate molecules across the external

boundary layer and also in the internal pores of the adsorbent particle²¹. Further, this could also be a result of increase in the mobility of MG dye, as temperature increased, because the dye molecules also acquire sufficient kinetic energy for effective collisions with the surface allowing entry within the internal structure of the PNB²². Mittal (2006) reported similar results for the adsorption of MG dye over hen feathers in the temperature range 303 to 323K²³.

The data on equilibrium constant (K_c), standard Gibbs free energy change (ΔG°), standard enthalpy change (ΔH°), and standard entropy change (ΔS°) for adsorption of MG dye onto PNB at different equilibrium pH are presented in Table 5. In general, an increase in temperature increased the value of K_c at all the three equilibrium pH values. The negative values of ΔG° indicated the spontaneous nature of adsorption reaction of MG dye on PNB at all the three equilibrium pH values. A positive value of ΔH° indicated endothermic nature of adsorption reaction while positive values of ΔS° indicated an increase in the disorderliness of the system due to dissociation of ionizing functional groups from PNB and retention of MG dye onto PNB surface. Bello *et al.* (2014) also confirmed the adsorption of MG dye on activated carbon produced from Pomelo peels to be temperature dependent as positive value of ΔH° indicated the endothermic nature of adsorption²⁴.

FTIR analysis

Since the removal of MG was maximum at pH 7, the FTIR analysis of MG dye, PNB before and after adsorption of MG dye at equilibrium pH 7 were conducted. In the FTIR spectra of MG dye, the absorption peak at 1589.21 cm^{-1} corresponded to aromatic C=C stretch while peak at 1383.99 cm^{-1} could be attributed to aromatic C-C stretching and peaks at 1311.97 and 1086.49 cm^{-1} were due to C-N vibrations. The FTIR spectra of untreated PNB showed absorption peaks at 3465.18 cm^{-1} due to intermolecular H-bonding in PNB while peak 1647.49 cm^{-1} could be assigned to carbonyl stretching

Table 5 — Equilibrium constant and thermodynamic constants for adsorption of MG dye onto PNB

Equilibrium pH	Temp. (°K)	Equilibrium Constant (K_c)	ΔG° (kJ mole ⁻¹)	ΔH° (kJ mole ⁻¹ K ⁻¹)	ΔS° (J mole ⁻¹ K ⁻¹)
4.60	288	444.6	-14.60	41.85	196.80
	298	1046.1	-17.23		
	308	1391.1	-18.53		
7.00	288	3690.1	-19.67	69.23	307.90
	298	7480.3	-22.10		
	308	23978.6	-25.83		
9.00	288	2592.7	-18.82	36.09	190.20
	298	3638.8	-20.32		
	308	6873.7	-22.63		

in aromatic amides while doublet at 1602.35 and 1424.98 cm⁻¹ were due to carboxylate anion stretch. The features at 1385.33, and 1309.71 cm⁻¹ could be assigned to, C-H bending and O-H bending, respectively. A sharp peak at 1079.48 cm⁻¹ could be also related to O-H bending of alcoholic-OH groups. A comparison of the FTIR spectra of untreated biochar, dye and biochar treated with MG dye at pH 7.0 showed a broadening of band at 3465.18 cm⁻¹ for biochar treated with dye possibly due to the formation of hydrogen bond between MG dye and PNB and retention of positively charged MG cationic species to the -OH functionality of PNB adsorbent. Further, diminution of absorption peak at 1589.21 cm⁻¹ in FTIR of MG dye after its adsorption onto PNB indicated a possible bonding of MG dye due to π - π electron donor-acceptor interaction between π -electron rich aromatic graphene in the carbonized region of biochar and π -electron deficient aromatic ring of positively charged MG²⁵.

Conclusion

Pine needle, an abundantly available waste material when used as an adsorbent demonstrated great potential to remove MG from synthetic wastewater prepared in different pH buffers. The maximum dye removal was obtained at pH 7 and increased with increasing temperature. The best correlation was obtained using the pseudo-first-order kinetic model with the coefficient of correlation $R^2 \geq 0.99$ for all the pH values. Equilibrium data fitted well to the Freundlich isotherm model at all dye concentrations. The various results obtained prove that the adsorbent chosen for the study was quite efficient and could be used as an effective low-cost alternative for the removal of industrial dye effluents from water bodies and would aid in the replenishment of aquatic systems.

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