Study of the Influence of Operational Parameters on the Adsorption of a Dye by a Potato Peels

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Abstract. The growing demand for adsorbent materials for environmental protection processes is prompting further research in the manufacture of unconventional and low cost adsorbents. In this work we have prepared a material from a natural waste namely potato peels to clean up contaminated water with a cationic dye i.e. Methylene Blue (MB). Firstly a characterization of the material was carried out in terms of bulk density, ash content, moisture content, pH and electrical conductivity. A parametric study was carried out subsequently and revealed that this adsorbent gives a better adsorption efficiency with respect to BM molecules (Tx = 95.13%) during a contact time of 45 min for a solid mass (4 g), a speed stirring (150 rpm), a solid mass/liquid volume ratio (4 g/250 mL) and an initial dye concentration (10 ppm). The modeling of the adsorption results gave an L-type isotherm with good compatibility with the Langmuir and Freundlich models.

Keywords: Adsorption · Peels of potatoes · Methylene blue · Characterization · Isotherm

1 Introduction

The dyes are used in many industrial sectors (textile, paper, leather, food …). The dyestuff industry is a large and growing economic market, but also a potential source of underground and atmospheric pollution. Water pollution has taken a large part of environmental concerns, as the water resources and wastewater volumes generated by the various sectors of activity have become increasingly important (Moussavi and Khosravi 2011).

Several methods have been developed for sewage treatment; polluted in particular by dyes; and the majority of which are based on physical separation processes using adsorbent materials (Yao et al. 2010), filtration on membranes (Saja et al. 2020), chemical

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and electrochemical as well as biological processes (El-Sheekh et al. 2009), flocculation–coagulation (Canizares et al. 2006) and chemical oxidation (Salem and El-Maazawi 2000).

The technique of adsorption which is the most favorable method for the elimination of dyes has become an analytical method of choice, very effective and simple in its use.

The principle of the adsorption treatment is to trap the dyes with a solid material called adsorbent. In the literature, there are several solid materials (clays, zeolites, activated aluminas, sludge, biomasses, agricultural residues, industrial by-products and activated carbon, etc.) that can be used in water bleaching processes (Amuda et al. 2014).

A large number of studies focus on the use of certain adsorbents from natural waste, as an example: sawdust (Ismaili M'hamdi et al. 2017), nut shells (Miyah et al. 2018), orange peel (Amin et al. 2019), wheat waste (Mousa and Hussein Taha 2015), coffee grounds (Kai and Gondal 2017), eggshell membrane (Abdel-Khalek et al. 2017) and lignocellulosic materials (Khelaifia et al. 2016).

These adsorbents are natural materials available in large quantities and at low prices (Fayoud et al. 2015; Tsamo et al. 2019).

Researchers have studied the application of biosorbent derived from different biomaterials for the removal of methylene blue (MB) dye (Chen et al. 2019; Jawad et al. 2018). Biomass of orange and banana biomass as well as their derived biochars have also been used for the adsorption of MB dye (Jawad et al. 2019; Dai et al. 2018) but with some sort of pretreatment and chemical modifications for enhanced performance (Liu et al. 2019; Lu and Li 2019).

The optimization by the experimental plans of the factors influencing the adsorption methylene blue on sawdust shows that the percentage of adsorption increases for low concentrations of methylene blue and large masses of wood sawdust (Ismaili M'hamdi et al. 2017).

On the other hand methylene blue can be removed from dye bearing effluent in an eco-friendly way using walnut shells powder. In this respect, the adsorption was rapid and could be considered to fit pseudo-second order kinetics model (Miyah et al. 2018).

Our study consists of purifying synthetic waters contaminated with a basic dye, Methylene Blue (MB), by adsorption on a non-expensive biomaterial while valuing one of our daily waste namely potato peels.

2 Experimental

The adsorbent was prepared from the potato skins which were washed extensively with distilled water and then dried in an oven at 105 ° C for 6 h. They are then crushed (Fig. 1) and sieved to retain only the fraction between 0.5 and 2 mm (Hazourli et al. 2007).

The retention capacity of potato peels was tested against solutions contaminated with methylene blue. An amount of adsorbent is mixed with a solution containing the MB dye at a specific concentration. The whole is stirred by a jar test at a well-defined speed and at room temperature (18 ± 2 °C). Adsorption kinetics was followed by sampling of the solution over time. The collected volumes were filtered and analyzed by spectrophotometer at 663 nm to determine the residual concentration of Methylene Blue.

Fig. 1. The peel of potatoes before and after grinding and sieving.

The adsorption rate (Tx%) was calculated by the ratio of the amount adsorbed to the initial quantity of MB:

$$\mathrm{TX}\,(\%) = \frac{(C_0 - C_e).100}{C_0} \tag{1}$$

Where

C_0 and C_e represent the initial and equilibrium MB concentrations respectively.

The amount of adsorbed solute is calculated using the following equation:

$$\frac{X}{m} = \frac{(C_0 - C_e).V}{m} \tag{2}$$

X: amount of solute adsorbed at equilibrium (mg), m: mass of adsorbent (g) and V: volume of the solution (L).

The equations of Langmuir (3) and Freundlich (4) are used in their linearized form for the exploitation of adsorption isotherms (Langmuir 1918; Freundlich 1906):

$$\frac{X}{m} = \frac{a.b.C_e}{1 + b.C_e} \tag{3}$$

With:

a: adsorption capacity at saturation ($mg.g^{-1}$);

b: adsorption coefficient ($L.mg^{-1}$)

$$\frac{X}{m} = K_F.C_e^{1/n} \tag{4}$$

K_F, n: Freundlich constants characteristics of the adsorbate.

3 Results and Discussion

3.1 Optimization of the Operational Conditions of the Adsorption of Methylene Blue

3.1.1 Effect of Adsorbent Mass

To examine the effect of this parameter, we varied the mass of adsorbent from 1 to 6 g (Fig. 2). The stirring speed applied is 150 rpm; the initial concentration of the dye equal to 20 ppm and the volume of the solution to be treated is 200 mL. It should be noted that the adsorption experiments were carried out at room temperature (17 ± 0.2 °C) and without any pH adjustment.

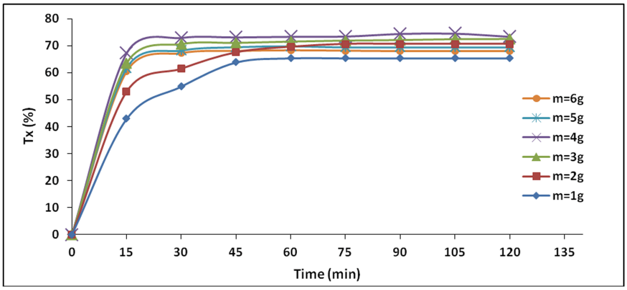

Fig. 2. Effect of the mass of potato peels on the adsorption rate of MB.

It is clear that the adsorption rate of BM increases as a function of time for all the masses used until reaching a saturation plateau (equilibrium time is estimated at 45 min). Likewise, the percentage of discoloration improves with the increase of the adsorbent mass from 1 g to 4 g. This result seems logical since increasing the dose of adsorbent in the solution for the same amount of adsorbate leads to an increase in the active sites and therefore a better elimination of the dye. On the other hand, the elimination rate of the dye is reduced, with the increase of the adsorbent dose at 5 and 6 g, this reduction can be attributed to the overlap or the aggregation of the adsorption sites, which leads to a decrease the total adsorption surface area available for the dye molecules and an increase in the length of the diffusion path (Guechi and Hamdaoui 2016). The best yield equal to 74.5% is obtained after 90 min for a mass of potato skins equal to 4 g.

3.1.2 Effect of Solid Mass to Liquid Volume Ratio

The influence of this ratio was carried out according to the operating conditions mentioned above by adopting the optimal mass 4 g of potato skins. The volumes of solutions taken as test samples are 200, 250 and 300 mL.

Figure 3 shows that increasing the volume of the solution from 200 to 250 mL for the same amount of adsorbent (4 g) increased the adsorption capacity of the dye at about 20%, hence an adsorption rate equal to 90.99% for a stirring time of 45 min. This result can be explained by the fact that a mass of 4 g can provide more active sites for the methylene blue molecules which are increased by increasing the volume of solution. However, a solution volume increase of up to 300 mL for the same initial dye concentration (20 ppm), lowers the adsorption rate because the amount of dye becomes more pleading which makes the mass of solid insufficient to retain all the dyes dye molecules. So a volume of 250 mL seems better for a mass of adsorbent of 4 g.

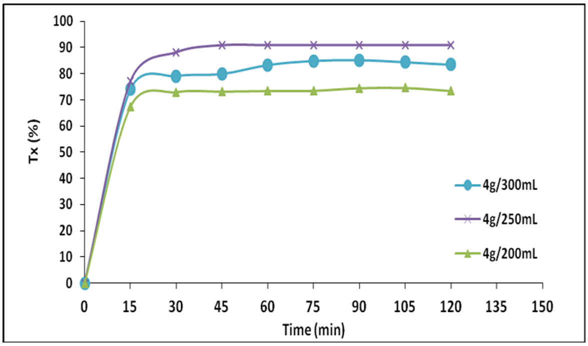

Fig. 3. Effect of the ratio (solid mass/liquid volume) on the adsorption rate of MB.

3.1.3 Effect of Stirring Speed

Several speeds have been tried to improve the adsorption capacity of potato skins towards the methylene blue dye (Fig. 4). The other parameters were kept fixed while respecting the optimal values already acquired.

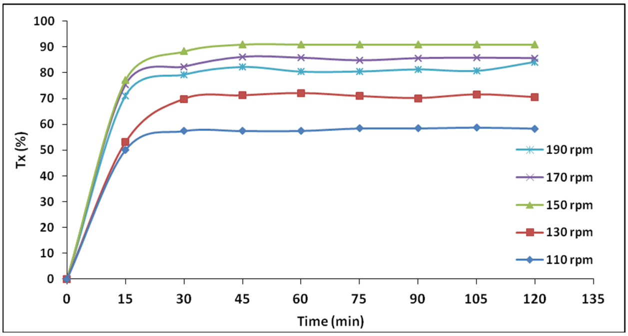

Fig. 4. Effect of the stirring rate on the adsorption rate of MB.

The adsorption kinetics of MB increases with time until a saturation plateau is obtained which reflects a state of equilibrium between the material and the solution. Increasing the speed from 110 to 150 rpm improved the adsorption capacity from 57.42% to 90.99%, which means that the stirring speed ensures a good transfer of the dye molecules to the adsorbent surface. However, the high speeds (170 and 190 rpm) generate a solute accumulation on the surface of solid and lead to a concentration gradient between the solid and the bulk of solution, this gradient favors the creation of diffusion flow antagonizes the convection flow of the solution and leads to a decrease in adsorption.

3.1.4 Effect of Initial Dye Concentration

To study the effect of the initial concentration of MB on the adsorption capacity, the operation was carried out with an initial concentration of MB ranging between 10 and 30 mg/L while maintaining the other parameters constant. As shown in Fig. 5, the adsorption rate showed a downward trend when the initial MB concentration was increased. At lower concentrations, most of the MB molecules present in the adsorption medium can interact with the surface sites of the adsorbent, therefore the highest adsorption yields were obtained (at 10 ppm MB, the Tx = 95.13% after 45 min). At higher concentrations, lower adsorption efficiencies have been observed due to saturation of the adsorption sites (Ozer and Dursun 2007; Abdallah et al. 2016).

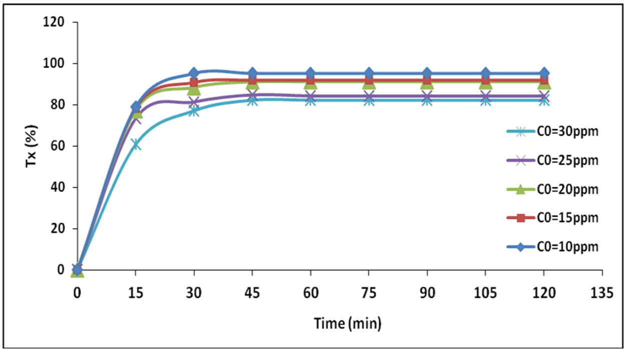

Fig. 5. Effect of the initial concentration of the MB dye on the adsorption rate.

3.2 Adsorption Modeling

3.2.1 Type of Adsorption Isotherm

The modeling of the obtained results shows that the variation of the ratio (X/m) as a function of the equilibrium concentration (C_e) gives a curve compatible with the "type L" isotherm (Fig. 6). It consists of localized adsorption on sites of the same energy, without interaction between the adsorbed molecules.

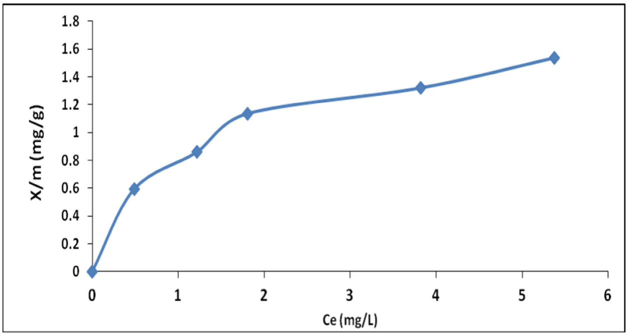

Fig. 6. Adsorption isotherm of MB dye on potato peels.

3.2.2 Langmuir and Freundlich Models

The results obtained show that the regression coefficient ($R^2 = 0.9748$) of the Langmuir model is very close to unity (Fig. 7). The linear regression line allowed us to determine the maximum adsorption capacity and the adsorption coefficient of Langmuir which are 1.6474 $mg.g^{-1}$ and 1.1255 $L.mg^{-1}$ respectively (Table 1).

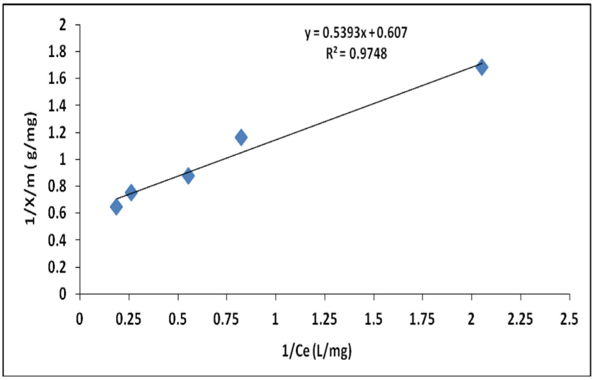

Fig. 7. Langmuir adsorption model of MB dye on potato peels.

Table 1. Constants of Freundlich and Langmuir

Langmuir			Freundlich		
b (L/mg)	a (mg/g)	R^2	K_F	1/n	R^2
1.1255	1.6474	0.9748	0.8130	0.3910	0.9750

The graphical representation of Log (X/m) as a function of Log C_e is a line of slope (1/n) and ordinate at the origin Log K_F (Fig. 8). This line defines the Freundlich model and presents a very high linear regression ($R^2 = 0.9750$).

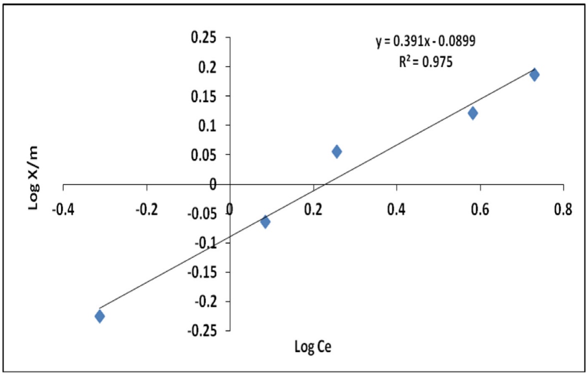

Fig. 8. Freundlich adsorption pattern of MB dye on potato peels

The equational parameters of Freundlich and Langmuir models are presented in the following table.

4 Conclusion

Absorption kinetics is almost similar for all studied parameters. A saturation plateau is reached after an equilibrium time of 45 min. The parametric study carried out allowed us to determine the optimal operational conditions for the adsorption of methylene blue on potato peels giving a yield of 95%. The optimal conditions are; a mass of adsorbent = 4 g, a solid mass to liquid volume ratio = 4 g/250 mL, a stirring speed = 150 rpm and an initial concentration of dye = 10 ppm. The modeling of adsorption results of the MB dye gave a curve compatible with the L-type isotherm and a good description with adsorption Langmuir and Freundlich models.

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