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Determination of the Optimal Adsorbent for Bromophenol Blue Dye: Adsorption from Aqueous Solution

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Abstract

The adsorption behavior of bromophenol blue has been studied on different adsorbents for the purpose of determining the best remover for this dye. The adsorbents were activated carbon (AC), K10 montmorillonite (MMT), acidic sawdust (ASD) and basic sawdust (BSD). The influence of various experimental parameters including time of reaction, concentration and pH of solution on the adsorption of (BPB) on the four adsorbents was investigated. It was found through this study that the best adsorbent for this dye is activated carbon, and since this dye is anionic, the pH has a direct effect on its adsorption process on different surfaces. The dye prefers a positively charged surface, therefore working at low pH is the favored choice. The tendency of the surface to gain negative charge increases as the pH of the solution rises resulting in a decrease in dye adsorption due to a decrease in the electrostatic force present on the adsorbent's surface. The amounts of dye adsorbed were calculated by using UV-Vis spectroscopy.

Keywords: Activated Carbon; Montmorillonite; Acidic sawdust; Basic sawdust; Adsorben

1. Introduction

One of the most important processes is the disposal of colored chemical dyes resulting from industrial laboratories that dump this waste [1]. The process of disposal of this type of waste is clearly visible due to its clear colors, in addition to having a toxic effect on the environment and soil [2]. Such substances may have even carcinogenic and mutagenic effects [3]. These dyes must be discharged before reaching ground and river water, and this issue has always been a major problem. Therefore, it became necessary to search for cheap and effective adsorbent materials that provide promising results to remove such montmorillonite was used to remove methyl orange from the aqueous solution. The experiment textile industrial waste. Various adsorption techniques have been used to eliminate such waste dyes and other impurities of organic and inorganic sources and heavy metal wastes [4]. The introduction of the technique of solid-liquid adsorption with low-cost adsorbents has been shown important results in the treatment of textile wastewater [5]. Due to the huge surface area of activated carbon [6], it has been widely used to eliminate numerous organic compounds including drugs [7, 8] and dyes [9-11].

Montmorillonite clay is another alternative adsorbent that processes a high surface area and interlayer spacing that is able to host different species [12]. This type of clay consists of three layers, two tetrahedral layers surrounding one octahedral [13]. Montmorillonite has been used to remove methylene blue from an aqueous solution. It was shown an effective ability in adsorbing the pigment [14]. Likewise, it has been used to remove malachite green pigment and showed strong efficacy [15]. Natural Algerian revealed that the contact time needed for sufficient adsorption is 40 minutes [16]. An experiment was performed to investigate the adsorption of reactive yellow 15 and reactive yellow 42 pigments on montmorillonite from aqueous

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solutions using different variables such as reaction time, pH, temperature and concentration. The results showed that all these variables have a great effect on the adsorption process [17]. Researchers have been used organo-MMT for the removal of methyl red pigment from an aqueous solution. They found that the adsorption data follow the pseudo-second-order kinetic and Freundlich models [18]. The adsorption of methyl orange on modified montmorillonite with chitosan using different variables has been studied. The study revealed that the process was rapid and reached equilibrium after 1 hour. The process was best fitted by the pseudo-second-order reaction and Langmuir isotherm [19]. The removal of bromophenol blue pigment from aqueous solutions has been prompted special attention from many researchers. A study of the adsorption of bromophenol blue on bentonite carbon composite material showed that the optimal condition for the adsorption is at pH 1, contact time 40 minutes and 10 g/L and 20 g/L. The experiment indicated that the process followed pseudo-second-order rate and was best fitted by the Freundlich equation [20]. Acid activated clay was used for the removal of bromophenol blue. The results showed that the removal process depends on dye concentration, pH, contact time and temperature. The process was best fitted by the Langmuir model [21].

The adsorption of bromophenol blue on protein-rich scales of Labeo bata showed that the best adsorption behavior at pH 4.8. The process followed pseudo-second order rate [22-23]. The adsorption of bromophenol blue from aqueous solution onto raw maize cob showed that the removal efficiency increases with increasing the concentration of the compound from 10 mg/L to 100 mg/L. The adsorption process was also found to be high at low pH [24]. comparative adsorption of methyl orange and bromophenol blue was conducted using sugarcane stem and maize stem activated carbon [25-26]. The adsorption process of bromophenol blue on α-chitin nanoparticles was found to increase with increasing the temperature, contact time and concentration and de-crease with increasing the initial concentration and strong acidic pH [27].

The current research aims to find out the best adsorbent for the removal of bromophenol blue from aqueous solution using four distinct adsorbents; activated carbon, K10 montmorillonite, acidic and basic sawdust.

2. Experimental

The AC, K10 MMT, BPB and all other chemicals used in this investigation were of analytical grade obtained from Sigma-Aldrich. The electronic absorption spectra of the pigment solutions were recorded on a double beam UV/Vis spectrophotometer instruments type PG T80. The pH of the solutions was measured using a Philips (PW-9409) digital pH meter.

2.1 Preparation of dye solution

The dye solution was prepared by dissolving 100 mg of the solid material in 100 ml distilled water in a 250 ml flask. The 100 ml drug solution was shaken thoroughly on a magnetic stirrer for 4 h in order to dissolve all the particles. The solution was then filtered through filter paper. The dye solution was then transferred to a 1 L volumetric flask and the volume was adjusted up to the mark of the flask with distilled water to obtain a stock solution of 100 mg L^{-1}.

2.2 Preparation of sawdust

The sawdust used in the current experiment was obtained from the Bischofia javanica - Aquatic Plant. The wood chunks were rinsed several time with distilled water and air-dried for 3 hours, and then in the oven for 2 h at 75 ºC. The second process was to convert the material to a fine powder using electric grinder then sieved to 150 µm. To remove the color of the particles and all water-soluble substances, the sawdust powder was placed in 0.5 mol L^{-1} HCl solution for 4 hours. Afterward, it was filtered and washed three times with distilled water, and dried at 75 ºC for 3 hours and kept in a desiccator. To prepare the ASD, 0.1 mol L^{-1} HCl solution was used, and 0.5 mol L^{-1} NaOH solution was used to prepare the BSD. 10 g of the powder sawdust was immersed in 100 ml of mol L^{-1} HCl solution using a 250 ml round flask. While another 10 g of the powder sawdust was immersed in 100 ml 0.5 mol L^{-1} NaOH solution for BSD preparation. The mixtures were stirred for 3 hours at room temperature then kept overnight. After this stage, the sawdust was filtered, washed with distilled water three times and dried in the oven for 2 h at 75 ºC, and then kept in a desiccator for subsequent use.

2.3 Adsorption studies

The adsorption studies of the BPB on the four adsorbents AC, K10 MMT, ASD and BSD were carried out to investigate the effect of time, concentration and pH on the adsorption process. To investigate the effect of contact time of the dye on the adsorption ability of the four adsorbents, 100 ml of the 100 mg L^{-1} BPB solution was placed in a 250 ml flask, then 0.5 g of each adsorbent was added separately. The four flasks were kept on an orbital shaker for 15, 30, 60, and 90 minutes. To investigate the effect of concentration, the experiment was conducted for 60 minutes for each adsorbent using 100 ml BPB concentration of 25, 50, 75, and 100 mg L^{-1} and 0.5 g of each adsorbent. For the pH investigation, 100 ml of the 100 mg L^{-1} BPB solution was placed in a 250 ml flask then 0.5 g of each adsorbent was added. The pH was adjusted at 2, 5, 8 and 10 using 0.1 mol L^{-1} HCl and NaOH solutions. The mixtures were left to proceed on the magnetic stirrer for 60 minutes. After the end of each experiment, the mixtures were filtered through filter paper and the filtrate was analyzed spectrophotometrically in the visible region at λ_{max}=590 nm and 440 nm for pH 2. The amounts of the BPB adsorbed on each adsorbent (mg g^{-1}) and the % of dye removal was calculated using the following equations:

$$Q_e = (C_o - C_e)\ V / m$$

$$\%\ \text{Dye removal} = [C_o - C_e / C_o] \times 100$$

where Q_e is the maximum quantity of BPB in mg gm-1 adsorbed, C_o is the initial BPB concentration (mg L^{-1}), C_e is the concentration of the BPB (mg L^{-1}) in the supernatant at the equilibrium stage, V is the volume of the BPB solution in L and m is the adsorbent mass in grams. By measuring the solutions absorbance for each experiment, a calibration curve was performed.

3. Results and discussion

The BPB dye used has the chemical formula $C_{19}H_{10}Br_4O_5S$, and the chemical name 3′,3″,5′,5″-tetrabromophenolsulfonphthalein [25]. The chemical structure is shown in Fig. 1.

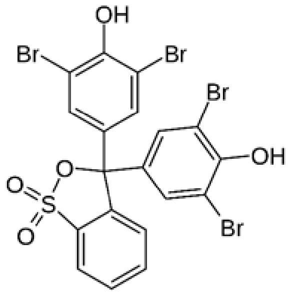

Fig. 1. The chemical structure of bromophenol Blue.

3.1 The effect of time

The effect of reaction time on the BPB adsorption at room temperature (25 ºC) was investigated at 100 mg L^{-1} concentration with 0.5 g adsorbent. The results are listed in Tables 1 and 2. The amount of BPB adsorbed by the four different adsorbents was found to differ from one adsorbent to another. Activated carbon adsorbed all the BPB amount in the solution, regardless of the time used. As for ASD, there is a clear increase in the amount of BPB adsorbed with increasing time. The amount of dye adsorbed on the BSD and MMT was small and the reaction time has no effect. Fig. 2 illustrates the rate of removal for the four periods used in the study.

Table 1. The amounts in mg/gm of BPB adsorbed for time study

Time (min.)	BPB Adsorbed on AC (mg/gm)	BPB Adsorbed on ASD (mg/gm)	BPB Adsorbed on BSD (mg/gm)	BPB Adsorbed on MMT (mg/gm)
15	20	3.8	0.6	0.6
30	20	4.4	0.6	0.4
60	20	6.5	0.6	0.6
90	20	6.2	0.7	0.6

Table 2. The % of BPB removal for time study

Time (min.)	% of BPB Removal by AC	% of BPB Removal by ASD	% of BPB Removal by BSD	% of BPB Removal by MMT
15	100	19	3	3
30	100	22	3	2
60	100	28	3	3
90	100	31	3.5	3

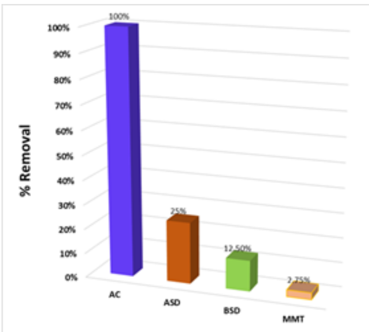

Fig. 2: Removal rate for time study.

3.2 The effect of concentration

The effect of the initial dye concentration on the adsorption of the four adsorbents was investigated under the same circumstances that were used for time study, using 25, 50, 75 and 100 mg L^{-1} concentrations (Table 3 and 4). Concentration has a great impact on the whole adsorption process. It provides the required driving force for mass transfer between the solid and aqueous phases, furthermore, the number of dye-adsorbent collisions increases, resulting in increased adsorption [28]. Once again, the activated charcoal removed all the dye molecules in the solution at all concentrations. There is also a significant increase in the amount of dye adsorbed using ASD regardless of a lower percentage of removal. The amount of dye absorbed on the BSD and MMT was low, which in turn made the removal percentage low (Fig. 3).

Table 3. The amounts in mg/gm of BPB adsorbed for concentration study

Con. (mg/L)	BPB Adsorbed on AC (mg/gm)	BPB Adsorbed on ASD (mg/gm)	BPB Adsorbed on BSD (mg/gm)	BPB Adsorbed on MMT (mg/gm)
25	5	3.58	0.14	0.14
50	10	5.6	0.4	0.28
75	15	5.68	0.6	0.6
100	20	6.4	0.6	0.6

Table 4. The % of BPB removal for concentration study

Con. (mg/L)	% of BPB Removal by AC	% of BPB Removal by ASD	% of BPB Removal by BSD	% of BPB Removal by MMT
25	100	71	2.8	2.8
50	100	56	4	2.8
75	100	38	4	4
100	100	32	3	3

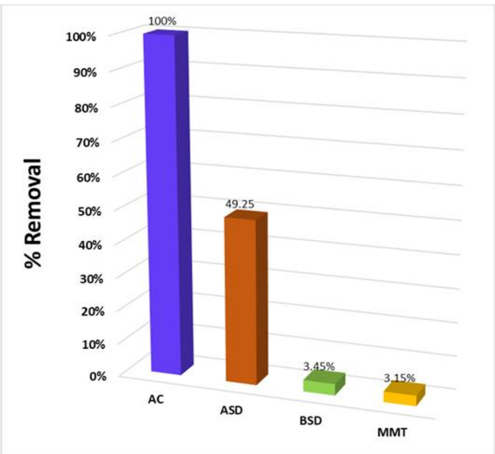

Fig. 3. Removal rate for concentration study.

3.2 The effect of pH

One of the most significant factors influencing dye adsorption on adsorbents is pH. The surface charge of the adsorbent as well as the degree of ionization of the dye present in the solution are affected by the pH of the solution; pH thus affects the structural stability of dye. Therefore, the pH has the greatest role in aqueous chemistry as well as the surface binding sites of any adsorbent. Adsorption experiments were carried out at various initial pH levels to determine the effect of pH on dye adsorption. It was found that as the pH increases, the adsorption decreases. Tables 5 and 6 show the pH influence on the amount adsorbed by the adsorbents. Since BPB is an anionic dye it produces negatively charged ions when dissolved in water, the adsorption of BPB dye on the positively charged surface is facilitated in the acid pH environment. At low pH, the adsorbent surface becomes positively charged resulting in a significant enhancement in adsorption of the negatively charged species via the attraction of electrostatic forces. While at high pH the adsorption process decreases for the anionic dye, because increasing the pH of the solution will increase the tendency of the surface to acquire negative charge, resulting in a decrease in the adsorption of dyes due to the decrease in the electrostatic force existing with the surface of the adsorbent [29-30]. The adsorbent surface favors cationic species at high pH [31-34].

Table 5. The amounts in mg/gm of BPB adsorbed for pH study.

pH	BPB Adsorbed on AC (mg/g)	BPB Adsorbed on ASD (mg/g)	BPB Adsorbed on BSD (mg/g)	BPB Adsorbed on MMT (mg/g)
2	20	16.9	6.4	16.3
5	20	15.2	0.6	17
8	20	1	0.8	0.6
10	20	1	0.8	0.6

Table 6. The % of BPB removal for pH study.

pH	% of BPB Removal by AC	% of BPB Removal by ASD	% of BPB Removal by BSD	% of BPB Removal by MMT
2	100	84.5	32	81.5
5	100	76.4	3	85
8	100	5	4	3
10	100	5	4	3

From the study of the effect of pH, again activated carbon appears to be the best adsorbent for this dye among the four adsorbents, followed by acidic sawdust, then MMT. The BSD has very little removal activity due to the basicity of the surface (Fig. 4).

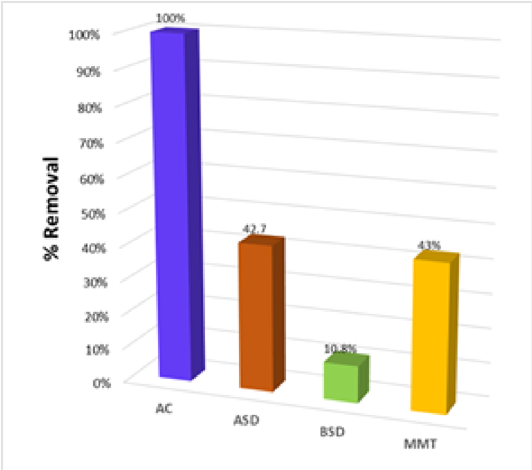

Fig. 4. Removal rate for pH study.

4. Conclusion

The adsorption of the industrial anionic dye BPB form an aqueous solution using four different adsorbents which were AC, MMT, ASD and BSD revealed that the best adsorbent among these four is AC. The effectiveness of AC is distinguishable regardless of the time, concentration or pH used. Activated carbon appears to be the optimal adsorbent for all the variables used in the study. The ASD exhibited high removal capacity with a lower concentration, and the amounts of dye adsorbed per gram increased with increasing concentration. MMT processes a good adsorption efficacy at low pH. BPB is an anionic dye and when dissolved in water produces negatively charged ions that prefer to be attracted to positively charged surfaces.

Conflict of Interest

There is no conflict of interest in the publication of this article.

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