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Effective Removal of Reactive Violet2 Dye by Using Different Geopolymers Containing Bentonite

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Abstract

The excessive potency of pollutant effluent is an issue that needs to be handled globally. The untreated discharge of toxic compounds into water resources, such as dyes, heavy metals, surfactants, medicines, and pesticides, is a major problem. As a result, different technologies have been used to treat wastewater, including coagulation-flocculation, precipitation, and adsorption.Geopolymers and composites are revolutionizing wastewater clean-up by effectively removing pollutants and immobilizing contaminants, reducing reliance on costly, less environmentally friendly traditional methods.The objective of the current study was to examine the adsorptive characteristics of different geopolymer mixes using different aluminosilicate precursors such as metakaolin (MK), slag (GBFS), fly ash (FA), and bentonite (BT) for the adsorption of reactive violet 2 dye.In order to enhance the removal process, the impact of pH, adsorbent quantity, contact time, and starting concentration was investigated.The results revealed that geopolymer mixbased on slag and bentonite removed 94.8% of the dye, geopolymer mix based on fly ash with bentonite removed 92.8% of the dye, and geopolymer mixes containing bentonite and metakaolin removed 90.2 of the dye from the aqueous solution

Keywords: Geopolymer,Bentonite,Slag, Fly ash, Metakaolin, Water treatment, Adsorption.

1. Introduction

Water pollution is now recognized as one of the most severe issues confronting humanity, and it is getting worse every day as a result of the massive industrial development taking place in numerous regions [1]. Water is used extensively by many industries, and a sizable portion of this contaminated water is released as wastewater into the environment system [2].A significant amount of azo dyesis present in the wastewater stream from the textile sector, which endangers the health of humans and animals as well as contributing to the carcinogenic activity of ground and surface waters [3].As approximately 50% of the used dye disappears in discharged flows during the textile dyeing process, the effluent from these textiles contributes to aesthetic problems, hinders light penetration and oxygen transfer in an aquatic environment [4].Reactive dye is an important class of dyes that are largely used for textiles especially cotton because of their great wet fastness, brilliance, and wide range of vibrant colours [5].In order to minimize the effects of these pollutants on the environment, it is nowadays essential to purify effluents containing them before releasing them back into the surrounding environment. Due to this, various effective and affordable techniques, including electrochemical oxidation, ion-exchange, and adsorption, have been developed in recent years for treating colourfulwastewater [6-8].Adsorption is the most commonly used technique for the treatment of biologically polluted water because it is straightforward to use, economical, highly effective, and comprehensive [9].

The removal of dyes from industrial wastewater involves a variety of adsorbent materials such as zeolites, different clay species and geopolymercomposites.For the adsorption of various contaminants, geopolymers represent potential alternative adsorbents[10-13].Geopolymers, or inorganic polymers, are one type of adsorbent that has seen growing interest recently for purifying aqueous media due to their distinctive and varied physicochemical properties, including their porous

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nature, large adsorption capacity by ion-exchange, and the affordable price [14,15].Geopolymers are stable inorganic polymers consisting of a main three-dimensional aluminosilicate network skeletonthat produced from an eco-friendly aluminosilicate polymerization process at a lower temperature with fewer CO_2 emissions, employing activators such strong alkalis (NaOH and KOH) and natural/industrial wastes allowing the considerable use of excess or waste materials in various operations [16,17]. Calcined clay, metakaolin (MK), fly ash (FA), and slag are typical aluminosilicate components utilized in the production of geopolymers [18].Bentonite (BT) is favoured as calcined clay due to several factorsincluding its biologicalavailability, chemical durability, substantial porosity and surface area, and high capacity for cation-exchange, make it an ideal adsorbent for a variety of uses [19]. Each of slag, FA, MK and BT are considered as a good absorbent. Slag geopolymer has been investigated as an effective adsorbent for the removal of MB, Pb(II) and Ni (II) when combined with MK or FA[20-22].Both fly ash and metakaolin-based geopolymers were investigated as promising adsorbents for removing different inorganic as well as organic contaminants (i.e. dyes) through an ion exchange mechanism between dyes and the counter-cations of the geopolymer [23-27].In our earlier experiments [28–33], we found that various geopolymer composites made from industrial waste, such as slag and fly ash, as well as natural materials like metakaolin, can effectively remove reactive yellow 145 and reactive red 195 dyes from wastewater.

This research aims to provide a new, ecologically safe, and practical method for removing the colour of reactive violet dye 2, rather than just disposing of this hazardous material without treatment. The adsorption approach was utilised in our study to treat organic dyes using cementitious materials. The adsorption test for reactive violet 2 dye was performed on three distinct geopolymer mixes based on bentonite as a natural by-product combined with fly ash, metakaolin, and slag (B-Slag, B-FA, and B-MK).

2. Materials and Methods

2.1. Materials

Metakaolin (MK), fly ash (FA), slag and bentonite (BT) are utilized as aluminosilicate precursors. Bentonite is ignited to 800 °C at a rate of 5 °C per minutefor two hours following by cooling, grounding and sievingto size less than 200mesh.Bentonite is supplied from Sphinx Milling Station, Egypt. Fly ash (FA) is provided by Sika Chemical Company in Burg Al-Arab, Egypt. While Egyptian Iron and Steel of Helwan Company, Egypt is source of slag. Metakaolin is provided by Hemts Construction Chemical Company, Cairo, Egypt.The alkaline activator employed are sodium hydroxide(NaOH) pelletswith 99% purityand sodium silicate liquid (SSL) with SiO_2/Na_2O= 2.80. Sodium hydroxide and SSL are purchased from (El goumhouria chemical company, Cairo, Egypt)and (Silica Egypt company, Alexandria, Egypt), respectively.

Table (1) displays the chemical composition of the four aluminosilicate sources determined by XRF analysis.The dye used in our experiments is reactive violet 2. The chemical structure of reactive violet 2dye is shown in figure (1).

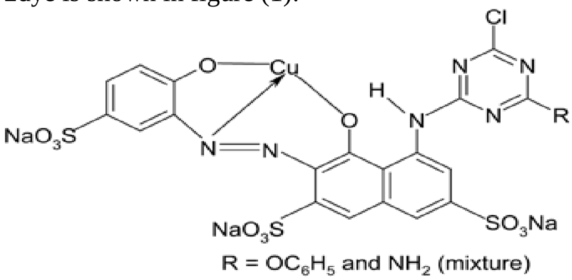


Figure (1): Chemical structure of reactive violet2dye

Table (1): Chemical composition of raw materials (wt.%)

Oxides	BT	FA	GBFS	MK
SiO_2	48.52	63.10	32.86	52.23
Fe_2O_3	18.81	5.40	1.14	2.26
Al_2O_3	9.68	26.54	7.02	29.65
Na_2O	0.14	--	0.29	0.20
CaO	17.04	2.33	42.56	18.73
MgO	3.97	0.52	11.58	0.96
SO_3	0.07	--	2.5	--
K_2O	1.77	0.09	0.15	0.80
Cl^-	--	0.85	--	
H_2O	--	--	--	55.5
Total	100	98.83	98.1	100

2.2. Methods

2.2.1. Preparation of geopolymer

The appropriate aluminosilicate precursors mixes, as shown in Table (2), were created by thoroughly combining the alkaline solution with it at a predetermined solid-to-liquid mass ratio of 1.5. The alkaline activator was prepared by mixing sodium hydroxide (12M) with water glass (sodium silicate SSL) at 1:2.5 ratio.

After being filled into cubic stainless-steel mold of 5 mm x 5 mm x 5 mm, the fresh geopolymer pastes were then briefly vibrated electro-mechanically to remove any forming air spaces. The synthetic geopolymer specimens were subjected to a 24-hour treatment at 70 °C, followed by 7 days of curing at 100% relative humidity. In order to get fine geopolymer particles suitable for adsorption research, the curedspecimens were crushed and sorted.

2.2.2. Preparation of dye

A 600 mg/L concentration of the reactive violet 2 dye was achieved by dissolving 0.6g of dye in 100ml of distilled water. Additionally, distilled water was used to dilute the stock solution in order to get the appropriate concentration for the adsorption experiments (120 mg/l).

2.2.3. Adsorption Experiment

In the preliminary experiment, three geopolymer samples were used to execute an adsorptive decolorization of 30 mL (120 mg/l) reactive violet 2 dye performance at starting pH of 8.0, a fixed adsorbate dose (0.05 g), and contact time of 60 min.At an initial dye concentration of 120 ppm, the effects of several doses (i.e., 0.05 g, 0.07, 0.1 g, 0.2 g, and 0.3g) of geopolymer mixtures were evaluated. The pH of dye solutions was varied from 2 to 8 using 0.1 N NaOH and 0.1 N HCl before adsorbents were added in order to test the impact of pH on the adsorption of dye. It was noted that dyes were removed using various adsorbents over intervals of 30, 60, 120, 360 and 540 minutes in order to examine the effect of contact time. At 30, 60, 120, and 150 ppm, the effects of varying dye concentrations on adsorption of dye were observed.

By using a UV spectrophotometer (Spectrophotometer V-670)at a wavelength of 552 nm, which corresponds to the maximum absorption of reactive violet2dye, the residual dye concentration was determined. The percentage of dye removal by the adsorbent (%) and adsorption capacity (mg/g) were calculated by the following equation.[34, 35].

Removal efficiency $R= (C_o – C)/ C_o \times 100$ (1)

Adsorption capacity $qe = (C_o - C) V/W$ (2)

C_o, C(mg/L) refer to the entail and remaining concentrations of the dye at equilibrium. V (L) donates the volume of dye solution and W (g) is the amount of adsorbent used.

Table (2):Geopolymer pastes' mix formulation

Mixes	BT	Slag	FA	MK
B-Slag	30	70	--	--
B-FA	30	--	70	--
B-MK	30	--	--	70

3. Results and discussion

3.1. Effect of pH

The pH shift has a significant impact on the adsorption process since it affects the chemical composition of both the adsorbent and the adsorbate.It also influences both the surface charges of the adsorbent and the movement of adsorbent from aqueous solution to adsorbent [36,37].

Figures (2 a, b)illustrates the impact of pH on the efficiency of geopolymer pastes to absorb reactive violet2 dye and its adsorption capacity.

As the pH decrease from 8 (initial pH) to 2, the removal efficiency increases for mixes B-slag and B-MK. The maximum removal efficiency of B-slag and B-MK are 74.6 and 78 % respectively. While B-FA achieve maximum removal efficiency (80.8 %) at pH=4. It also observed that the adsorption capacity of all mixes decreases as pH increase.

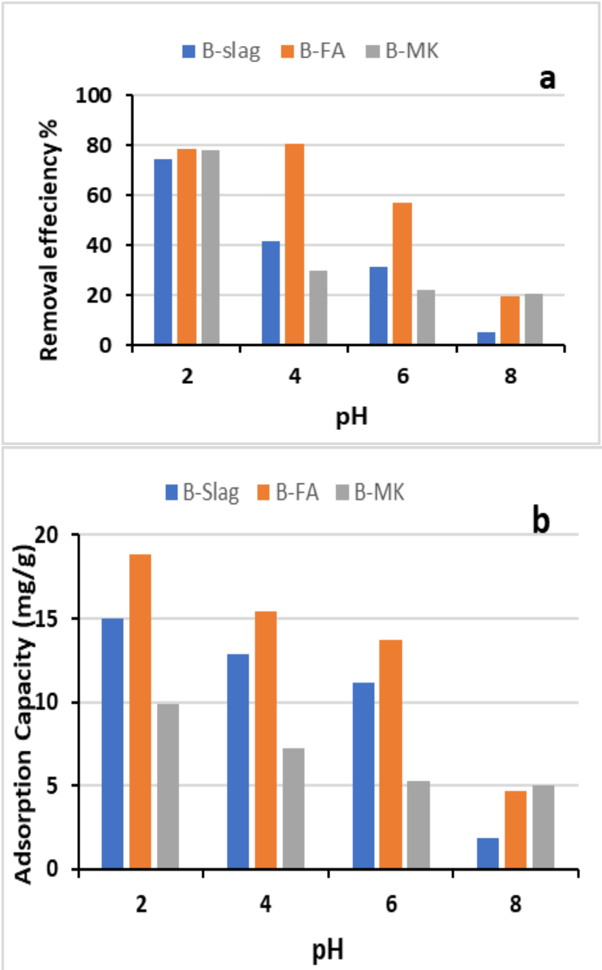


Figure (2): The effect of pH on a) removal effectiveness b) adsorption capacity*(**Adsorbent dosage**= 0.05 g, **Time** = 60 min, **Dye conc**.=120 ppm)*

So, thenext experiment will be conducted with pH 2 for mixes B-Slag and B-MK and pH 4 for B-FA mix.

3.2. Effect of dosage

While maintaining all other parameters constant, the removal efficacy and adsorption capacity of each of three mixes at various doses was presented in Figures (3 a, b).

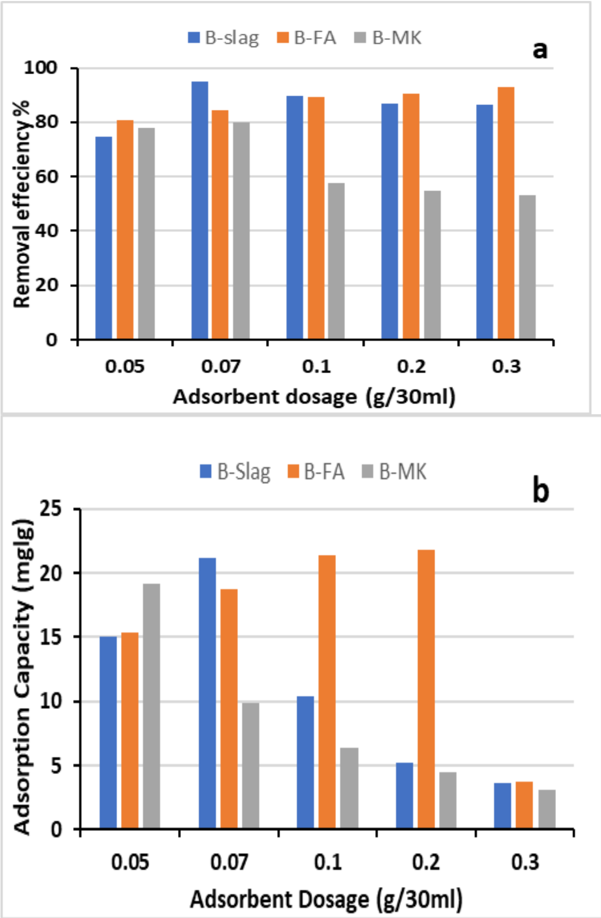


Figure (3): The effect of adsorbent dose on a) removal effectiveness b) adsorption capacity *(**Dye conc**.= 120 ppm, **Time**= 60 min, **pH** 2 for mixes B-Slag and B-MK and pH 4 for B-FA mix)*

The quantity of dye adsorbed firstly increases as adsorbent dose increase up to 0.07 gm for B-Slag and B-MK. By further increasing in geopolymer dose up to 0.3 gm, the removal efficiency decreases. As a result of using high amount of absorbent, many active sites developed on the geopolymeric surface, eventually reaching saturation. After reaching equilibrium, desorption began [38].The percentages of removal increased from74.6 to 94.8 for B-Slag and 78 to 79.8 for B-MK.For B-FA mix, the removal efficiency increases by increasing absorbent dosage up to 0.3 gm. This is attributed to the active sites'availability was increased as the dose of geopolymerincreased, which improved the removal efficiency [39].

3.3. Effect of initial concentration dye

Figure (4 a,b) exhibitthe impact of different initial dye concentration on removal efficiencies and adsorption capacities for the three mixes.

A certain amount of absorbents (0.07 gm for B-Slag, B-MK and 0.3 gm for B-FA) were used in each solution of different dye concentration while maintaining all other variablesconstant.The observable data indicate thata higher initial dye concentration may cause more or less dye removal in accordance with the type of geopolymer mixes. Mixes containing FA and slag show maximum removal at dye concentration 120 ppm. The dye removal was increased till an equilibrium value of 94.8 and 92.8 %for B-Slag and B-FAwas attained and then decrease at 150 ppm concentration of reactive violet 2 dye.In contrast, mix containing metakaolin present more effective removal of dye at high concentration up to 150 ppm. B-MK mix removed 90.2 % of dye at high concentration.

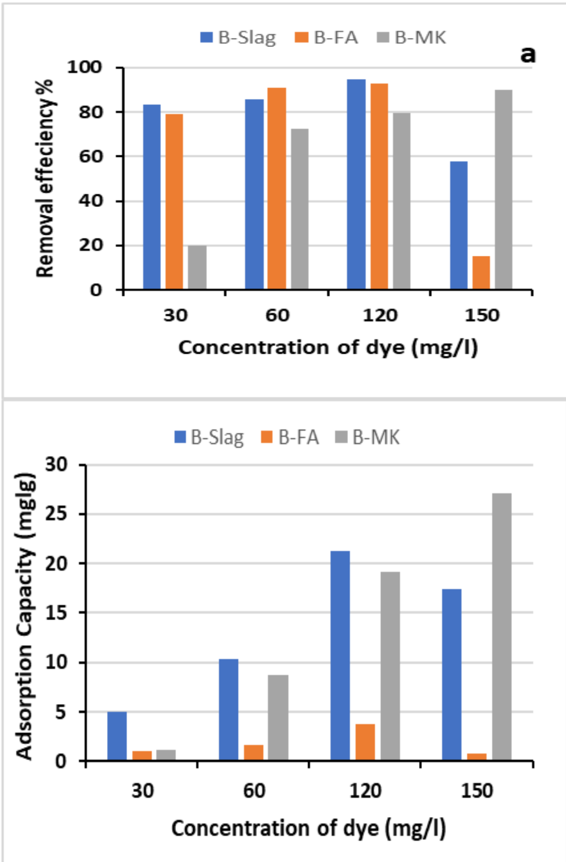
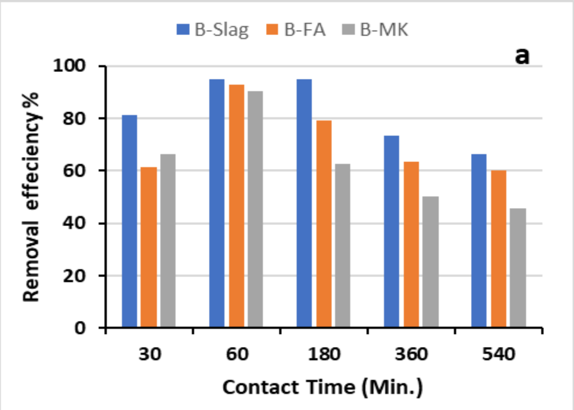


Figure (4): The effect of dye concentration on a) removal effectiveness b) adsorption capacity *(**Time** = 60 min, pH 2 for mixes B-Slag and B-MK and **pH** 4 for B-FA mix, **Absorbents dosage** = 0.07 gm for B-Slag, B-MK and 0.3 gm for B-FA)*

It is also clear that the adsorption capacities of B-Slag and B-FA are increase as dye concentration increase up 120 ppm and then decrease. However, the adsorption capacity of B-MK is rises with increasing concentration of dye up to 150 ppm.

3.4. Effect of time

The effect of contact time was studied at changing contact durations of 30, 60, 180, 360 and 540 min.The removal effectiveness and capacity of adsorption of mixes are shownin Figures (5 a,b).The percentage of dye eliminated improved as the contact duration was extended. After approximately60 minutes, the highest adsorption of the reactive violet dye had been reached and was almost finishedsince all of the active sites were filled.In other word, each of them reached equilibrium at 60 minutes and the maximum adsorption removal attained were 95, 92.8 and 90.2 for B-Slag, B-FA and B-MK, respectively.



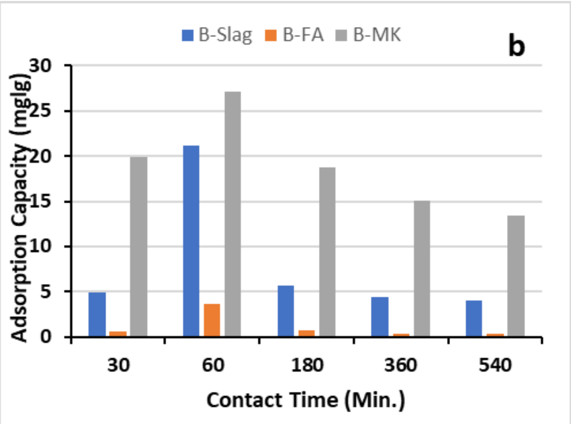


Figure (5): The effect of contact time on a) removal effectiveness b) adsorption capacity
*(**pH** 2 for mixes B-Slag and B-MK and **pH** 4 for B-FA mix, **Absorbents dosage** = 0.07 gm for B-Slag, B-MK and 0.3 gm for B-FA, **Dye conc**.=120 ppm in case of B-Slag, B-FA and 150 ppm incase B-MK mix)*

4. Conclusion

In this study, a new type of geopolymer adsorbent was created to effectively remove reactive dye from water.

- Three geopolymer samples were made by alkaline activation of recommended ratios of metakaolin (MK), fly ash (FA), slag, and bentonite (BT) as sources of aluminosilicates. These samples were then tested for their ability to adsorb reactive violet 2 dye from water.
- The results showed that B-Slag mix is the most effective at removing 94.8% of dye when pH is at 2, adsorbent dose is at 0.07 g, dye concentration is at 120 mg/l, and time is at 60 min.
- In addition, B-MK mix is most efficient at removing high concentrations of dye (150 mg/l) under the same conditions.
- However, B-FA mix shows different behaviour than the other two mixes, removing about 92.8% of reactive violet 2 dye at pH 4, adsorbent dose of 0.3 gm, dye concentration of 120 mg/l, and time of 60 min.
- Overall, the study found that all geopolymer mixes are effective in removing reactive violet 2 dye, but B-MK mix works best for high dye concentrations.

These findings have important implications for the development of environmentally friendly and sustainable construction materials that can also filter out dangerous contaminants from wastewater.

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