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Decolorization of Reactive Dyes, Part VII: Eco-Friendly Approach of Reactive Dye Effluents Decolorization Using Geopolymer Cement Based on Metakaolin-Slag mixes

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Abstract

Using two different types of geopolymers based on metakaolin-slag mixes by 80 to 20% and 60 to 40%, we did this investigation to remove the color from the dyeing bath residues from the liquid waste of reactive yellow dye 145 in an effort to reduce pollution and preserve the environment. The findings demonstrated that this technique offered colour reduction and environmental safety.

Keywords: Reactive dyes, Metakaolin- Slag mixes.

1. Introduction

Geopolymers are considered as alkali-activated substances. Raw resources and waste materials are acknowledged as the main basic materials for geopolymers, which are produced by alkali or acid activation reactions. The development of geopolymer, a new eco-friendly cementitious material, can lessen CO_2 emitted from the fabrication of cement, and this gas is a primary cause of the greenhouse effect and global warming.

Geopolymers have the advantages of chemical corrosion resistance, high mechanical strength, fire resistance, freeze-thaw resistance, lower rate for chloride diffusion, low energy consumption, resist abrasion, thermal constancy, low shrinkage, and excellent durability [1-6].Geopolymers are thus sought after for industrial uses such as green concrete, building materials, fire-resistant materials, and adsorption materials [7-13]. Chemically, geopolymers can be obtained by the reaction of an alkaline solution with alumino-silicate raw materials that are rich in alumina (Al_2O_3) and silica (SiO_2), like bottom ash[14], fly ash, kaolin or clayand fabricated silico-aluminate (pure Al_2O_3-SiO_2).The concentrations of silica and alumina, respectively, have a great influence on the geopolymer's mechanical strength and setting [15].

They also minimize the mobility of heavy metal ions and dyes present in geopolymer materials. Recent studies have focused on how geopolymers may be used to make low-cost sorbents that can effectively remove colors, dangerous metals, and detergents from wastewater. [16-18]. To address the environmental concerns that industrial sectors confront, many researches have lately used geopolymer substances to extract dye [11] and heavy metals [13] from sewer water.

In the alkaline medium, ground-granulated blast furnace slag (GGBFS) possesses pozzolanic and binding characteristics. Slag (GGBFS) is the most suitable material for alkali-activated cements, as it was the first cementitious material to be alkali-activated. Slag was also the first cementitious material to possess latent hydraulic characteristics. Several studies [19-21] investigated the addition of activated slag to industrial waste products such as fly ash (FA), cement kiln dust (CKD), and silica fume (SF) for the synthesis of various geopolymers cement. Processes such as precipitation, adsorption, oxidation, reduction, coagulation, and electrolysis are used to decolorize the

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material physically and chemically to remove the dye [22, 23].

Metakaolin (MK), which is produced at an appropriate temperature (600°C–900°C) by dehydrating kaolin, is an anhydrous aluminum silicate. To create geopolymers, MK has been extensively used. Greater thermal insulation [24,25], bonding strength, and compressive strength [26] are all exhibited by the MK-based geopolymers. According to Jindal et al. [27], have a variety of applications, such as fireproof materials needed for buildings, a sustainable concrete substitute, and an environmentally friendly material. Numerous studies have coupled the system with different materials to reduce costs, maintain excellent performance, and accomplish resource reuse since MK-based geopolymers offer better mechanical properties [28, 29].The use of MK-based geopolymers as "self-cleaning" building materials is another important application area [30].

Elapasery M.A. et al. [31–34] suggested using metakaolin-based geopolymer and slag-based geopolymer cement to eliminate the colour of the reactive dye that is still present in the dyeing bath rather than leaving this hazardous waste untreated. Numerous studies have shown that geopolymers with metakaolin as their primary ingredient are effective adsorbents for a range of water pollutants, including those containing heavy metals and dyes [35-40].

In this study, we compare the adsorption of various mixes containing metakaolin and slag-based geopolymer to the adsorption of metakaolin-based geopolymer alone to find the best mix that can remove a high percentage of the color of the reactive yellow 145 dye residual in the dyeing process, rather than dumping this hazardous waste without treatment.

2. Materials and Methods

2.1. Materials

A-Reactive yellow 145 was utilized for the decolorization studies. The structures of this dyes is shown.

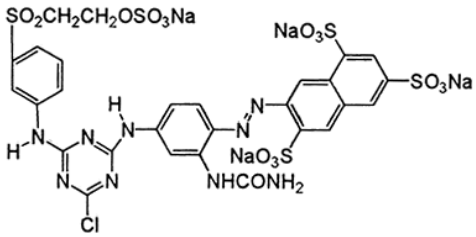

Figure 1. C.I. Reactive Yellow 145

B- Preparation of Hydrolyzed Reactive Dye

The reactive dyestuff was hydrolyzed by adding a 3 mL/L sodium hydroxide solution (33%) and a 5 g/L sodium carbonate solution, and heating them at 80°C for two hours while stirring. Finally, cooling and neutralisation with diluted sulfuric acid were applied to the hydrolyzed dye [32-34].

C- Starting Materials

- Metakaolin (MK) and granulated blast-furnace slag (GGBFS) are mainly our starting materials.
- Metakaolin (MK) was supplied by Hemts Construction Chemical Company, Cairo.
- Granulated blast furnace slag (GGBFS) was delivered from the Egyptian Iron & Steel of Helwan Company, Cairo, Egypt.
- In this study the solution of the alkaline activator was sodium hydroxide (NaOH) and the liquid of sodium silicate (Na2SiO3).The commercial liquid sodium silicate (LSS) was supplied by Silica Egypt Company, Burg Al-Arab, Alexandria, Egypt, while the 99% pure NaOH flakes were supplied by El-Goumhoria Chemical Company, Cairo, Egypt.
- The chemical compositions of metakaolin (MK) and granulated blast furnace slag (GGBFS) were determined as shown in Table 1.

Table1:Chemical oxide composition of starting materials in mass (%).

		Type	
		MK	GGBFS
Oxide constituents (%)	SiO_2	64.8	32.86
	Al_2O_3	30.1	7.02
	Fe_2O_3	0.55	1.14
	CaO	0.52	42.56
	MgO	----	11.58
	SO_3	0.13	2.5
	Na_2O	0.1	0.29
	K_2O	-----	0.15
	P_2O_5	0.06	----
	TiO_2	2.7	----
	Cl -	-----	----
	L.O.I	0.73	0.93
	Total	99.69	99.03

2.2. Geopolymer synthesis

2.2.1. Specimens preparation

The sodium silicate liquid (SSL) and sodium hydroxide pellets (SH) are combined in the first step to create the alkali activator (AA). The mixture is initially fairly hot; allow the mixture to cool to ambient temperature for a few minutes before continuing. Following that, each dry mix was mixed for about 5 minutes on a smooth, non-absorbent surface with varying amounts of alkali activator solution We use the typical Vicat device to measure the water consistency of the geopolymer paste after thorough mixing. The pastes are then poured into a 1inch cube-shaped stainless-steel mold. To eliminate any remaining air bubbles and improve paste compaction, the mould is immediately vibrated, after which it is placed in a room with 100% relative humidity for 24 hours. The cubes were then demolded and allowed to cure for 7 days of hydration. The mix compositions of the prepared samples are shown in Table (2).

Table 2: Mix composition of the investigated mixes, liquid/solid (L/S) ratio and setting times

Mix	MK (%)	GGBFS (%)	Na_2SiO_3: NaOH ratio	L/S ratio
MK	100	0	2.5 :1	0.56
MK-S1	80	20	2.5:1	0.48
MK-S3	60	40	2.5:1	0.44

2.2.2. Water of consistency:

According to ASTM recommendations, the vicat device is used to determine the standard water of consistency [41]. A paste that enables the vicat plunger (10 mm in diameter) to settle to a point 5 mm to 7 mm from the bottom of the vicatmould requires the same amount of liquid as a paste with a standard consistency.

2.3 Adsorption experiments

At 30 ºC and 140 rpm, a particular quantity of the adsorbent was shaken with 50 mL of the dye solution. The supernatant of the sample solutions was separated by filtering. The calibration curve was used to determine concentration while using SHIMADZU spectrophotometry to measure absorbance at the maximum wavelength (max = 475 nm for reactive yellow 145 dye). The amount of dye that was adsorbed onto the adsorbent, qe (mg/g), was calculated using a mass balance relationship.

$$q_e = (C_o - C) V/W \qquad (1)$$

Where V is the volume of solution (L), Co is the starting dye concentrations (mg/L), C is the equilibrium liquid-phase dye concentrations (mg/L), and W is the weight of the adsorbent (g).

$$\text{Removal efficiency \%} = 100 (q_e/ C_o) \qquad (2)$$

3. Results and discussion

3.1 Factors affecting on the adsorption

3.1.1 Effect of pH

When employing the dye residues of the reactive dye yellow 145 at varying pH levels in the adsorption bath, Figure 2 provides us with numerous evidences to demonstrate the change in removal efficiency%. The ideal pH value was researched, ranging from a pH value of 2 to 10, to establish the best value for geopolymer based on metakaolin combined with slag MK-S1 MK-S3 dye-treated. The data in Figure 2 unmistakably show that the percentage effectiveness of colour removal declines with rising pH for all wastewaters. For both geopolymer combinations (MK-S1 and MK-S3), the highest decolorization efficacy was at pH 2. The greatest values were 6% for MK-S1, and18% for MK-S3.

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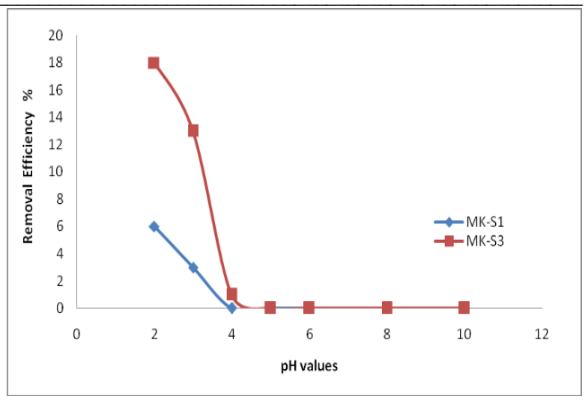

Figure 2. Effect of pH on dye removal efficiency % (Time 2hrs, Temperature 30 ºC, wt. of adsorbent 0.01g, concentration of dye 10 mg/L)

3.1.2 Effect of adsorbent dose

It is important to note that Figure 3's results demonstrate the correlation between the outcomes of the adsorption concentration and the removal efficiency percentage. Using reactive yellow 145 dye waste, the adsorption of the dye under study was examined at various concentrations (0.01-0.1 g/100 ml) of geopolymer cement for 2 hours. For MK-S1 and MK-S3, the dye concentration was (10 mg/L) at pH 2. The findings demonstrate unequivocally that a decrease in the weight of the adsorbent is accompanied with an improvement in removal efficiency. The maximum removal efficiency%, according to our calculations, was 6% for MK-S1 and 18% for MK-S3 at 0.01g/100ml for both geopolymers mixes.

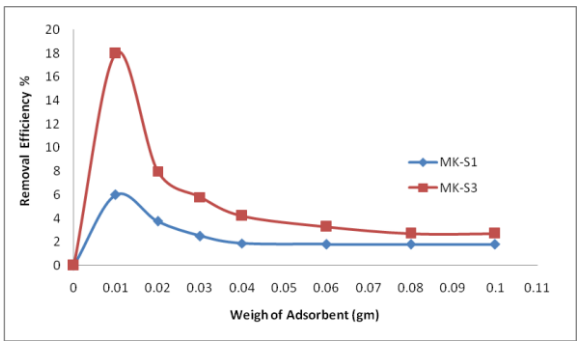

Figure 3. Effect of adsorbent weight on the removal efficiency % (Time 120 min, Temperature 30 ºC, concentration of dye 10 mg/L, pH 2)

3.1.3 Effect of time

The removal of the reactive dye was tested at various time intervals ranging from 1 to 5 hours in order to determine the ideal duration of response of the reactive dye with geopolymer cement materials. We could be revealed that the results in figure 4 show that the rate of colour removal efficiency increases with the lengthening of the adsorption time until it reaches a duration of two hours, reaching a maximum rate of 6% for the geopolymer mixture MK-S1 and 18% for the geopolymer mixture MK-S3, after which the rate of removal efficiency decreases for both mixtures.

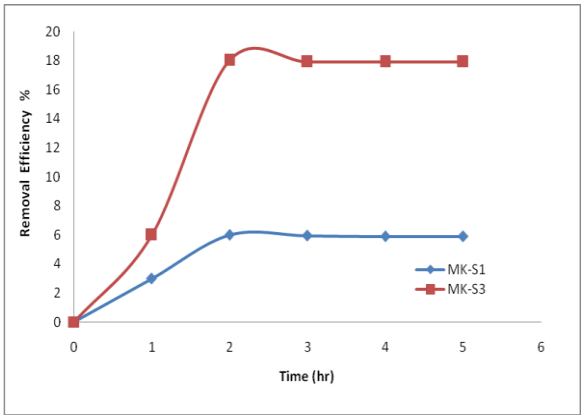

Figure 4. Effect of time on the removal efficiency % (Weight of adsorbent 0.02g, for Mk-S1 and 0.01 for MK-S3, Temperature 30 ºC, concentration of dye 10 mg/L, pH 2)

3.1.4 Effect of Dye concentration

The results shown in Figure 5 give us a clear and complete scientific picture of the link between the influence of the dye concentration on the colour removal efficiency% when using the constant weight of the cured geopolymer combination MK and MK-S1 with time and the appropriate pH. The dye's absorption was studied using various dye concentrations (1.25 - 100 mg/L). With MK-S1 geopolymer cement mix having a colour removal efficiency of 21.4% and MK-S3 geopolymer cement having a colour removal efficiency of 34.4%, we were able to achieve the highest colour removal efficiency. Additionally, the efficacy of colour removal declines as a percentage as we increase dye concentration.

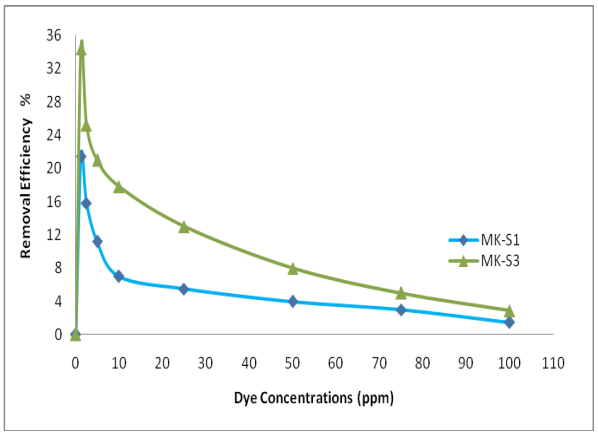

Figure 5. Effect of dye concentration on the removal efficiency % (Weight of adsorbent 0.01g, Time 2hrs and pH 2 , for MK-S3 Weight of adsorbent 0.02 g , Time 4hrs and pH 5 for MK-S1, Temperature 30 ºC for all)

4. Conclusion

This work paves the way for the potential use of a geopolymer based on metakaolin-slag mixtures at a rate of 80 to 20% MK-S1 and 60 to 40% MK-S3 to eliminate the lingering colour in the reactive yellow dye 145 dyeing baths. We can also state that the reactive yellow 145 dye under research had a higher absorption capacity when using 60 to 40% MK-S3 than when using 80 to 20% MK-S1, proving that the presence of 40% slag was advantageous for colour decontamination.

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