



Decolorization of Reactive Dyes, Part IX: Eco-Friendly Approach of Reactive Red 195 Dye Effluents Decolorization Using Geopolymer Cement Based on Metakaolin-Slag Mixes



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Abstract

In the light of our strategy based on reducing pollution and protecting the environment, and as a continuation of our previous work, we conducted this study to remove the color from the residues of the dyeing bath from the liquid waste of Reactive Red 195 using two different types of geopolymers based on metakaolin-slag mixtures in a ratio of 4 : 1 and 3 : 2. The results showed that this method gave environmental safety and colour reduction.

Keywords: Dyeing, Reactive dyes, Metakaolin-slag mixtures.

1. Introduction

Dyes are colouring agents and one of the main components of the wastewater released by a variety of industries including textile, leather, cosmetics, paper, printing, plastic, food, and pharmaceuticals. They can lead to aesthetic issues because they are visible at levels as low as 0.005 ppm. The fact that the dyes may have negative effects on health, microorganism proliferation, and aquatic plant photosynthesis is more significant than any possible aesthetic issues [1]. Additionally, dyes are more steady and more difficult to biodegrade in water due to the complex aromatic molecular structures of the dyes. There are several techniques for removing dye from wastewaters, including adsorption, coagulation, ultra filtration and chemical oxidation [2]. Among these strategies, activated carbon adsorption techniques have been proven to be relatively successful in the removal of dyes [3]. However, activated carbon is rather pricey, and its usage causes a significant loss of the adsorbent during regeneration (10–15%) [4]. As an adsorbent for the removal of dyes, it is necessary to select materials that are affordable and readily available locally due to economic reasons. Agricultural goods [8,9] including

wool, rice straw, coconut husk, sawdust, and peat moss are examples of such adsorbents. Industrial waste items [5-7] such as scrap rubber tires, blast furnace slag, bottom ash, and lignin are other examples. Additionally, in recent years, interest has grown on the utilization of biosorbents due to their low cost and commercial availability [10]. One of the most popular methods for treating dye waste is adsorption since it is time-consuming, energy-free, non-toxic, cheap, and easy to use [11]. Several studies have determined that geopolymer, an adsorbent substance made from industrial waste, is the best option. Geopolymer materials are now the subject of extensive research due to their excellent chemical stability, strong compressive strength, great durability, and high thermal stability. Inorganic polymers known as geopolymers are a novel family of synthetic aluminasilicate materials that result from a reaction between alkali metal silicate solutions and alumina-silicate oxides in very alkaline circumstances. The source of aluminosilicates can be found in nature, such as metakaolin and volcanic ash, or in industry, such as fly ash and blast furnace slag [12, 13]. Additionally, geopolymers are more ecologically friendly cementitious materials when

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Receive Date: 15 December 2022, Revise Date: 13 January 2023, Accept Date: 15 January 2023

DOI: 10.21608/EJCHEM.2023.181064.7337

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compared to ordinary Portland cement because of their resilience to fire and acid attack [14-16] as well as the fact that their synthesis needs lower temperatures, which results in less CO₂ emission [17,18]. Recently, a lot of research has concentrated on the potential of geopolymers to construct inexpensive sorbents for the removal of colour (dyes), harmful metals, and detergents from wastewater [19–21]. Granulated blast furnace slag (GBFS) is a by-product created during the pig iron production process in blast furnaces and is created when the earthy components of iron ore are combined with limestone flux. Granulated slag is created when molten slag is quickly quenched with water and transforms into a fine, granular, nearly completely noncrystalline, and glassy form. Because GBFS contains significant amounts of silica and alumina in a non-crystalline form, it is utilised as a cementitious element in mortars, as a cement additive, as fine aggregate, or as a mineral admixture in concrete [22]. The addition of activated slag to industrial waste products including fly ash (FA), cement kiln dust (CKD) and silica fume (SF) for the synthesis of different geopolymers cement was the subject of several investigations [23–25]. Decolorizing the substance physically and chemically to get rid of the dye involves processes such as precipitation, adsorption, oxidation, reduction, coagulation, and electrolysis [26, 27]. By calcining the kaolin, metakaolin was produced. The process of calcination is the breakdown of kaolinite crystals into an amorphous and reactive structure [28]. Metakaolinite is the name of this new phase. Metakaolinite, in contrast to kaolin, will be quickly activated by alkaline ions. Numerous researchers have added other materials to the system because of the excellent mechanical properties of MK-based geopolymers to reduce costs, maintain great performance, and encourage resource utilization [29,30]. Numerous investigations have demonstrated that geopolymers with metakaolin as its main component work well as adsorbents for a variety of water contaminants, including those that contain heavy metals and dyes [31–36]. Using metakaolin-based geopolymer and slag-based geopolymer cement to remove the colour of the reactive dye that is still present in the dyeing bath was recommended by Elapasery M.A. et al. [37-42] and Ali *et al* [43-48] as opposed to letting this hazardous waste go untreated. In this study, we compare the adsorption of two mixtures containing metakaolin-slag based geopolymer (MK-S1 and MK-S3) to investigate the most excellent mixture that can decolorize the colour of the reactive red 195 dye residual in the dyeing process as a facile waste water treatment rather than simply dumping this hazardous waste without any treatment.

2. Materials and Methods

2.1 Materials

A. Reactive red dye 195

The structure of reactive red dye 195 which was utilized is presented in figure 1.

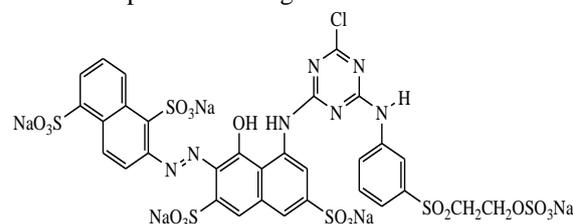


Figure 1. C.I. Reactive Red 195

B- Preparation of Hydrolyzed Reactive Dye

A 3 mL/L sodium hydroxide solution (33%) and a 5 g/L sodium carbonate solution were added, and the reactive dyestuff was heated at 80 °C for two hours while being stirred. The hydrolyzed dye was then cooled and neutralised using diluted sulfuric acid. [31].

C- Starting Materials

Materials utilized in this study included: granulated blast furnace slag (GBFS) was acquired from the Helwan Company of Egyptian Iron & Steel. Metakaolin (MK) was obtained from Hemts Construction Chemical Company, Cairo, Egypt. The chemical compositions of metakaolin (MK) and granulated blast furnace slag (GGBFS) were presented in Table 1. The alkaline activator was a solution of sodium hydroxide and sodium silicate. The industrial liquid sodium silicate (Na₂O 11.7 wt%, SiO₂ 32.8 wt%, and H₂O 55.5 wt%) was manufactured by Silica Egypt Company, Burg Al-Arab, Alexandria, Egypt and SiO₂/Na₂O has a silica modulus of 2.80. The NaOH flakes with 99% purity were purchased from EL-Goumhouria Chemical Company in Cairo, Egypt.

2.2. Geopolymer synthesis

2.2.1. Specimens preparation

Each of the considered additives (GGBFS and MK) are firstly mixed thoroughly in the dry state to attain complete homogeneity. The composition of the various mixes in addition to, the liquid/solid ratio which gave standard consistency are given in Table (2). MK, MK-S1 & MK-S3 samples are prepared by using 100% MK and mixing it with 20% & 40% of GGBFS respectively as shown in Table (2).

The sodium silicate liquid (SSL) and sodium hydroxide pellets (SH) are mixed and agitated to create the alkali activator (AA) in the first step. Because the temperature of the combination was originally fairly high, it was given some time to cool

to room temperature before continuing. Then, add various mixing ratios of alkali activator solution to each dry mix, and mix them for about 5 minutes on a smooth, non-absorbent surface. We use the standard Vicate device to verify the geopolymer pastes water consistency after thorough mixing. The pastes are then placed in stainless steel one-inch in dimension cube-shaped moulds, and during the first 24 hours, the

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

Type	Oxide constituents (%)											L.O.I
	SiO ₂	CaO	MgO	Al ₂ O ₃	Fe ₂ O ₃	K ₂ O	P ₂ O ₅	SO ₃	Na ₂ O	TiO ₂	Cl ⁻	
MK	64.8	0.52	----	30.1	0.55	----	0.06	0.13	0.1	2.7	----	0.73
GGBFS	32.86	42.56	11.58	7.02	1.14	0.15	----	2.5	0.29	----	----	0.93

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

Mix	MK (%)	GGBFS (%)	Na ₂ SiO ₃ : NaOH ratio	L/S ratio
MK-S1	80	20	2.5:1	0.48
MK-S3	60	40	2.5:1	0.44

Water of consistency:

Using the Vicate device, the standard water's consistency is determined in accordance with ASTM standards [36]. The amount of liquid necessary to make a paste with a standard consistency is the amount that will allow the vicate plunger, which has a diameter of 10 mm, to settle to a point 5 to 7 mm from the bottom of the vacatemould.

2.3 Adsorption experiments

At 30 °C 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. Utilizing the calibration curve and Shimadzu spectrophotometry, absorbance at the maximum wavelength (max = 504 nm for reactive red 195) was detected. The amount of dye that was adsorbed onto the adsorbent, q_e (mg/g), was calculated using a mass balance relationship.

$$q_e = (C_0 - C) V/W$$

Where W is the weight of the adsorbent, V is the solution volume in litres (L), C_0 is the initial dye concentration in milligrammes per litre (mg/L), C is the equilibrium liquid-phase dye concentration in mg/L.

$$\text{Removal efficiency \%} = 100 (q_e / C_0)$$

3. Results and discussion

3.1 Effect of pH

We could reveal here that figure 2 provides numerous instances of how the removal efficiency% changes when reactive dye red 195 effluents are used, and the examples are done at different pH levels in the adsorption solution. The ideal pH value,

moulds are held at a relative humidity of 100% to achieve the final setting and hardening. Following the moulding process, the cubes were taken out of the mould and hydrated at 100% relative humidity for 7 days

ranging from 2 to 10, for a geopolymer based on metakaolin mixed with slag MK-S1 MK-S3 dye-treated was examined. The results in Figure 2 conclusively show that the % efficacy of colour removal reduces with rising pH for all wastewaters. For both geopolymer combinations (MK-S1 and MK-S3), decolorization effectiveness was greatest at pH 2. The best outcomes were 38.1% and 59.16% for MK-S1 and MK-S3, respectively.

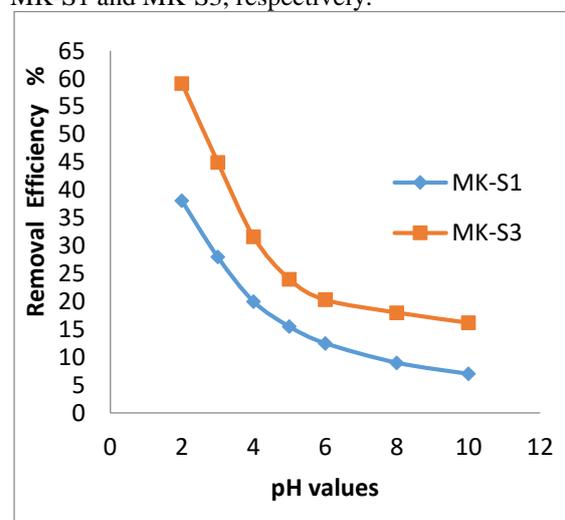


Figure 2. Effect of pH on dye removal efficiency % (Time 1hr , Temperature 30 °C, wt. of adsorbent 0.01g, concentration of dye 20 mg/L)

3.2 Effect of adsorbent dosage

It is important to note that Figure 3's results clearly demonstrate the correlation between the results of the adsorption concentration and the removal efficiency percentage. Using reactive dye red 195 effluents , the adsorption of the dye under study

was examined at various concentrations (0.01-0.1 g/50 ml) of geopolymer cement for two hours.

For MK-S1 and MK-S3, the dye concentration was 20 mg/L at pH 2. The findings unmistakably demonstrate that a decrease in the weight of the adsorbent is associated with an improvement in removal efficiency. According to our calculations, MK-S1 had a removal efficiency of 38.1% at 0.01 g/50 mL for geopolymers and MK-S3 had a removal efficiency of 62% at 0.02 g/50 mL for geopolymers.

3.3 The effect of Time

Reactive dye removal was assessed at various time intervals ranging from 1 to 5 hours in order to determine the proper length of response of the reactive dye with geopolymer cement components.

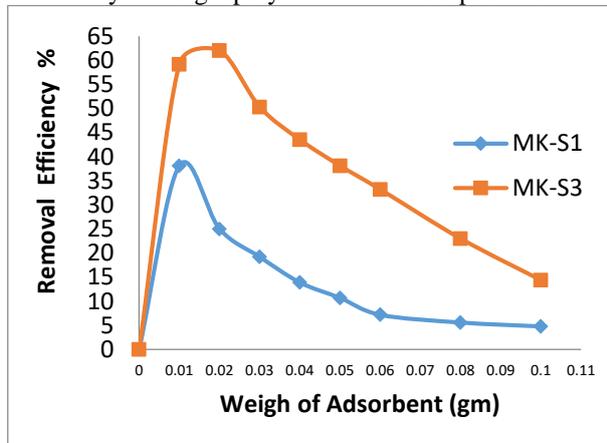


Figure 3. Effect of adsorbent weight on the removal efficiency % (Time 1hr, Temperature 30 °C, concentration of dye 20 mg/L, pH 2)

Figure 4's results show that as the adsorption period is prolonged to two hours, the rate of colour removal efficiency increases, peaking at 60% for the geopolymer mixture MK-S1 and 84.1% for the geopolymer mixture MK-S3 before decreasing for both combinations.

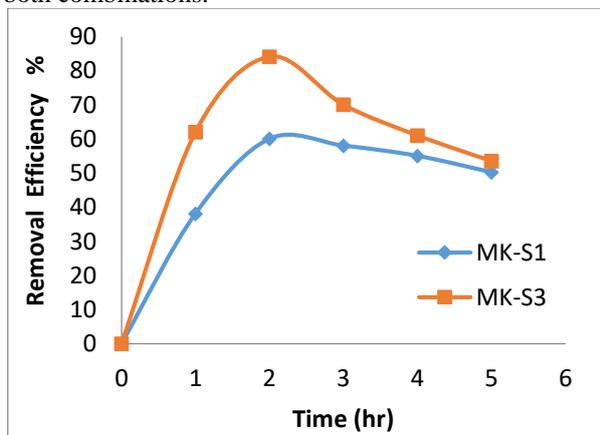


Figure 4. Effect of time on the removal efficiency % (Weight of adsorbent 0.02g, for Mk-S1 and 0.01 for

MK-S3, Temperature 30 °C, concentration of dye 20 mg/L, pH 2)

3.4 Effect of Dye Concentration

The results given 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 employing the constant weight of the cured geopolymer combination MK-S1 and MK-S3 with time and the right pH. There were various dye concentrations (5-100 mg/L) utilised to examine the dye's absorption. With a dye concentration of 5 ppm, MK-S1 had a maximum removal effectiveness percentage of 74% after 2 hours at pH 2. While MK-S3 had a maximum removal effectiveness of 84.1% at the same time and pH but with a dye concentration of 20 ppm.

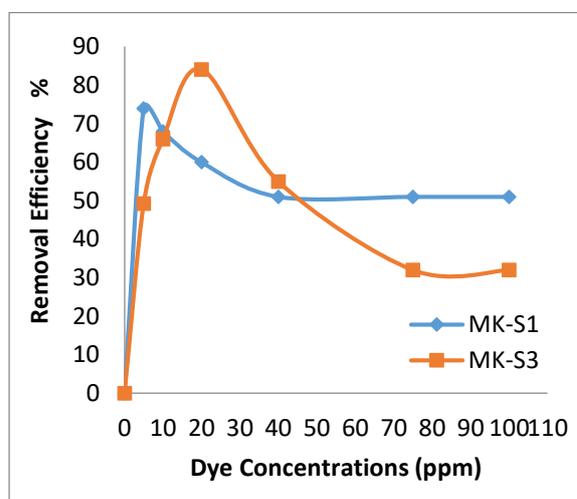


Figure 5. Effect of dye concentration on the removal efficiency % (Weight of adsorbent 0.01g for MK-S1, and t 0.02 g for MK-S3, Time 2hrs and pH2, Temperature 30 °C)

4. Conclusions

The results of this study open the way for the prospective application of a geopolymer based on metakaolin-slag combinations at a rate of 80 to 20 percent MK-S1 and 60 to 40 percent MK-S3 to remove the remaining colour in reactive red dye 195 dyeing pools. Further evidence that the presence of 40% slag was helpful for colour decontamination comes from the fact that the reactive red dye 195 under study had a better absorption capacity when using MK-S3 than when using MK-S1.

5. Conflicts of interest

“There are no conflicts to declare”.

6. Acknowledgement

Supports of this work provided by Anhalt University of Applied Sciences and the facilities through a Molecular biotechnology Master of Science for Pharmacist Sara Morsy Ahmed are highly appreciated

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