Synthesis and Utilization of Inorganic Geopolymer for the Adsorption of Acidic and Basic Dyes

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ABSTRACT

In present study, adsorption of Methylene blue (MB) and Congo Red (CG) dyes from aqueous solution on the surface of synthesized inorganic geopolymer (GP) were studied under the optimized condition of contact time, initial concentration of dyes, amount of adsorbent, pH of the solution and temperature. The concentrations of dyes prior to the interaction with adsorbent and later the progression of adsorption was evaluated by using spectrophotometer. The surface structures of the selected adsorbent were studied through Scanning electron microscope (SEM) and FTIR analysis. Two adsorption models such as Langmuir and Freundlich adsorption isotherms were used to obtain adsorption equilibrium data which is used to calculate the values of relevant constants. Thermodynamic parameters like Gibbs free energy, enthalpy and entropy demonstrates the spontaneity of the systems, transfer of energy between system to surrounding and randomness of the system were also calculated.

INTRODUCTION

Pollution can be seen in a variety of places, including the atmosphere, water, and soil pollution. The water pollution is one of the major environmental issues on the global scale. Dyes have been used in the textile, plastic, paper, leather, and printing industries, that increase the economic growth but producing a bulk amount of dye wastewater, that is directly affect our ecosystems. Dyes shows high resistivity towards light, heat and biodegradability which tends to increase their bioaccumulation in ecosystem (Bano *et al*. 2024).

The large number of unsustainable industrial development and increase in population are the major cause of water scarcity due to release of untreated waste water in water bodies (Umejuru *et al*. 2024). The industrial discharge waste material and all the pollutants and contaminants released from industries also pollute the environment. The main source of water pollution is due to the industrial effluent that containing complex nature of pollutants such as organic and inorganic substances like pharmaceutical residues, toxic metals and mainly soluble reactive dyes (Khan, Pathak and Fulekar).

Many physical, chemical and biological techniques are used to eliminate the colour from the pollutants, but adsorption is more competitive than all other processes due to its simple design, high efficiency, low maintenance cost, highly economic benefits, and have higher rate towards pollutants removal (Kausar *et al*. 2023).

In recent years, one of the most important adsorbent, the geopolymers are tremendously used for the water purification process because of its ease of synthesis, higher adsorption capability and low-cost process (Nurlina *et al*. 2024). Based on their unique zeolite-like three-dimensional network structure, geopolymer has great porosity and more surface area to adhere organic and inorganic pollutants and plays an essential role in the removal of contaminants from waste water (Bassam *et al*. 2024).

OBJECTIVE

The objectives of this study are:

- To investigate the adsorption capacity of inorganic geopolymer to remove the acidic and basic dyes.
- Determine the critical adsorbent characteristics and parameters which govern adsorption onto surface of activated modified form of inorganic geopolymer.

- Quantitative Structure-Activity Relations (QSAR) can be used to predict these critical properties based on dye molecular structures, binding force, adsorption isotherm, thermodynamic parameters and its effect on adsorption.
- Thermodynamic comparative study of adsorption of dyes on the surfaces of inorganic geopolymer at different concentration, amount, and contact time and at different temperatures.

METHODOLOGY

Preparation of Adsorbent

Synthesis of Geopolymer

The raw kaolin was calcined at temperature of 800° C for about 3 h to convert the kaolin into metakaolin state. After calcination the synthesis of geopolymer is based on the many steps. First step is to make the alkaline activator by using 12M sodium hydroxide (NaOH) solution and sodium silicate (Na_2SiO_3) powder. The sodium silicate initially dissolved in NaOH at the mass ration 2.5. The shaker was used to stir the solution at room temperature for about fifteen minutes. Second step was the mixing of powdered metakaolin produced from the calcination of kaolin at 800° C and mixed with the activator solution and stirring at the room temperature for fifteen minutes to get the good homogenization. The desired consistency of the product geopolymer was obtained by adding the distilled water at the ration water/metakaolin of 0.34. The mixture was placed in an oven at 60° for 24 hr (El Alouani *et al*. 2019).

Preparation of Stock Solutions

The stock solutions of $1x10^{-3}$ M concentration of Congo Red (Mol.wt 696.68) and Methylene blue (Mol.wt 319.86) were prepared by taken the amount of 0.174g of CR and 0.079g of MB. The stock solutions were prepared using distilled water in 250.0 ml volumetric flask. From stock solution, the other desired concentrations of sample solutions were made by dilution in 100.0 ml volumetric flasks.

Optimization of Contact Time, Initial Concentration, Amount and pH

Adsorption of Methylene blue (MB) and Congo Red (CG) textile dyes from aqueous solution on the surface of a synthesized inorganic geopolymer (GP) were studied under the optimized condition of contact time, initial concentration of dyes, amount of adsorbents and pH of the solutions. The concentrations of dye prior to the interaction with adsorbent and later the progression of adsorption was evaluated by using spectrophotometer. The surface structures of all the selected solid materials were studied through Scanning electron microscope (SEM) and FTIR analysis.

Adsorption Isotherm Study

The solutions of variable concentrations of dyes were prepared and then initial absorbance was measured using spectrophotometer. A particular volume of each dye solution was held in different conical flask with optimized amount of adsorbents and placed on orbital incubator shaker at the desired temperatures (303-333±2K) and then shaken for an optimized time period. After shaking, the solutions were filtered using Whatmaan42 filter paper and then final absorbance of solutions was measured spectrophotometrically. The initial and final absorbance data were used for the further calculations of different adsorption isotherms. Results are shown in the Figure **1.1**,**1.2** and table **2.1**,**2.2**.

RESULT

Graph

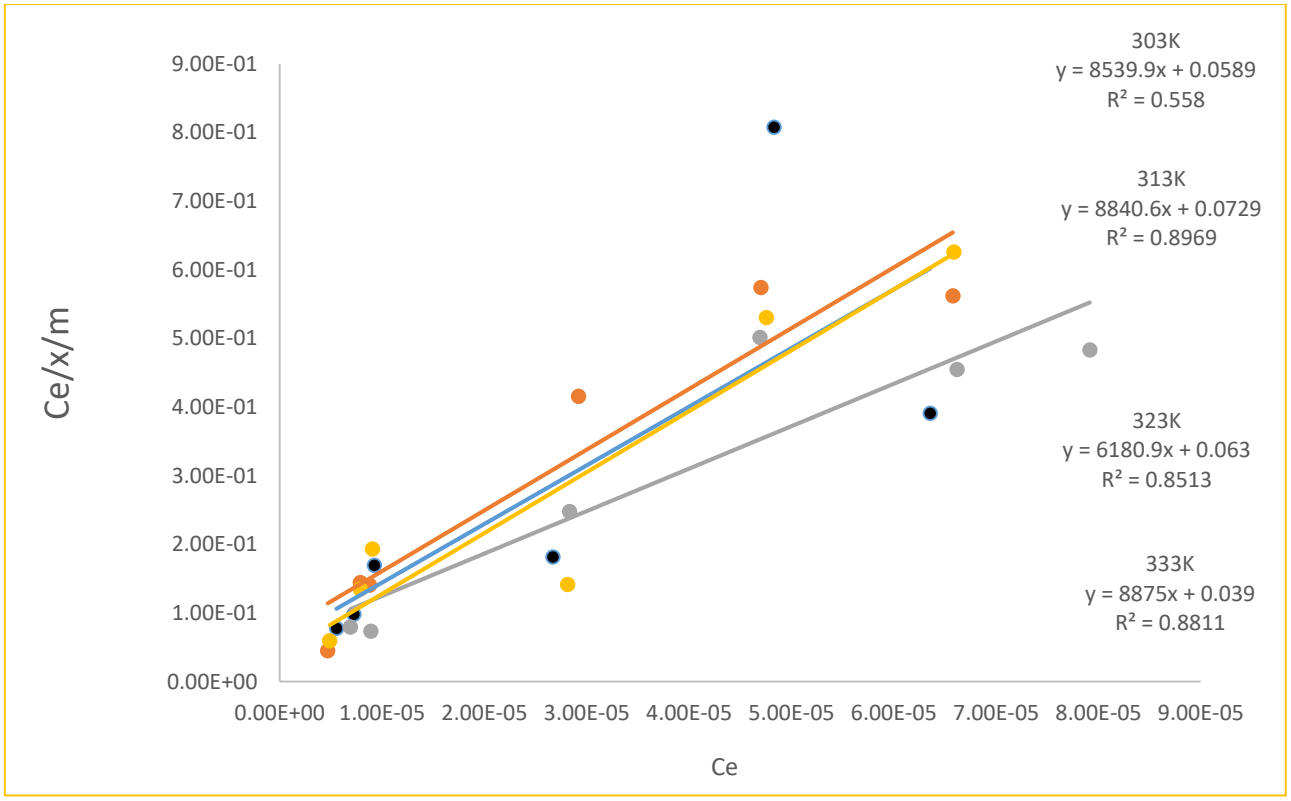

Figure 1.1. Langmuir adsorption isotherm for the adsorption of Congo red on the surface of geopolymer.

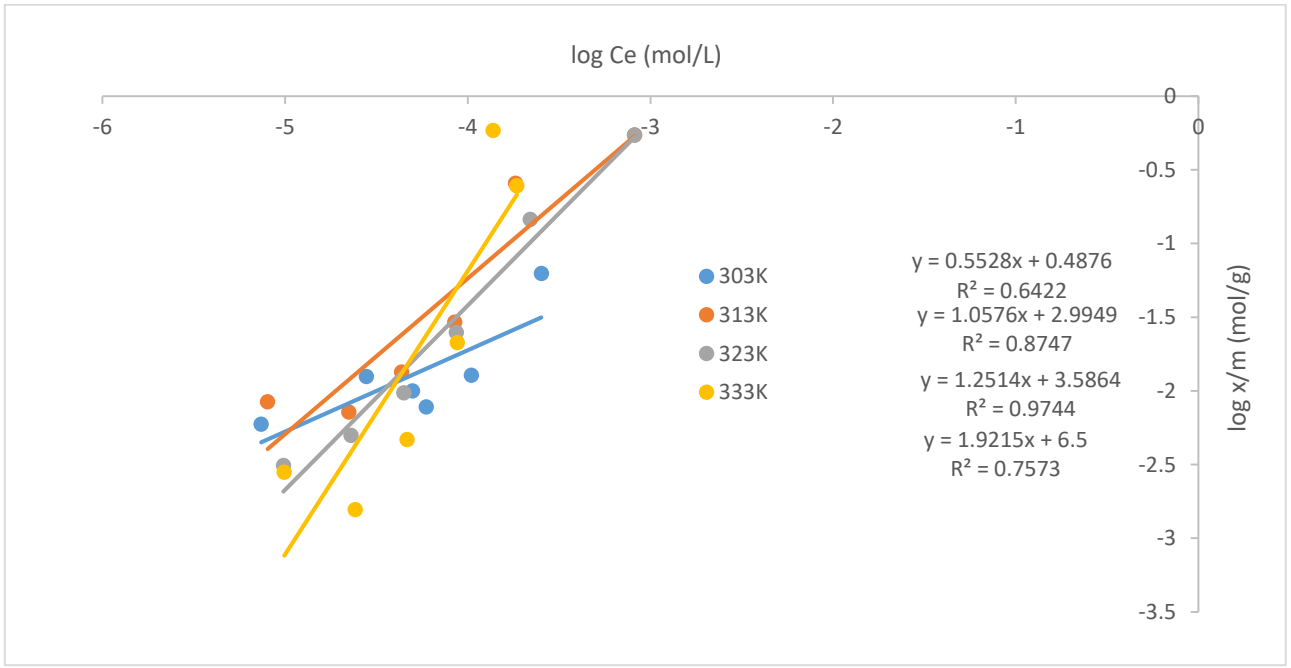

Figure 1.2. Freundlich adsorption isotherm for the adsorption of Methylene Blue dye on the surface of geopolymer.

Table

Table 2.1. Langmuir Adsorption Isotherm Parameters for the Adsorption of Congo Red on the Surface of Geopolymer.

Temperature	K_L (dm³/mol)	Vm (mol/g)	R2
303K	6.90×10^{-06}	16.978	0.558
313K	8.25×10^{-06}	13.717	0.8969
323K	1.02×10^{-05}	15.873	0.8513
333K	4.39×10^{-06}	25.641	0.8811

Table 2.2. Freundlich Adsorption Isotherm Parameter for the Adsorption of Methylene Blue Dye on the Surface of Geopolymer.

Temperature	K_F(dm³/mol)	n	R^2
303K	3.07326492	1.808	0.6422
313K	988.325498	0.945	0.8747
323K	3858.33559	0.799	0.9744
333K	3162277.66	0.520	0.7573

CONCLUSION

In case of GP-CR system, there was an increase in the value of K_L with the increase in temperature (303K to 323K) then at 333K, it decreased. It showed that the interaction of adsorbate-adsorbent was strong at high temperatures except 333K.

For the adsorption of MB dye on the surface of GP, there were decrease in the value of K_L with the increase in temperature (303K to 333K). It showed that the interaction of adsorbate-adsorbent was strong at low temperature for GP-MB.

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