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Cost Efficient Removal of Toxic Acid Dye Using Abundantly Available Waste Material

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Abstract

The present study describes the removal of toxic acid dye at reduced cost. The surface of adsorbents and dyes exhibited a strong electrostatic interaction at pH 7.0 in the present study. The results clearly show that calcinized form of adsorbent has better dye adsorption ability as compared to native form. At lower dose of adsorbent higher efficiency of dye removal occurred. Higher adsorption of acid red dye occurred at higher initial dye concentrations. The obtained results indicated that the R^2 value for the Freundlich isotherm is larger than 0.96, implying that it fits best to adsorption process. The adsorption of acid red dye occurred in two phases. In the first initial stage, during 120min, acid red dye adsorption was very fast followed by a slower phase till the equilibrium time of 240 min. The kinetics data revealed that pseudo second order explains the results better. Maximum dye removal occurred at 40 ˚C.

Keywords: Acid dye, Toxic, Pollutant, Adsorption, Low cost

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1. Introduction

Water plays an important role for all living organisms, including economic development and food production. Lage amount of industrial process utilize water and almost 40 percent of food supply is cultivated under irrigation worldwide. All sectors including development projects, economic growth, and environmental conditions are influenced by the quality and availability of water. Human activities and increasing industrialization, fossil fuels combustion, urbanization, climate change, and population growth along with many other factors are declining and affecting the quality of water. Developing countries are poorly managing and monitoring the drinking water quality. In many countries, up to 40% water borne diseases results from industrial wastewater contamination [1]. Among the classes of pollutants dye is one of the important class, and their discharge in water is not good and sometimes it is difficult to remove the dyes from wastewater due to their synthetic nature and diverse structure [2-3]. The different dyes are leather tanning and textile [4-5] industry, color photography, food, paper production, photo-electrochemical cells, light-harvesting arrays, chemical, and biological research, agricultural, wood staining, hair coloring, pharmaceuticals and medicine [6-8]. About 40,000 synthetic pigments and dyes are consumed in different industries throughout the world.

The dyeing industry is one of the largest consumers of dyes [2]. Around 15% of non-biodegradable synthetic dyes are released into different waterbodies as textile waste effluents during the process of dyeing. According to World Bank, approximately 17%–20% of water pollution is due to textile dyeing and finishing industries [9]. The removal of water-soluble and bright colored dyes including acidic and reactive dyes, is very difficult, has been reported in the literature [10-13]. The presence of dye, even at a low concentration affects transparency and gas solubility in water. The aquatic organisms are badly affected by dyes, because they reduce the entering of sunlight into the water, and hence decrease photosynthesis [14]. Photocatalysts are substances that have both hydrophilic nature and dye decomposition properties. Large toxic substances are converted into small environmentally friendly molecules in the presence of photons or sunlight. Photocatalysts like titanium dioxide (TiO_2) are used in food and cosmetic products as these are harmless. The use of magnetic materials in the form of nanoparticles for the removal of dyes from water is an emerging field of research. Due to magnetization properties of these materials under the influence of the magnetic field, the separation of nanomagnetic materials become very easy [15]. Nanoforms of adsorbent materials can be efficiently used to remove dyes from water [16] and [17-20]. The present study reports the use of a low cost and very efficient stone powder material for the removal of acid red dye from water.

2. Materials and Methods

2.1. Materials

White powder waste (WPW) was collected from a marble factory and calcinized in furnace at 700˚C for 4h to prepare Calcinized white powder waste (CWPW). All the chemicals used during present study were of analytical grade. Acid red dye was collected from local dye market near clock tower, Faisalabad, Pakistan.

2.2. Methods

To determine the effect of pH was tested at 5, 6, 7, 8, and 9 pH. The pH of solutions was set using a 1N solution of nitric acid and a 1N solution of sodium hydroxide [21]. The effect adsorbent dose was determined at 0.5, 1, 2, 3, 4 g/L. [18]. The effect of initial dye concentration was determined at 5, 10, 15, 25, and 50 mg/L [22]. The effect of time and temperature was determined by performing experiments at temperature of 30, 40, 50, 60, and 70 ˚C and for a contact time interval of 15, 30, 60, 120, and 240 minutes. After completion of every experiment, solutions were separated using syringe filter (0.45μm) and absorbance was determined using a UV-Visible spectrophotometer at the λ_{max} of acid red dye [22].

3. Results and discussion

3.1. Spectrophotometric analysis

Spectroscopic analysis are used extensively as these are low cost, high sensitivity, good accuracy and no destructive technique [23]. The absorption wavelength of acid red dye was scanned through 330 to 1000 nm. λ_{max} (Lambda-max) of acid red dye was found to be 521 nm. There was only one absorption peak detected in acid red dye absorption spectra. At λ_{max} sensitive changes in the solution concentrations can be accurate measured [1]. Standard curves are plotted to determine the relationship between two quantities or variables. Standard curves are used for finding the relationship between absorbance and concentration. The standard curves for acid red dye were drawn using standards of 5, 10, 15, 25, 50, 75 and 100 ppm.

3.2. Effect of pH

pH effect on the surface binding sites of the sorbent and has a significant impact on dye sorptive process. pH significantly influences the degree of ionization of the adsorbate in the solution, adsorbent surface charge, and surface functional groups dissociation. At low acidic to neutral pH conditions, the surface of adsorbent with positive charge surface of the adsorbent and dye are electrostatically attracted to each other and resultantly dye adsorption increases. However, increase in pH over neutral pH results in diminishing the positively charged adsorbent sites and overall negative charge appears on the adsorbent's surface. Resultantly, the competition between OH- ions and dye ions occurs at high pH and dye sorption is reduced. The effect of the pH (5, 6, 7, 8, 9 and 10) on acid red dye adsorption is shown in the fig. 1. The results clearly show that calcinized form of adsorbent has better dye adsorption ability as compared to native form [24]. The calcination of adsorbent material removes volatile materials and impurities from adsorbent material.

3.3. Effect of dose

The process of partition occurs in adsorption between the adsorbent and the fluid phases. The effect of adsorbent dosage on acid red dye removal is shown in Fig. 2. At lower dose of adsorbent higher efficiency of dye removal occurred [25]. It suggests that small amount of adsorbent will be beneficial in removing higher quantities of dyes [26]. At higher doses lower dyes uptake occurs per surface are due to agglomeration of adsorbent molecules [27].

3.4. Effect of initial dye concentration

The effect of initial dye concentration was studied by varying initial dye concentration from 5 to 50 mg/L (Fig. 3). After calcination, the adsorption of dyes increased as compared to pure forms. Higher adsorption of acid red dye occurred at higher initial dye concentrations. This might be due to availability of higher number of dye molecules in the solution for interaction with adsorbent molecules [25-28-29]. Adsorption isotherms effectively describe dye adsorption behavior in solid-liquid adsorption systems. Langmuir, Freundlich, Temkin, and Dubinin-Radushkevich (DR) are commonly used to predict adsorption mechanisms (Table 1). Acid red dye adsorption was best described by Freundlich adsorption isotherm as shown by close agreement between calculated and experimental q values in addition to higher R^2 values.

3.5. Effect of time

The adsorption of acid red dye occurred in two phases (Fig. 4). In first initial stage for 120min, acid red dye adsorption was very fast followed by a slower phase till equilibrium time of 240 min. The initial amount of dye is also critical because it serves as the catalyst for mass transfer between the adsorbent and solution [25-29]. Pseudo first and second order model were used to describe the dye adsorption process. Pseudo second order model fits well to acid red dye adsorption data as shown by close agreement between experimental and calculated uptake capacities and higher R^2 values (Table 2).

3.6. Effect of temperature

Acid red dye adsorption increased on increasing temperature from 30 to 40 ˚C and then decreased on increasing temperature 40 to 70 ˚C (Fig. 5). Maximum dye removal occurred at 40 ˚C which means that dye removal can be efficiently conducted at ambient conditions without any requirement of elevated temperatures [29].

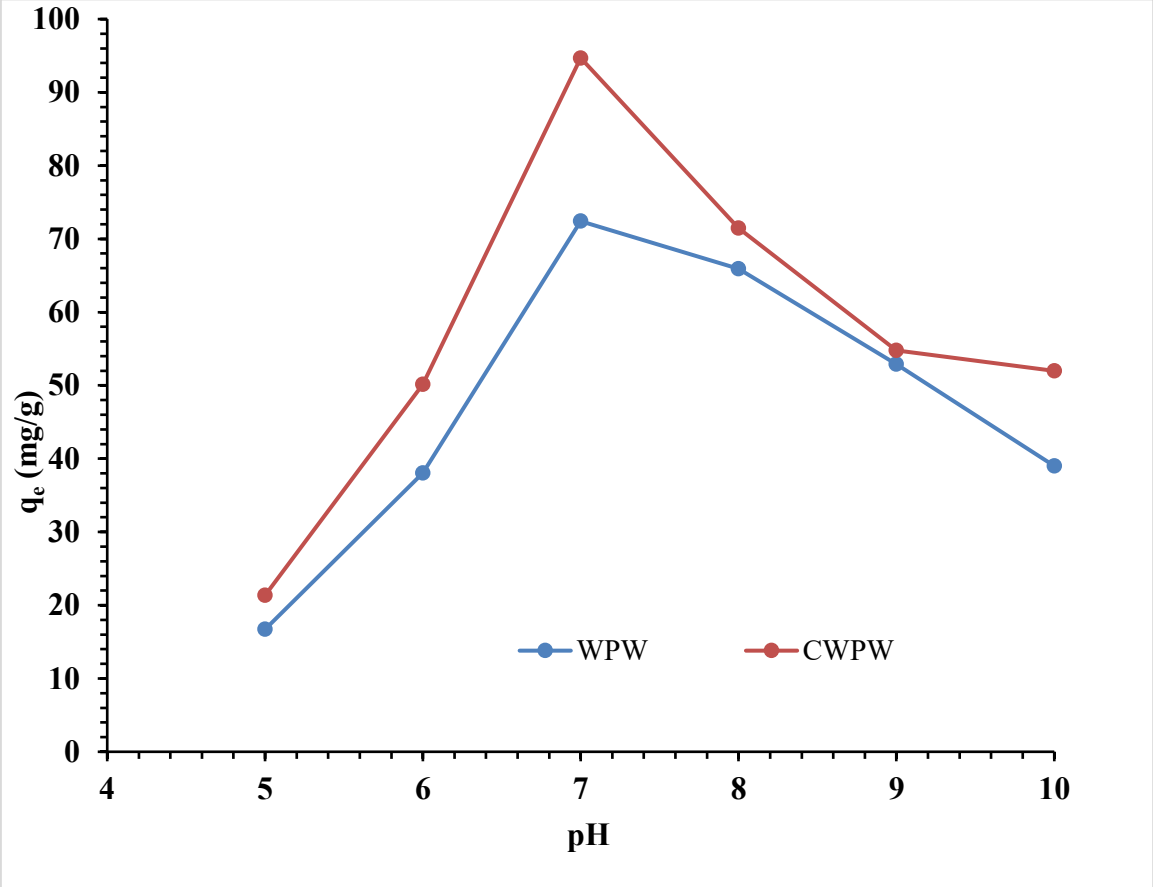

Fig. 1. Effect of pH on acid red dye removal

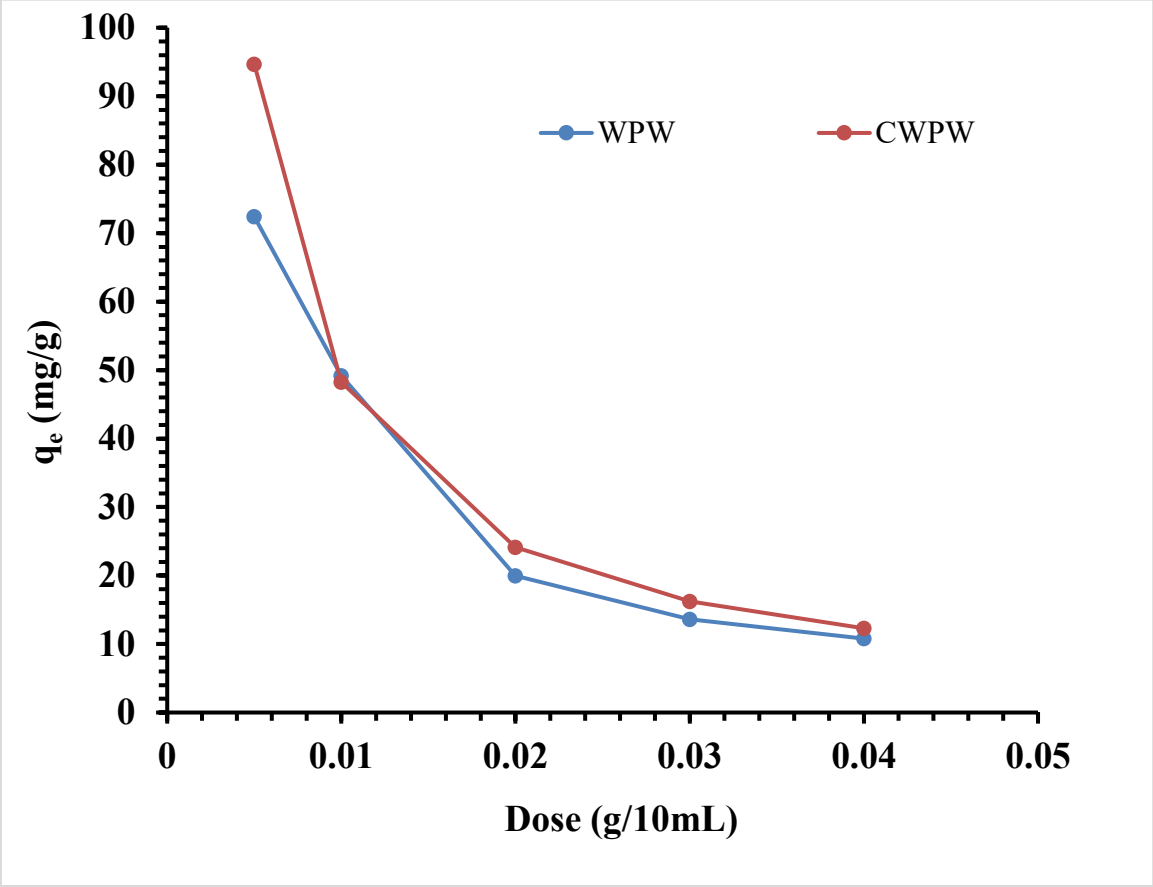

Fig. 2. Effect of dose on acid red dye removal

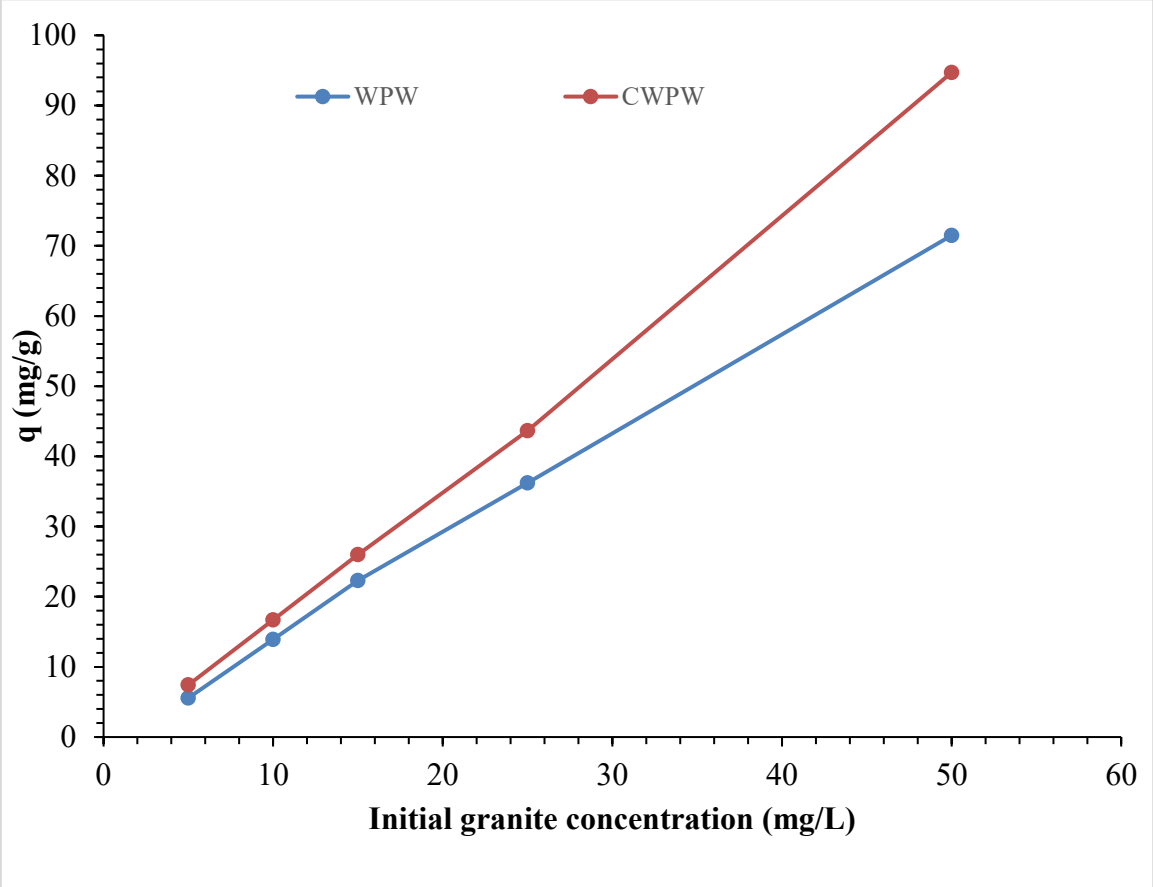

Fig. 3. Effect of initial concentration on acid red dye removal

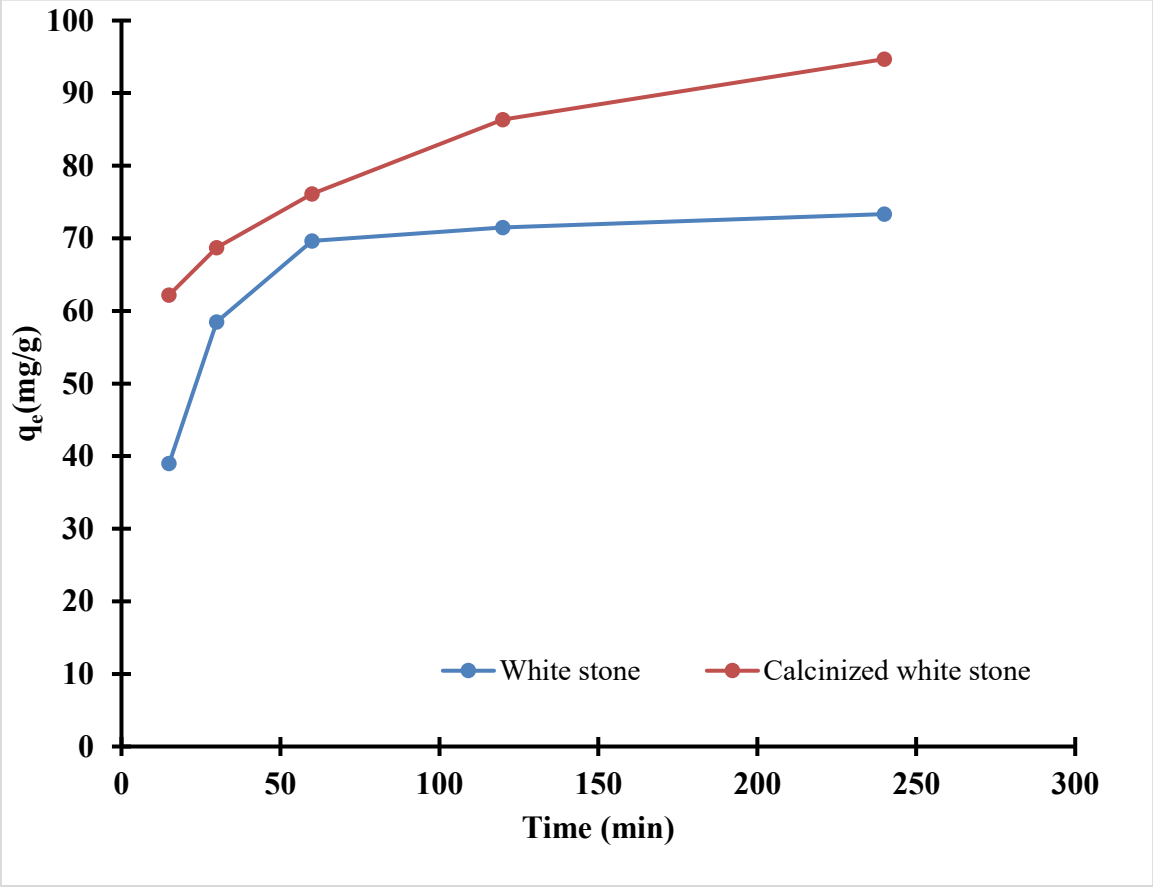

Fig. 4. Effect of time at 30 ˚C on acid red dye removal

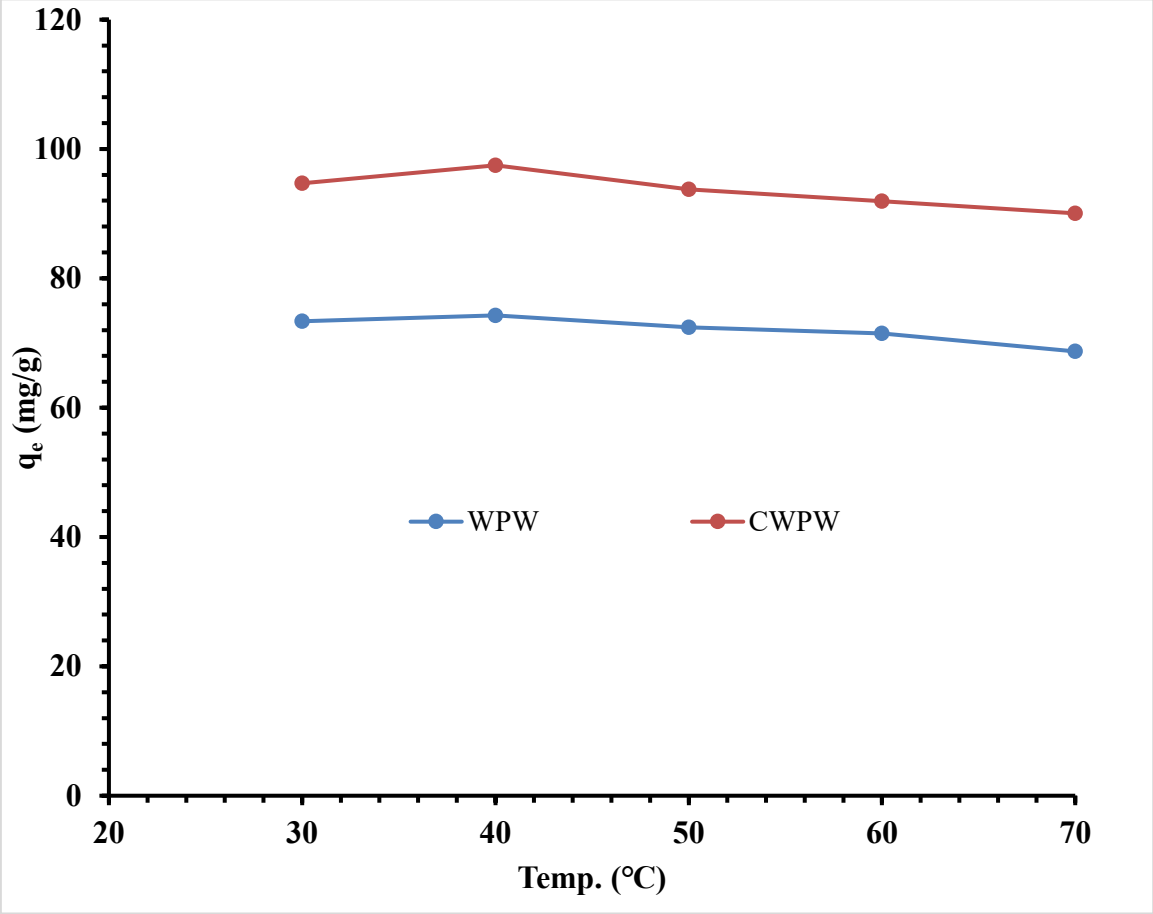

Fig. 5. Effect of temperature on acid red dye removal

Table 1. Adsorption models for acid red

Adsorbent	Langmuir Isotherm				Freundlich isotherm				Dubinin Radushkevich Isotherm			Temkin isotherm model				Harkin–Jura isotherm model		
	Q_{Exp} (mg/g)	R^2	Q_{Cal}	K_L	R^2	Q_{Cal}	K_f	1/n	R^2	Q_{Cal}	β	R^2	A_t	Qcal	B	R^2	Q_{Cal}	A	B
White stone	71.48	0.185	120.4	0.027	0.9219	87.388	2.694	1.2915	0.9726	61.6208	3.00E-06	0.8631	0.310	37.989	24.87	0.4643	12.0205	33.557	0.9549
Calcinized form	94.69	0.927	13.12	0.278	0.9773	77.806	2.747	2.8418	0.9133	132.687	2.00E-06	0.8688	0.231	9.599	33.48	0.7676	9.4334	22.222	0.7615

Table 2. Kinetic models for acid red dye

Adsorbents	Pseudo first order kinetics				Pseudo second order kinetics		
	q_e (mg/g) Cal	$K_{1, ads}$	R^2	q (mg/g) Exp	q_e (mg/g)	$K_{2, ads}$	R^2
White stone	34.4349	0.02671	0.8792	73.34	76.92307	0.001279	0.9989
Calcinized white stone	39.084	0.01289	0.9988	94.69	99.0099	0.000729	0.9981

4. Conclusions

Acid red dye is an extremely toxic dye that not only disturbs human life but also damage ecosystems and environment. White stone powder has shown higher dye uptake capacity as compared to other adsorbents. The dye adsorption capacity of white stone-powder further increased on calcination. The present study clearly concluded that acid red dye can be effectively removed using calcinized form of white stone as compared to native form at pH 7 and 40 ˚C.

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