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Uptake of Reactive Black 5 by pumice and walnut activated carbon: Chemistry and adsorption mechanisms

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ABSTRACT

The potential of using pumice and walnut wood activated carbon as low-cost adsorbents for the removal of the diazo dye Reactive Black 5 (RB5) from aqueous solutions was investigated. The Langmuir isotherm fit to the data specified the presence of two different natures of adsorption sites with different binding energies on the AC-W surface. Kinetic modelling showed that the adsorption behaviour and mechanism of RB5 for both adsorbents is believed to happen via surface adsorption followed by diffusion into the pores of the AC-W and pumice. The main adsorption mechanisms are hydrogen bonding, electrostatic bonding and n–π interactions.

1. Introduction

Coloured effluents have been extensively produced for years from different industries such as textile dying and pigmentation, drug, food, tannery, cosmetic, and pulp and paper [1]. Owing to their colouration, dyes could cause aquatic flora pollution and aesthetic pollution (colour is noticeable at a dye concentration as low as 1 mg L^{-1}), and even if the dye's toxicity is limited, the degraded by products should be considered as a potential source of pollution. Synthetic dyes cause, therefore, serious environmental pollution and cannot be discharged into the environment without any treatment. Reactive Black 5 (RB5) is one of the most commonly used reactive dyes in the textile dying industries. Textile industries are basic industries in several countries and their major problem is the production of large amounts of coloured wastewater originated from dyes and pigmentation applications. In a dying process approximately 15% of the total amount of the dye used is lost in the discharged effluent [2]. Most of the used dyes are synthetic dyes, which are commonly grouped into acid, reactive (or fibre-reactive), direct, basic and azoic dyes [3]. It has been estimated that approximately 70% of all the known commercial dyes produced are azo dyes [4,5]. Most azo dyes contain only one azo group, but some contain two (diazo), three (triazo) or more and have been extensively used in textile dying due to their low cost, easy application and low toxicity [4–6]. Synthetic dyes have usually one or several benzene rings, leading, therefore, to low degradation rates and possible formation of toxic degradation by-products. Effluents containing azo dyes should be, therefore, treated prior to their discharge into the environment.

So far, several methods including biological treatments, physical and physico-chemical processes have been tested for the treatment of dye-containing effluents [7–10]. Biological processes, the most cost-effective ones for wastewater treatment, have been extensively studied [11–19] but did not always appear relevant for dye removal owing to the low or total absence of biodegradability of this class of pollutants [20]. Physico-chemical processes, such as oxidation or advanced oxidation processes are efficient [21] but costly due to the high required energy. Physical techniques such as adsorption, coagulation and flocculation, electro-flocculation, ultrafiltration and reverse osmosis can also be efficiently used to remove these recalcitrant pollutants [16,22].

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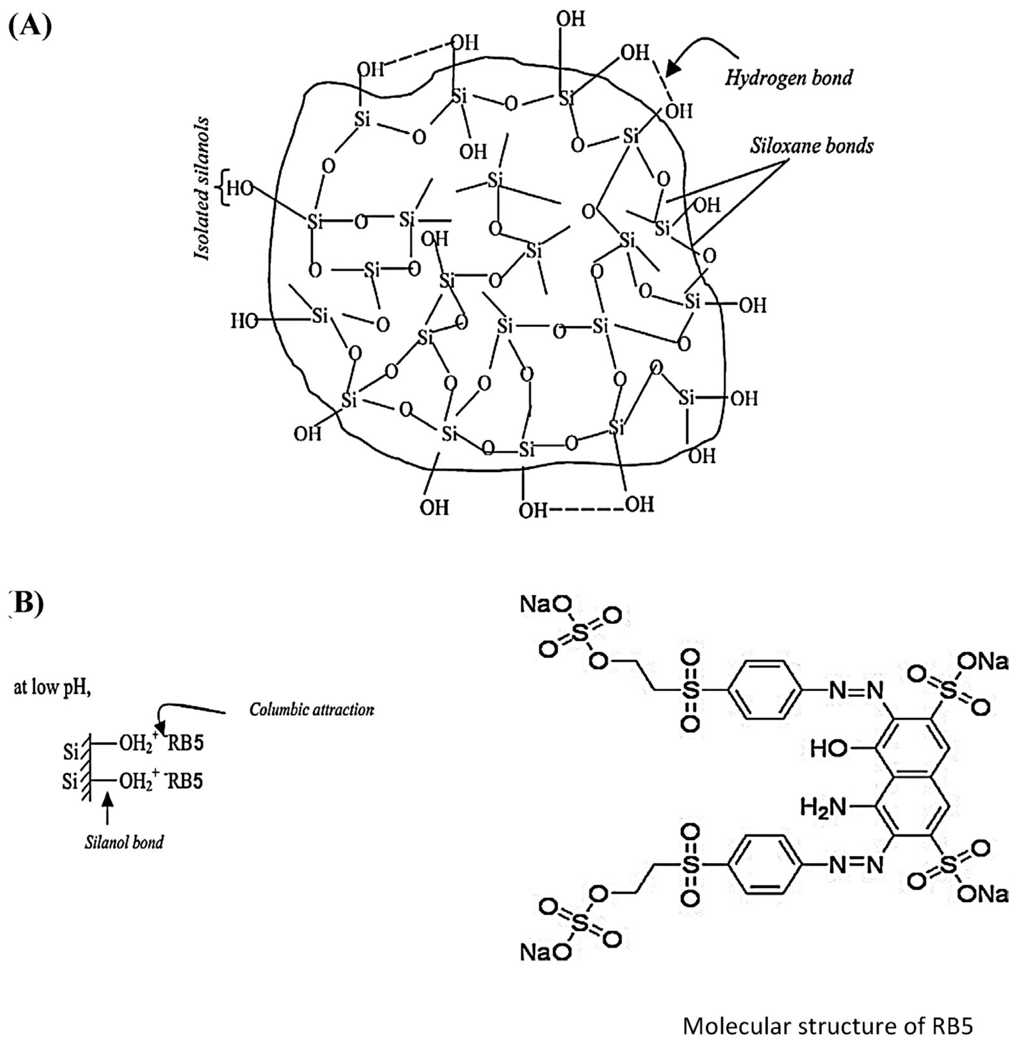

Fig. 1. (A) Structure of silica surface showing its silanol groups [30]. (B) Schematic representation of adsorption mechanism of RB5 at low pH value.

Among them, adsorption is a common process that has been extensively used in the field of water and wastewater treatment. The most usual adsorbent used is activated carbon, which appears especially useful for the removal of organic pollutants [22]. However due to their high cost, the replacement of commercial activated carbons by naturally available and low-cost adsorbents has attracted a considerable interest in recent years. So far, researchers have tested many different types of adsorbents including chitosan [23], aluminium oxide hydroxide [24], fly ash [25], etc. in order to remove organic and inorganic pollutants from water and wastewater. Pumice is a volcanic rock coming from solidified volcanic lava and can be found in many places worldwide. In particular, in Iran, this rock can be abundantly found in many parts, especially in Azerbaijan. Pumice has high porosity and low weight where it normally either floats on water or sinks slowly. Pumice has a high silica content (generally 60–75% SiO_2), which results in high abrasive characteristics. Its hardness is about 5–6 according to the Mohs scale [26–28]. The silica surface comprises silanol groups that extent over the matrix of the silica as shown in Fig. 1(A). The silanol group is a very active group, which can react with many polar organic compounds and various functional groups. The purpose of this work was to examine the potential of using pumice as a low cost adsorbent to remove a widely used azo dye namely, RB5. To test the efficiency of the studied adsorbent it was compared with another low cost adsorbent namely, activated carbon prepared in the laboratory from walnut wood. The possible use of activated carbon made from a naturally available and low-cost resource, such as walnut wood, for the removing of various pollutants has been previously studied [29].

The study will also illustrate the significance of the different functional groups, available on the surface of pumice and AC-W, on the different adsorption mechanisms. Pumice surface ends with OH groups and oxygen bridges, which would perform as adsorption spots. In adsorption methods, it is vital to identify the features of these various adsorption spots or sites and gain a better understanding of their role in the adsorption process. The heteroatoms on the AC-W surface would take a vital role on its dye removal applications [31]. Its surface principally comprises oxygen, nitrogen, hydrogen, halogen, etc. Among these heteroatoms, the oxygen-containing functional groups such as carbonyl, carboxyl, and phenol are the broadly documented and the greatest common species created on the surface, which would considerably affect its performance in dye adsorption and remediation.

2. Materials and methods

2.1. Reagents

All the chemicals used in this study were purchased from Merck Co. The azo dye, Reactive Black 5 (RB5), was kindly provided by Alvan Sabet (Iran) and used as received without further