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A comparative adsorption study with different industrial wastes as adsorbents for the removal of cationic dyes from water

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Abstract

Four adsorbents have been prepared from industrial wastes obtained from the steel and fertilizer industries and investigated for their utility to remove cationic dyes. Studies have shown that the adsorbents prepared from blast furnace sludge, dust, and slag have poor porosity and low surface area, resulting in very low efficiency for the adsorption of dyes. On the other hand, carbonaceous adsorbent prepared from carbon slurry waste obtained from the fertilizer industry was found to show good porosity and appreciable surface area and consequently adsorbs dyes to an appreciable extent. The adsorption of two cationic dyes, viz., rhodamine B and Bismark Brown R on carbonaceous adsorbent conforms to Langmuir equation, is a first-order process and pore diffusion controlled. As the adsorption of dyes investigated was appreciable on carbonaceous adsorbent, its efficiency was evaluated by comparing the results with those obtained on a standard activated charcoal sample. It was found that prepared carbonaceous adsorbent exhibits dye removal efficiency that is about 80–90% of that observed with standard activated charcoal samples. Thus, it can be fruitfully used for the removal of dyes and is a suitable alternative to standard activated charcoal in view of its cheaper cost.

Keywords: Rhodamine B; Bismark Brown R; Wastewater; Industrial solid wastes; Adsorbents

1. Introduction

Dyes are important water pollutants which are generally present in the effluents of the textile, leather, food processing, dyeing, cosmetics, paper, and dye manufacturing industries. They are synthetic aromatic compounds which are embodied with various functional groups. The worldwide high level of production and extensive use of dyes generates colored wastewaters which cause environmental pollution. The colored dye effluents are generally considered to be highly toxic to the aquatic biota [1] and affect the symbiotic process by disturbing the natural equilibrium through reduced photosynthetic activity due to the coloration of the water in streams. The nonbiodegradable, toxic, and inhibitory nature of spent dye baths has a considerable deleterious effect on the environmental matrix (water and soil). Some dyes are reported to cause allergy, dermatitis, skin irritation, cancer, and mutations in humans [2,3]. Thus, the removal of dyes from effluents before they are mixed up with unpolluted natural water bodies is important. Several treatment technologies exist for dye removal [4], but the process of adsorption using activated carbon [5–8] has been found to be an efficient technology for decolorization of wastewater. Though the removal of dyes through adsorption is quite effective, its use is restricted sometimes due to the higher cost of activated carbon and difficulties associated with regeneration. Attempts have therefore been made to utilize natural as well as waste materials as alternative adsorbents. But the utilization of industrial waste materials is of vital concern over the past few years because these wastes represent unused resources and, in many cases, cause serious disposal problems. The aim behind using waste materials as adsorbents is

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that it will provide a twofold advantage with respect to environmental pollution. First, the volume of waste materials could be partly reduced, and second, the low-cost adsorbent, if developed, can reduce the pollution of wastewaters at a reasonable cost. In view of the low cost of such adsorbents, it would not be necessary to regenerate spent materials. Thus, a number of waste materials from different sources have been investigated with or without treatment as adsorbents for the removal of dyes from wastewater. Recently, Garg et al. [9] have listed materials studied as adsorbents for dye removal from aqueous solutions.

A number of low-cost alternative adsorbents have been explored but they have not been highly successful. In general the limitations of such studies have been

(i) the surface area of alternative adsorbents developed has been low in most cases, resulting in poor adsorptive power;
(ii) comparative studies on different adsorbents have not been carried out; and
(iii) the performance of alternative adsorbents has not been assessed by comparing the results with those obtained on activated carbon.

It is therefore still important to develop low-cost adsorbents with good surface area, which may in turn exhibit good adsorption potential for the removal of aqueous pollutants.

Keeping the above points under consideration, a comparative adsorption study was carried out by us [10] using carbon slurry waste obtained from a fertilizer plant and blast furnace sludge, dust, and slag from steel plant wastes as adsorbents for the removal of two anionic dyes, methyl orange and brilliant blue G. It was found that carbonaceous adsorbent prepared from a fertilizer plant exhibits good potential for the removal of dyes as compared to the other three adsorbents prepared. In order to further test the versatility of the carbonaceous adsorbent, investigations with regard to the adsorption of another class of dyes, cationic dyes, were also undertaken, and two important and widely used cationic dyes, rhodamine B and Bismark Brown R, were studied on all the adsorbents prepared. Further, a comparative study with standard activated charcoal was also carried out and the results are incorporated into the present communication.

2. Materials and methods

2.1. Materials

Rhodamine B and Bismark Brown R were procured from S.D. Fine-Chem. Limited (India). The standard activated charcoal sample was obtained from E. Merck. Other reagents used were of AR grade. Double-distilled water was used in preparing solutions throughout these investigations.

2.2. Preparation of adsorbents

The adsorbents under investigation have been prepared from fertilizer and steel plant wastes.

2.2.1. Preparation of carbonaceous adsorbent

In India, carbonaceous slurry waste is produced in fertilizer plants using fuel oil/LSHS (low sulfur heavy stock). This slurry is available at a very cheap rate ($0.007 per kg) and can act as a good adsorbent in view of its porous nature. The dried carbon slurry was procured from National Fertilizer Limited (NFL), Panipat (India). It was found to consist of small, black, greasy granules and treated [10,11] with H_2O_2 to oxidize the adhering organic material. It was then washed with distilled water and heated at 200 °C till the evolution of black soot stopped. The activation of this material was done in the range 300–700 °C in a muffle furnace for 1 h in the presence of air. After the activation, the ash content was removed by treating the material with 1 M HCl and washed with distilled water and dried. The surface area of samples activated at temperatures of 300, 400, 500, 600, and 700 °C was found to be 280, 363, 380, 374, and 367 $m^2\,g^{-1}$, respectively. Thus, the activation at 500 °C imparts maximum surface area and it was also seen that the extent of adsorption was at a maximum for the sample activated at 500 °C. Therefore, all studies reported in this paper are on a sample activated at 500 °C. The yield of the finished product was found to be $\sim 90\%$ and it is now called “carbonaceous adsorbent.” Different mesh sizes were obtained after sieving and kept in a desiccator for further use.

2.2.2. Preparation of blast furnace sludge, dust, and slag adsorbents

These adsorbents were prepared from wastes obtained from Malvika Steels, Jagdishpur (India), by the method reported elsewhere [10]. The products were sieved and stored in a desiccator.

2.3. Instrumentation

The spectrophotometric determination of dyes was done on a Shimadzu 1601 UV–vis spectrophotometer. The pH of solutions was measured with an ELICO LI 127 pH meter. A Vario EL III, C H N S elemental analyzer was used to determine the carbon content of the adsorbents.

2.4. Adsorption studies

The adsorption of dyes on prepared adsorbents was studied at room temperature by employing the batch method. A known volume (10 ml) of dye solutions of varying initial concentrations, taken in 50-ml stoppered glass tubes, was shaken with a fixed dose of adsorbent (0.01 g) for a specified period of contact time in a thermostated shaking assembly. After equilibrium, the concentration of the adsorbate in the residual solution was determined spectrophotometrically at