Comparative Evaluation of Activated Carbon with Natural Adsorbents for the Decolorisation of Dye Solution

Rashmi Sanghi* and Bani Bhattacharya

302 Southern laboratories, Facility for Ecological and Analytical Testing, Indian Institute of Technology, Kanpur 208 016

Received: 24 August 2001; accepted: 27 March 2002

Comparative evaluation of low cost and biodegradable naturally occurring adsorbents of animal (chitin) and plant origin (radish leaves) as potential adsorbent is made against granular activated carbon for the removal of reactive dye Remazol Brilliant Violet SR from aqueous solution. The variables studied are pH, initial dye concentration/adsorbent concentration ratio, temperature, and contact time. All variables studied have significant influence on the adsorption process at the level of 1-3 per cent probability. The order being initial dye concentration > adsorbent concentration > initial pH > temperature. Almost 100 per cent removal can be achieved for 20 ppm dye at optimum parameters of 2.5 pH and adsorbent dose of 1.2g/L at 60-70 °C with 1h stirring.

Introduction

The textile industry produces a multi-component waste, which can be difficult to treat. The discharge of dye bearing wastewater into natural stream or on land has created significant concern as the dye imports toxicity and impedes light penetration, thus upsetting the biological activity. Various treatment methods for removal of colour and dye are coagulation, ozone membrane separation, anaerobic decolourisation, and adsorption process.

Adsorption process offers most economical and effective treatment method for removal of dyes and has an edge over other methods due to its sludge-free clean operation. Though activated carbon is an ideal adsorbent for organic matter due to its organophilic character, it is uneconomical for wastewater treatment, owing to its high production and regeneration costs, and about 10-15 per cent loss during regeneration by chemical or thermal treatment. High cost of activated carbon in India has prompted search for cheaper natural substitutes, which are biodegradable, and abundant in nature. Natural materials that are available in large quantities, or certain waste products from industrial or agricultural operations, may have potential as inexpensive sorbents. Due to their low cost, after these materials have been expended, they can be disposed off without expensive regeneration.

Reactive dyes are commercially a very important class of textile dyes. Due to their low fixation level and removal rate in treatment stations, reactive dye make unique and separate class of dyes that must be treated as such. The adsorptivity of naturally occurring animal waste chitin and plant waste radish leaves, against granular activated carbon was studied for removal of reactive dye, Remazol Brilliant Violet 5R (RV) from its aqueous solution on a laboratory scale. The adsorption efficiency is dependent on the particle size. The adsorbents studied have been compared with granular activated carbon (GAC) which is not even half as efficient as powdered activated carbon (PAC), keeping in view the flaky big particles of chitin.

The effect of process variables such as pH, contact time, concentration of dye, adsorbent dose, and temperature have been studied to understand the kinetic and thermodynamic parameters of the process. The choice of the variables to study was based on theoretical knowledge, concerning the several factors that may influence the adsorption extension and on information dealing with works performed with similar materials.
Materials and Methods

Chitin is a waste product of crab meat canning industry. However, more important than chitin is its deacetylated derivative, glucosamine from chitin and is found naturally in some fungal cell walls. Radish leaves (RL) used were collected in March 2001 from the adult radish plants from Indian Institute of Technology, Kanpur. The leaves were further dried at room temperature and ground to a fine powder. The powdered leaves were then repeatedly washed with water and again dried in oven at 50°C. The leaves were not treated any further as it decreased its adsorption capacity and besides the green chlorophyll, colour did not interfere with the experiments.

The Remazol Brilliant Violet 5R (RV) dye was purchased locally and stock solutions (20 mg/L) were prepared in water.

Batch Experiment

Dye adsorption experiments were conducted at ambient temperature and in batch mode with 150 mL of stock solutions. The variables studied were - pH, adsorbent dose, initial dye concentrations, temperature and contact time. The adsorbent dose was varied from 0.025 to 0.2 g. The contact time was 1 h with continuous stirring and at the end of each experiment the solution was centrifuged and filtered with Whatman 41 filter paper and analyzed by UV-Vis spectrophotometer for dye colour concentration. To determine the dye concentration in solution before and after the contact with the adsorbent, the method chosen was spectrophotometry in the visible region, as the dye concentration is controlled through colour. The selected wavelength for RV dye solution of 20 ppm at original pH of 7.54 was 559 nm with the absorbance value of 0.26.

Effect of pH

In any adsorbate-adsorbent system, pH of the system affects the nature of the surface charge of the adsorbent, effect of ionization and the extent and rate of adsorption. The pH has a very important role to play in effective decolourisation of dye colour.

Several 150 mL portions of 20 mg/L of dye solution each having assigned pH (adjusted with NaOH or H2SO4) were mixed with different adsorbent doses with continuous stirring for 1 h. The maximum adsorbance at $\lambda_{max}$ is then noted by UV-Vis spectrophotometer. Then their per centage colour removal was calculated by comparing the absorbance value of the blank with treated dye solution. In the case of RV dye the colour removal decreased with increase in pH and acidic conditions seemed to favour the decolourisation process. At lower pH of 2.5 the removal was found to be maximum for all the three adsorbents studied. For a very low dose of 0.05 g and with increase in pH from 2.5 to 8.5, the colour removal efficiencies decreased from 30 to 14, 72 to 25, and 63 to 29 for GAC, RL and chitin, respectively (Figure 1).

Effect of Dose of Adsorbent

The removal of dye per unit weight of adsorbent increases with decrease in adsorbent dose. Higher removal at lower adsorbent dose may be attributed to better accessibility of the adsorbent to the adsorption sites with the lower concentration of adsorbent particle.

Several 150 mL portions of 20 mg/L of dye solution each having pH 2.5 were taken at room temperature. Different doses of adsorbent such as 0.025, 0.05, 0.1, 0.15, 0.2, 0.3 g were added and absorbance at $\lambda_{max}$ was noted after 1 h of stirring. Graph of dose vs per centage removal is shown in Figure 2. Significant removal of 81, 86 and 87 per cent is recorded in dye solution with 0.3 g GAC, 0.2 g RL and 0.15 g chitin doses. GAC is effective only at higher doses, whereas RL and chitin as adsorbents were found comparable at almost all doses. In the case of RL the 86 per cent removal is almost constant even after increasing the dose. This is due to the leaching of its own colour at acidic pH and at higher doses. In the case of GAC and chitin, further increase in dose could increase the colour removal but not substantially.

![Figure 1—Effect of pH on colour removal (adsorbent dose=0.5g)](image-url)
Effect of Dye Concentration

Keeping the pH (2.5) and adsorbent dose (0.1mg) constant at room temperature, several 150 mL dye solutions with different concentrations were taken and their absorbance was recorded. The decolourisation increased significantly with initial increase in concentration of dye from 5 to 20ppm, after which it showed only slight increase till at 30ppm it became almost constant in all the three cases (Figure 3). Significant colour removal was recorded for 20 ppm dye solution.

Effect of Contact time

At room temperature, keeping the dye concentration (20mg/L) and pH (2.5), constant absorbance was recorded for different durations from 30 to 180 min for 0.2g GAC, 0.05g RL, and 0.1g chitin. The doses chosen were on the basis of the optimum performance shown by the adsorbents at different doses. Maximum colour removal was achieved in the first 20 min after which there was only a gradual increase for 60 min till it became constant after 120 min (Figure 4).

Effect of Temperature

It was found that with increase in temperature's, the amount of dye adsorbed per unit mass of adsorbent increases. The increase in decolourisation rates with GAC, RL and chitin was 68 to 96, 86 to 95 and 89 to 100 per cent, respectively, with increase from 30 to 70°C (Figure 5). Almost complete removal could be achieved by increasing the temperature.

Adsorption Isotherms

The equilibrium isotherm is a significant criteria for the design of the adsorption system. It essentially expresses the relation between the concentration of the solute in solution at equilibrium with the concentration of the solute adsorbed onto the adsorbent at constant temperature.

Langmuir Model — Sorption data have been analysed in the light of Langmuir adsorption model. The isotherm derived by Langmuir for adsorption of dye from the aqueous solution is $q = q_m K_A C / (1 + K_A C)$ where $q =$ mass of dye adsorbed / mass adsorbent, $q_m =$ mass of dye adsorbed /mass adsorbent for a complete monolayer, $C =$ concentration of dye in solution, mass/volume, $K_A =$ constant related to enthalpy of adsorption. The langmuir isotherms can be rearranged in the following linear forms: $C/q = 1/q_m K_A + C/q_m$, $1/q = 1/q_m + (1/K_A q_m) + 1/C$. The nonlinear plots of $1/q_r$ vs $1/Ce$ at a constant temperature (Figure 6) suggested that the monolayer theory may not be applicable to this system. This may be due to the formation of additional layers of adsorbed dye molecules onto the adsorbent.
FREUNDLICH CONSTANTS RELATED TO SORPTION CAPACITY AND

\[ q = K_f C^{1/n} \]

where \( K_f \) and \( n \) (greater than one) are Freundlich constants related to sorption capacity and sorption intensity, respectively. The equation can be converted to a linear form \( \log q = \log K_f + 1/n \log C \).

A plot of \( \log q \) vs \( \log C \) (Figure 7) gives almost a straight line, showing favourable adsorption. This can be explained by the fact that the concentration of the dye on the adsorbent increases with the increase in dye concentration (Figure 7).

Conclusions

The overall efficiency of RL and chitin is found to be much better for dye decolourisation than that of GAC, which is effective only at higher doses. The adsorption capacities of GAC, RL and chitin were found to be 13.6, 40 and 38.2 mg/g, respectively. Radish leaves and chitin are economical and biodegradable, hence are eco-friendly alternatives for activated carbon with much better efficiencies.

References


