

Activated Carbon as an Adsorbent for Basic Yellow Dye. Part I. Factors Affecting the Rate of Dye Adsorption

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The effect of certain parameters on the rate of adsorption of Basic Yellow 2G Dye on activated carbon has been studied. The rate of dye removal is influenced by agitation, initial dye concentration, carbon particle size range, temperature and mass of carbon per unit volume of solution.

THE effluents from many textile plants contain small concentrations of coloured compounds. Due to their high degree of colour, these effluents are easily visible when the effluents enter a waterway. Adsorption processes are rapidly gaining prominence as methods of producing high quality effluents which are low in concentrations of organic compounds.

Activated carbon is the most widely used adsorbent for the treatment of aqueous solutions¹⁻³. The best decolourising carbons are made from lignin and lignite and the more important applications of such carbons in industry have been reviewed by Mantell⁴ and Culp and Culp⁵.

The aim of the present work is to study the variables which affect the rate of basic dye adsorption onto activated carbon. A basic dye was selected since these dyes have the highest tinctorial value and less than 1 ppm of the dye produces an obvious colouration in water. Deorlene Yellow 2G was selected for study. Experimental results are reported on the effects of five parameters: agitation, initial dye concentration, particle size range, temperature and mass of carbon.

Materials and Apparatus:

Materials: The adsorbate used in all the experiments was Victoria Blue Dye (Basic Blue 26) C.I. Constitution Number 44045, and was supplied by Brico Dyestuffs and Chemicals, London, England. Activated carbon was supplied by Hopkins and Williams, the material was broken down using a hammer mill and sieved into discrete particle size ranges.

Analysis: The concentrations of dye in the samples were determined spectrophotometrically, using a Unicam SP600, Series 2 Spectrophotometer. All measurements were made at the wavelength corresponding to maximum absorbance, namely, $\lambda_{max} = 614$ nm.

Apparatus: Construction of adsorption vessel as shown in Fig. 1. In order that the adsorption vessel was designed according to Standard Tank Configuration, the following correlations had to be satisfied with respect to the vessel inside diameter, D_t (1) Z = height of liquid in the vessel = D_t ; (2) B = baffle width = $3/40$

D_t ; (3) b = height of impeller blade = $1/10 D_t$; (4) diameter of impeller blade = $1/2 D_t$ and (5) distance between impeller blade and vessel bottom = $1/2 D_t$.

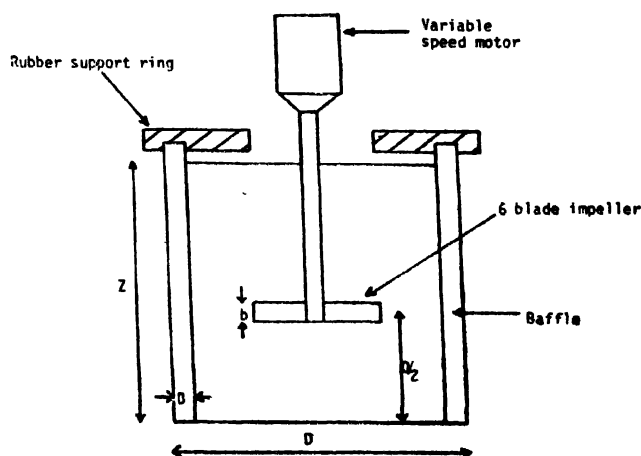


Fig. 1. Agitation unit.

A 2,000 ml glass beaker was used as the main vessel in the equipment and had an internal diameter of 0.13 m. Now from (1) above, the liquid level in the vessel must be 0.13 m. Using these dimensions, the liquid volume required was 1,700 ml. This liquid volume was used in all investigations using the adsorber vessel.

Good mixing in the vessel was provided by the use of a six bladed stainless steel flat bladed impeller. The standard impeller used was 0.075 m in diameter and had a blade height of 0.01 m. A Heidolph Type 50111 variable speed motor was used to drive the impeller using a 0.013 m diameter aluminium shaft. This motor gave an impeller speed range of 20-1,700 r.p.m.

In agitating a low viscosity liquid, there is a tendency for a swirling flow pattern to develop, regardless of the type of impeller used; either axial flow or radial flow. The vortex produced leads to a reduced relative motion between liquid-liquid particles or liquid-solid particles and also limits the amount of power that

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can be applied to the system since once the vortex reaches the impeller severe air entrainment occurs.

Reducing the swirl and hence achieving top-to-bottom turnover involves creating an unbalanced flow pattern and baffles are used for this purpose. The most common type of baffles used are flat vertical strips set radially along the vessel wall. The baffles used in the adsorber vessel were constructed from aluminium and were 0.2 m long and 0.015 m wide.

The eight baffles were spaced evenly around the vessel circumference (45° intervals) and kept about one quarter of the baffle's width from the vessel wall to prevent the accumulation of solids on the baffles. For the same reason the baffles were terminated just above the tank bottom. To be effective, the baffles must remain rigid at all impeller speeds. This was achieved by securing a thick rubber ring to the top of the vessel and by cutting slits in the ring so that the baffles inserted into the slits were not free to move. The rubber ring also prevented the loss of liquid over the lip of the vessel during agitation.

Results

(i) *Effect of agitation*: A series of experiments were undertaken at different degrees of agitation, namely, 150, 200, 400, 500 and 600 r.p.m. The relative dye removal is shown in Fig. 2, which is a plot of C_t/C_0 against time. The rate of removal of Basic Yellow 2G is influenced by the degree of agitation. The experiments were carried out using an initial dye concentration of 300 mg dm^{-3} , a particle size range of $500\text{--}710 (\times 10^{-4}) \text{ cm}$, and a solid density of 2 g dm^{-3} . The rate of adsorption would be affected by the boundary layer resistance and increasing the degree of agitation would reduce this resistance thus increasing the mass transfer. Below an agitation speed of 150 r.p.m. the particles are not fully agitated in the solution and therefore boundary layer mass transfer effects cannot be studied accurately below this value. Above 600 r.p.m. the rate of increases of β_L with agitation decreases suggesting that a limiting speed of 600 r.p.m. is sufficient to reduce the boundary layer resistance to a minimum.

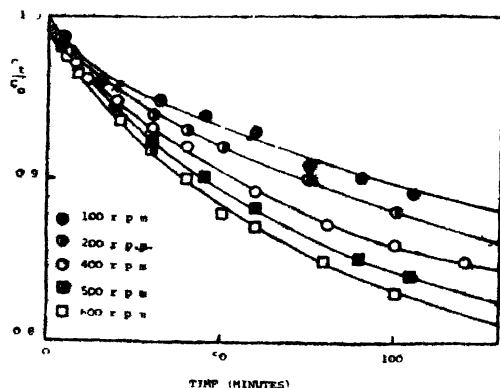


Fig. 2. The effect of agitation on the adsorption of Basic Yellow dye ($C_0 = 300 \text{ mg dm}^{-3}$) on carbon ($500\text{--}710\mu$) at 18° .

(ii) *Effect of initial dye concentration*: The effect of varying the initial dye concentration was studied

using dye concentrations of 50, 100, 200, 300, 400 mg dm^{-3} . Fig. 3 shows the concentration change against time for the various dye concentrations using a constant agitation speed of 500 r.p.m., a particle size range of $500\text{--}710 (\times 10^{-4}) \text{ cm}$ and a carbon concentration of 2 g dm^{-3} . At high concentrations, the fraction of dye removed is low. For low concentrations of 50 and 100 mg dm^{-3} the initial uptake of dye was rapid indicating a fast surface reaction.

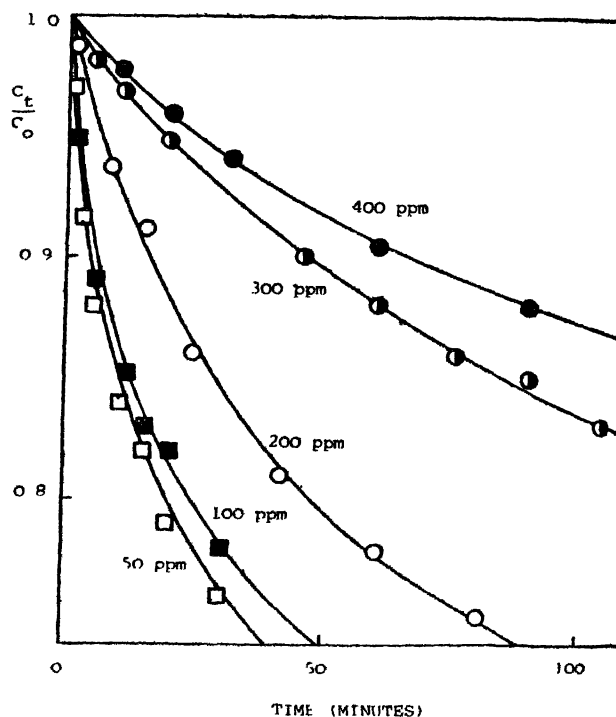


Fig. 3. The effect of initial dye concentration on the adsorption of Basic Yellow dye on carbon ($500\text{--}710\mu$) at 18° using a constant agitation of 500 r.p.m.

(iii) *Effect of particle size*: The influence of particle size is important since the smaller the particle diameter the greater becomes the external surface area per unit mass of carbon. However, in column operation, smaller adsorbent particles will lead to high pressure drops and a tendency for columns to block. Fig. 4 shows the influence of particle size with time for a constant initial dye concentration of 3.0 mg dm^{-3} , a constant agitation rate of 500 r.p.m. and a carbon concentration of 2 g dm^{-3} . The lines in Fig. 4 show the expected trend that the rate of dye uptake is greater, the smaller the carbon particle size range.

(iv) *Effect of temperature*: A series of experiments were undertaken to study the effect of temperature. Investigations were carried out at $20, 40, 60$ and 80° , using 3.4 g carbon, 1.7 dm^3 of 300 mg dm^{-3} dye solution, and an agitator speed of 500 r.p.m. Fig. 5 shows that the rate of dye uptake increases rapidly with temperature. The adsorption rate terms will increase with increasing temperature since the diffusion coefficients and rate parameters will rise with temperature.

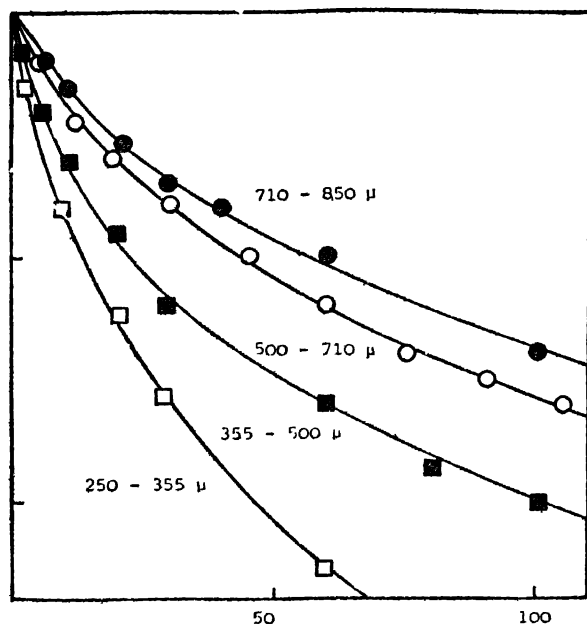


Fig. 4. The effect of particle size on the adsorption of Basic Yellow dye ($C_0=300 \text{ mg dm}^{-3}$) on carbon at 18° using an agitation speed of 500 r.p.m.

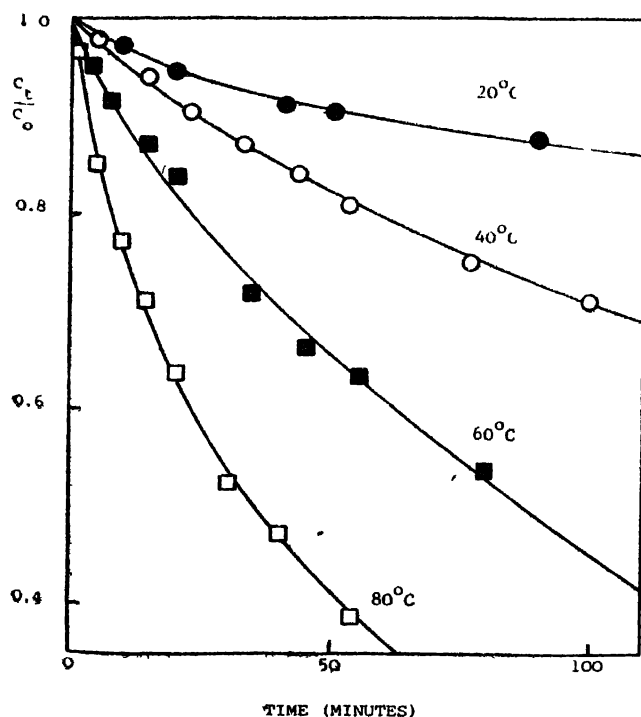


Fig. 5. The effect of temperature on the adsorption of Basic Yellow dye ($C_0=300 \text{ mg dm}^{-3}$) on carbon (500-710 μ) at an agitation speed of 500 r.p.m.

(v) *Effect of carbon mass*: Various masses of carbon, namely, 2.6, 3.0, 3.4, 3.8 and 4.6 g, were agitated with 1.7 dm^3 of 300 mg dm^{-3} dye solution, using an agitation speed of 500 r.p.m. The rate of dye uptake increases with increasing carbon mass and the results are shown in Fig. 6.

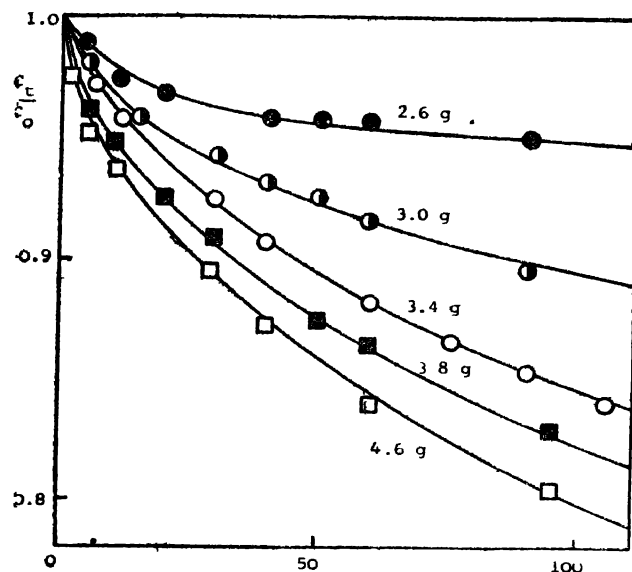


Fig. 6. The effect of carbon mass on the adsorption of Basic Yellow dye ($C_0=300 \text{ mg dm}^{-3}$) on carbon (500-710 μ) at 18° and using an agitation speed of 500 r.p.m.

Conclusion: The factors affecting the rate of Basic Yellow dye (Deorlene Yellow 2G) from effluent have been studied. The five parameters investigated, i.e., agitation, initial dye concentration, carbon particle size range, temperature and mass of carbon have significant effect on the adsorption rate. Furthermore, Fig. 2 to 6 indicate that there is an initial rapid uptake of dye attributed to a surface mass transfer process. This initial adsorption is followed by a slower process, namely, intraparticle diffusion which lasts for many hours. These two rate controlling steps are the basis for the model presented in Parts II and III of the paper.

References

1. C. A. RODMAN, *Text. Chem. Colorist.*, 1976, 8, 69.
2. J. S. SEBASTIAN, *Water and Waste Treatment*, May 9, 1972.
3. R. A. DAVIES, *et. al.*, *Chem. and Ind.*, 1973, 1, 827.
4. R. MANTELL, 'Adsorption', McGraw-Hill, London, 1945.
5. G. L. CULP and R. L. CULP, 'New Concepts in Water Purification', Van Nostrand Reinhold Environmental Engineering Series, New York.