

Letter to Editor

# Surface Mass Transfer during the Sorption of Basic Dye onto Boiler Bottom Ash

K. Vasanth Kumar<sup>1\*</sup>, S. Sivanesan<sup>2</sup>

<sup>1</sup>Department of Environmental Engineering, Vellore Institute of Technology (Deemed University), Vellore, TN, INDIA – 632 014.

<sup>2</sup>Department of Chemical Engineering, Anna University, Guindy, Chennai, TN, INDIA – 600 025.

Received: 2 October 2003

Accepted: 12 December 2003

## Abstract

Sorption experiments were carried out in batch process for the removal of color methylene blue from its aqueous solution using boiler bottom ash as an adsorbent. The operating variables studied were initial concentration and adsorbent dosage. The effect of external mass transfer coefficient,  $\beta$ , on these operating variables studied were estimated using Furusuwa – Smith model. The calculated  $\beta$  values were then correlated to dimensionless mass transfer numbers ( $Sh/Sc^{0.33}$ ). The dimensionless mass transfer numbers were found to vary with initial concentration,  $C_o^{-0.000002}$  and adsorbent dosage,  $M^{0.0085}$ .

**Keywords:** adsorption, methylene blue, bottom ash, external mass transfer, mass transfer coefficient.

## Introduction

Many dyes and pigments used in textile industries are inert and non-toxic at the concentrations discharged into receiving waters [1]. Also, most of the dyes used in the textile industry are difficult to remove by conventional waste water treatment methods since they are stable to light and oxidizing agents and are also resistant to aerobic digestion. For removal of color from industrial wastewater, adsorption has become one of the most economic and effective methods [1, 2, 4-6]. Thus, this process has aroused considerable interest during recent years. A large number of studies have been previously reported on color removal by different low-cost adsorbents [1,4-10] and only limited studies explain the actual transport mechanism involved in the sorption process. However, no studies have been carried out elsewhere to explain the transport mechanism that occurs at solid liquid interface during the sorption of methylene blue onto boiler bottom ash particles. The aim of the present communication is to remove color (methylene blue), a basic dye from its

aqueous solution using industrial waste material boiler bottom ash as an adsorbent and to explain the transport mechanisms involved at solid liquid interface using the previously existing mass transfer model.

## Experimental

The sorbent, bottom ash used in the present study was procured from Vellore Co-operative sugar mills, TN and the sorbate used in all the experiments was methylene blue. The details and properties of methylene blue and boiler bottom ash were already discussed. Batch experiments were carried out in 250mL reagent bottles. 100 mL of prepared synthetic dye solution of known initial concentration and weighed amount of boiler bottom ash were fed into the bottles and kept for agitation in a bottle shaker at constant agitation speed of 175 RPM. Samples were taken at shorter time intervals at initial time periods and later at larger time intervals and centrifuged. The left out concentrations in the samples were analyzed using UV-Spectrophotometer.

Blank experiments were performed (i) dye solution without bottom ash to check that no dye adsorbed onto

---

\*Corresponding author; e-mail: vasanth\_vit@yahoo.com

the container jars, and (ii) with bottom ash and water only to ensure that no leaching occurred, which would interfere with the measurement of dye concentrations on the spectrophotometer.

### Results and Discussion

Figure 1 shows the plot between  $C/C_0$  versus time at different initial concentrations. From Fig. 1 it was observed that the color removal rate decreased with increase in initial solute concentration. This is due to decrease in ratio of active site in adsorbents to solute concentration with increase in initial methylene blue concentration. From Figure 1, it was also observed that at all solute concentrations sorption is fast for the first 30 minutes and thereafter it proceeds slowly and finally reaches saturation. The faster adsorption rate at earlier stages may be due to the occurrence of sorption process only by sorbate/sorbent interactions. Whereas the slower sorption rate at later stage is due to both sorbate/sorbent and sorbate reactions. The adsorption decay curve in Figure 1 served to determine the external mass transfer using equation proposed by Furusuwa and Smith [1], which is given by equation (1) as follows:

$$\frac{d(C/C_0)}{dt} = \beta S \tag{1}$$

Where  $\beta$  in equation (1) indicates the external mass transfer coefficient and  $S$  represents the external surface

area of adsorbent per unit volume of particle free slurry and the details were previously explained by McKay et al. [1]. Thus, the mass transfer coefficient,  $\beta$ , can be calculated from the slope of curves in figure using equation (1). The calculated mass transfer coefficients were then correlated in the form of mass transfer dimensionless numbers ( $Sh/Sc^{0.33}$ ) and were plotted against  $C_0$  as shown in Fig. 2. Where  $Sh$  and  $Sc$  denote Sherwood and Schmidt number, respectively. From Fig. 2, it was observed that the mass transfer rate decreases with increase in initial concentration. A similar observation was previously reported by McKay et al. [1] for mechanically agitated sorption systems and also by Nassar and Magdy [6] for air agitated systems. The decrease in mass transfer rate with increasing initial concentration can be explained on the basis of molecular association and interionic groups of dye, which can reduce the activity coefficient of the dye and effective diffusivity [6]. The curve in Fig. 2 fits the equation as follows:

$$Sh/Sc^{0.33} = -7 \times 10^{-9} (C_0)^{-0.000002} \tag{2}$$

Figure 3 shows the plot between  $C/C_0$  versus time at different bottom ash dosages. From Fig. 3, it was observed that the color removal rate gets increased with increase in adsorbent dosage. This is because with increasing adsorbent dosage, the active site required for more uptake of solute transfer to take place increase.

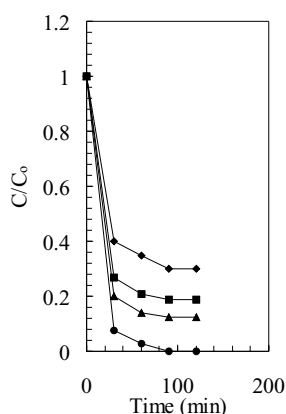


Fig. 1. Effect of initial dye concentration. (M: 1 g;  $\diamond$ : 100 mg/l;  $\blacksquare$ : 75 mg/l;  $\blacktriangle$ : 50 mg/l;  $\bullet$ : 25 mg/l; pH: 7; RPM: 175 rev.min<sup>-1</sup>).

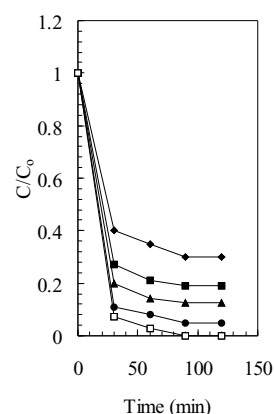


Fig. 3. Effect of bottom ash dosage. ( $C_0$ : 100 mg/l;  $\diamond$ : 1 g;  $\blacksquare$ : 2 g;  $\blacktriangle$ : 3 g;  $\bullet$ : 4 g;  $\square$ : 5 g; pH: 7; RPM: 175 rev.min<sup>-1</sup>).

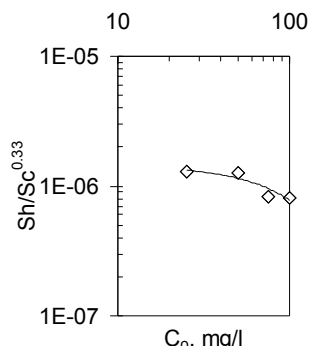


Fig. 2. Effect of Mass Transfer on Methylene Blue Concentration.

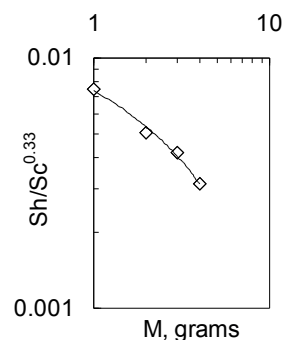


Fig. 4. Effect of mass transfer on boiler bottom ash dosage.

Also, Fig. 3 confirms that the sorption rate increases with increase in bottom ash mass. This is due to the increase in methylene blue transfer rate per unit time onto unit surface area of bottom ash with increasing bottom ash dosage. As explained before the mass transfer coefficient,  $\beta$ , values were calculated from the slope of curves in Figure 3 using equation (1). The calculated  $\beta$  values were correlated in the form of dimensionless mass transfer numbers ( $Sh/Sc^{0.33}$ ) as shown in Fig. 4. From Fig. 4, it was observed that the mass transfer rate decreases with increase in bottom ash dosage. This is because with increasing adsorbent dosage, the concentration gradient required for mass transfer to take place decreases with increase in bottom ash dosage. As a result the solute transfer rate per unit time onto unit surface area splits, which causes a decrease in mass transfer rate. The curve in Fig. 4 fits the equation (3) as follows:

$$Sh/Sc^{0.33} = -0.0014(M)^{0.0085} \quad (3)$$

### Conclusions

The surface phenomena influencing the extent and initial rate of uptake of methylene blue on bottom ash have been studied. The Furusuwa – Smith model has been successfully used to explain the external mass transfer mechanism. The external mass transfer rate was found to decrease with both increase in initial methylene blue concentration and bottom ash dose.

### References

1. MCKAY G., ALLEN S.J., MCCONVEY I.F., OTTERBURN, M.S. Transport process in the sorption of colored ions by peat particles. *J. Colloid. Interface. Sci.* **80**, 323, **1981**.
2. MCKAY G. The adsorption of dye stuffs from aqueous solution using activated carbon IV: External mass transfer process. *J. Chem. Tech. Biotechnol.* **33A**, 205, **1983**.
3. FURUSUWA T., SMITH J.M. Intraparticle mass transport in slurries by dynamic adsorption studies. *AiChE*, **20**, 88, **1974**.
4. MCKAY G., ALLEN S.J. Surface mass transfer process using peat as an adsorbent for dyestuffs. *Can. J. Chem. Engn.* **58**, 521, **1980**.
5. MCKAY G., MCCONVEY I.F. The external mass transfer of basic and acidic dyes on wood. *J. Chem. Tech. Biotechnol.* **31**, 401, **1981**.
6. NASSAR M.M., MAGDY Y.H. Mass transfer during adsorption of basic dyes on clay in fixed bed. *Indian. Chem. Engn.* **40**, 27, **1999**.
7. VASANTH KUMAR K. Adsorption isotherms for basic dye onto low cost adsorbents. *Res.J. Chem. Environ.* **6** (4), 61, **2002**.
8. VASANTH KUMAR K., BHAGAVANULU D.V.S. Adsorption dynamics for the sorption of basic dyes onto fly ash. *Nature Environment and Pollution Technology.* **2** (3), 299, **2003**.
9. VASANTH KUMAR K., BHAGAVANULU D.V.S. Mass transfer during the sorption of basic dye onto cow dung ash. *Nature Environment and Pollution Technology.* **2** (3), 349, **2003**.
10. VASANTH KUMAR K. Treatment of dye bearing wastewater using sugar industry wastes. *Res.J. Chem. Environ.* **7** (3), 73, **2003**.