Micelle-Assisted Dyeing of Cotton with Reactive Dyes

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Abstract: The adsorption kinetics of two bi-functional reactive dyes, tetrasodium 4-amino-5-hydroxy-3,6-bis[[4-[[2-(sulphonatooxy)ethyl] sulphonyl] phenyl]azo]naphthalene-2,7-disulphonate (Navy Sc) and Tetra-sodium 7-[[2-[(aminocarbonyl)amino]-4-[[4-chloro-6-[[3-[[2-(sulphonetooxy)ethyl] sulphonyl]phenyl] amino]-1,3,5-triazin-2-yl]amino] phenyl] azo]naphthalene-1,3,6-trisulphonate (Yellow) used for textile dyeing on cotton has been studied in aqueous medium and in micellar solutions of cationic, anionic and non-ionic surfactants such as cetyltrimethyl-ammonium bromide (CTAB), sodium dodecylsulphate (SDS) and Triton (TX-100). CTAB has been found to assist the dyeing of cotton with remarkable adsorption of both dyes compared to SDS and TX-100. The retainment of the dyes on cotton upon washing has been investigated. The adsorption kinetics of dyeing for both Navy Sc and Yellow dyes has been fitted to available kinetic models and the best fit could be obtained for pseudo second-order kinetic model.

***Keywords:* Micellar solution, adsorption, reactive dye, kinetics**

1. INTRODUCTION

Modern civilization depends to a large extent on different industries, such as, textile, paper, plastics, leather, power, food, cosmetics and dyeing industries. In particular, the textile and clothing industries have emerged as the single source contributing to the rapid economic growth of Bangladesh. Bangladesh earns valuable foreign currencies through exports of textiles and garments to foreign countries. However, research on textile and clothing in Bangladesh is still in the rudimentary stage.

Dye-surfactant interactions [1-6] are of great importance in dyeing of textile fibres. Surfactants which contain both hydrophilic and hydrophobic moieties are used as levelling, dispersing and wetting agent in the dyeing process. Surfactants act mostly in two ways, either they can form a complex with ionic dyes or they can be adsorbed onto the fibre. Some recent reports [8-10] on natural dye-surfactant interactions have shown micellization of dyes in surfactants as well as adsorption of the dyes on surfactants. Since the surfactant and dyes are two important components in textiles dyeing; the investigations of the dyeing of natural dye on fibers in presence of surfactant solutions can provide useful information for understanding the kinetics and thermodynamics of dyeing process and finishing the textile materials. In a recent study [11,12] on dyeing of the cotton fiber by a natural dye in presence of surfactants, the adsorption capacity at equilibrium and initial rate of adsorption were found to increase in presence of the surfactants. Further studies in this direction may be useful in understanding the role of dye moiety and surfactant during the dyeing process.

Navy Sc and Yellow dyes are frequently used in textile dyeing. However, mechanism and kinetics of adsorption of dyes on cotton are not known yet. Therefore, it may be worth studying dyeing of cotton fibres by some other natural dyes to investigate the detail kinetics of dyeing process.

In the present study, the adsorption of two bi-functional reactive dyes having two/three active functional group vinyl sulphone and monochloro triazine, tetrasodium 4-amino-5-hydroxy-3,6-bis[[4-[[2-(sulphonatooxy)ethyl] sulphonyl] phenyl] azo]naphthalene-2,7-disulphonate (Navy Sc) and tetra-sodium 7-[[2-[(aminocarbonyl)amino]-4-[[4-chloro-6-[[3-[[2-(sulphonetooxy) ethyl]sulphonyl]phenyl] amino]-1,3,5-triazin-2-yl]amino] phenyl] azo]naphthalene-1,3,6-trisulphonate (Yellow) dyes on cotton fibre in absence and in presence of a cationic surfactant, cetyltrimethylammonium bromide (CTAB), anionic surfactants, sodium dodecyl- sulphate (SDS), and non-ionic surfactants, Triton (TX-100) has been investigated. The kinetics of adsorption of dyes has also been revealed.

2. EXPERIMENTAL

SDS, CTAB and TX-100 were purchased from Aldrich Chemical Co. and used as received. Navy Sc and Yellow dyes were purchased from BEZEMA AG, Switzerland. Both dyes were used without further purification. Ultrapure water (specific conductance < 0.1 $\mu S\ cm^{-1}$) was used in this study. The spectroscopic measurements were carried out by UV-visible spectrometer (Model: UVD 3500, Labomed, USA).

Definite amount of yarn (~400 mg) was taken for every run. 0.01% (w/v) aqueous dye solution was prepared in the absence and presence of surfactants. Concentrations of all surfactants were maintained above critical micelle concentration (CMC). The solutions of different dye concentrations in absence and presence of CTAB, SDS, TX-100 were freshly prepared in deionized water and were kept in the thermostatic water bath at 25 °C in reagent bottle (125 mL). The cotton fabric yarn (400 mg) was immersed in the dye solution. The absorbance of the dye solution at different time intervals was monitored by spectrophotometer at absorption maxima (λ_{max}) of each dye until the absorbance attains its constant value. The initial and equilibrium dye concentrations were determined using a calibration curve based on absorbance at λ_{max} versus dye concentration in standard dye solutions. The amount of dye adsorbed per gram of cotton (mg/g) at t (q_t) and at equilibrium (q_e) were calculated by mass-balance relationship equations [12] as follows,

$$q_t = (C_o - C_t)\frac{V}{W}$$

$$q_e = (C_o - C_e)\frac{V}{W}$$

where C_o, C_e and C_t are the concentration of dye (mg/L) at initial, equilibrium and at time t. V is the volume of dye solution (mL) and W is weight of cotton yarn (g) used.

3. RESULTS AND DISCUSSION

Fig. 1 shows UV-visible spectra of Navy Sc and Yellow dyes in presence of CTAB, SDS and TX-100. The characteristic λ_{max} could be observed at 420 and 590 nm for Yellow and Navy Sc, respectively. The spectra were analysed for investigation of adsorption. The Significant decrease in absorbance at the λ_{max} indicates that adsorption of Navy SC on cotton was significantly affected by the micellar solutions of CTAB of (Fig. 1(a) and (d). Similar observation can be seen for Yellow dye.

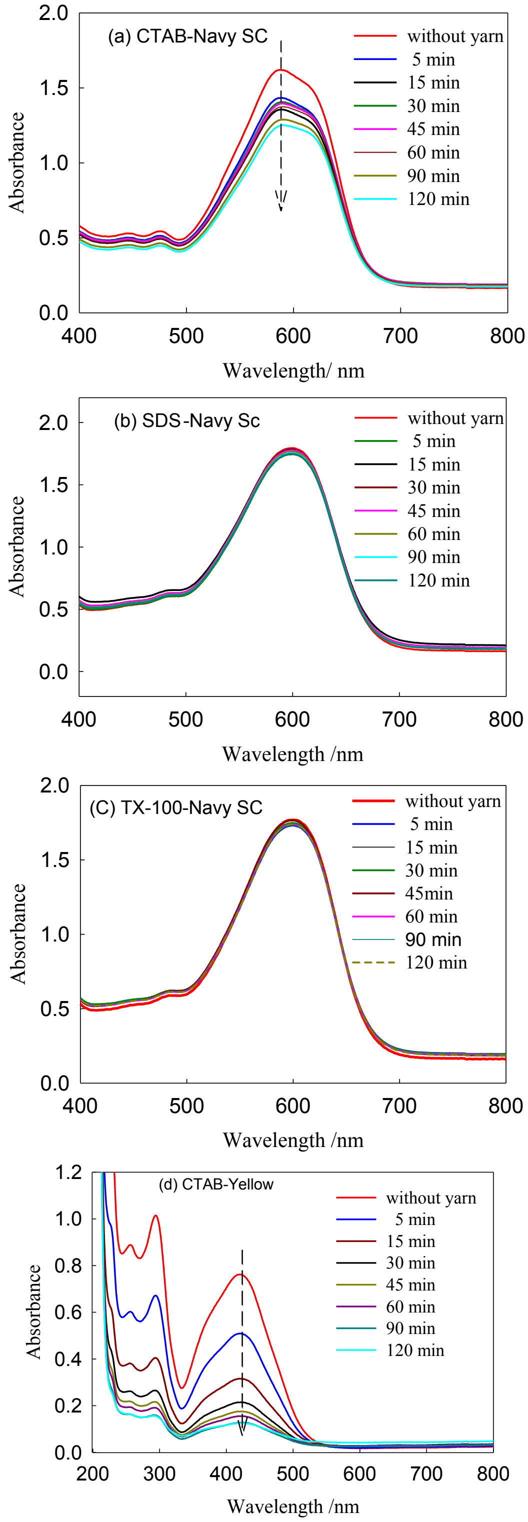

Fig. 1: UV-Visible spectra of dyes at different times in presence of various surfactants.

Typically the absorbance of dye in solution can be seen to decrease, i.e., the adsorption increases, with increasing contact time. A rapid adsorption of dye was reasonably observed up to 15 min then adsorption became steady and reached at equilibrium within 120 min.

On the other hand, adsorption of these dyes was not observed on the cotton in case of SDS and TX-100 (**Fig. 1(b)** and **(c)**. Adsorption of these dyes was not also observed in aqueous system in absence of CTAB. Therefore, it was found that cationic surfactant; CTAB act as a catalyst for the adsorption of these dyes on cotton though anionic surfactant, SDS and non-ionic surfactant, TX-100 have no effect on the adsorption process. Therefore, detail adsorption kinetics was made only for CTAB systems.

Kinetics of Adsorption: In order to analyze the adsorption kinetics of natural dye on cotton, the pseudo first-and second-order kinetics models were used and experimental data were interpreted.

The integrated form of pseudo first-order equation known as the Lagergren equation [13-14] is given in equation (1).

$$\frac{dq_t}{dt} = k_1(q_e - q_t) \qquad (1)$$

where, k_1 (s^{-1}) is the pseudo first-order rate constant and q_e and q_t are amount of dye adsorbed (mg/g cotton) at equilibrium and at time t, respectively. After integration and applying the initial conditions, the equation (1) gives,

$$\ln(q_e - q_t) = \ln q_e - k_1 t \qquad (2)$$

According to this equation, a plot of $\ln(q_e\text{-}q_t)$ versus time should be linear.

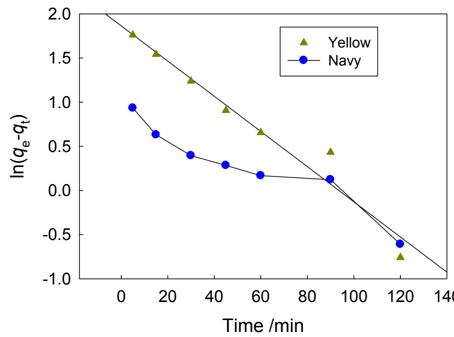

Fig. 2: Pseudo first-order plots for the adsorption of dyes on cotton in presence of CTAB.

Fig. 2 shows pseudo first-order model for the adsorption of dyes on cotton in presence of CTAB. The first-order equation of Lagergren fits well for the initial stage of adsorption process for Yellow dye however, it does not fit well for Navy for any range of contact time. This is in agreement with literature. [15]. Therefore, we have fitted our data for pseudo second-order model according to the following equation for further investigation.

$$\frac{dq_t}{dt} = k_2(q_e - q_t)^2 \qquad (3)$$

Where, k_2 (g cotton/ mg min) is the pseudo second-order rate constant. On integration and applying the initial condition ($q_t = 0$ at $t = 0$), the equation (3) give equation (4) as follows.

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} t \qquad (4)$$

According to equation (4), a plot of (t/q_t) versus t should be linear with an intercept. The values of q_e and k_2 can be determined from the slope and intercept of the plot respectively. Fig. 3 shows second-order kinetics model for the adsorption of dyes on CTAB. For both cases second-order model fit well for the whole range of contact time. The pseudo second-order kinetic model is more likely to predict the behaviour over the whole range of adsorption. The chemical sorption is therefore the rate controlling step.

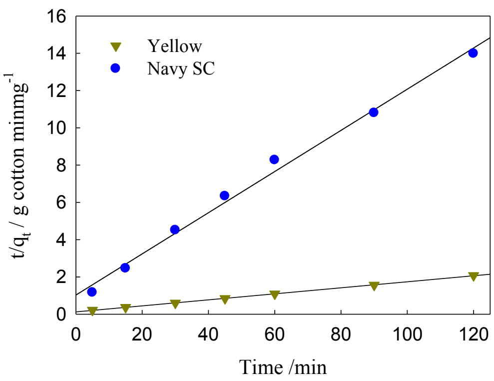

Fig. 3: Pseudo second-order plots for the adsorption of dyes on cotton in presence of CTAB.

Photographs of cotton after dyeing in absence and in presence of CTAB before and after several washes are shown in Fig. 4. It could be easily visualized that reactive dyes were not adsorbed at all in aqueous system (Fig. 4(a)) even after immersion of 24 h whereas both dyes were adsorbed very quickly on the cotton within 15 min in presence of CTAB (Fig. 4(b)).

These dyes retained on cotton even after several washes with washing powder. The bright colour of dye adsorbed cotton can be retained for prolonged period due to the use of micellar solutions of CTAB.

CONCLUSIONS

The adsorption kinetics of reactive dyes on cotton was found to follow the pseudo second-order kinetic model. Kinetic data suggests the adsorption process is a chemical process. In presence of the cationic surfactant (CTAB), the adsorption capacity at equilibrium and initial rate of adsorption were found to increase compared to any other surfactants and aqueous systems. Finally, it was found that micelle-assisted dyeing of cotton may save huge chemicals and time for effective dyeing of fabrics. Further studies are now underway.

Fig. 4: Photographs of cotton after adsorption of dyes in absence (a) and presence of CTAB (b).

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