Short Communications

Kinetics of dyeing of rotor- and ring-spun cotton yarns

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Ring-spun and rotor-spun cotton yarns were dyed with one commercial reactive dye (Amective Golden Yellow IRX) and two direct dyes (Chrysophenine G and Incomine Sky Blue 6B) at three different temperatures till the equilibrium was attained in each case. The dyebath exhaustion and equilibrium exhaustion values were used to calculate the apparent diffusion coefficients using a simple equation. The apparent diffusion coefficients determined at different temperatures were further used to derive the apparent activation energy of the dyeing process. The activation energies for both ring-spun and rotor-spun yarns have been found to be comparable. The apparent activation energies of direct dyes are much higher than those of reactive dyes.

Keywords: Apparent activation energy, Apparent diffusion coefficient, Cotton yarn, Dyeing, Ring-spun yarn, Rotor-spun yarn

In the recent years, open-end method of spinning yarns in a rotor system has become a well established process. Considerable amount of work has been devoted to its process development, study of structural and mechanical properties and the advantages and disadvantages of open-end spun yarns compared to conventional ring-spun yarns.

The unique feature of the open-end (OE) yarn lies in its open structure, lending it more amenable for the penetration of various chemicals during wet processing, finishing and dyeing. However, very little work has been reported on this aspect of OE yarns. Recently, a detailed account of the differential dyeing behaviour of ring-spun (RS) and OE cotton yarns has been reported.

In the process of dyeing of yarn or cloth, besides the chemical nature of the dye and the substrate to be dyed, the phenomenon of diffusion of dye molecules into the fibres comprising the yarn or the cloth plays a crucial role, affecting the kinetics of dyeing in general. Diffusion studies involving simple equations have been reported for dyeing of animal fibres with acid dyes. Shenai and Lagu have reported the kinetics data for the dyeing of Muga silk with acid dyes. Although a good amount of work has been devoted to the phenomenon of dye diffusion in cellulosics in the form of viscose and cellophane, very little work has been done on cotton yarn itself. The present communication reports the analysis of kinetics data obtained in the dyeing of reactive and direct dyes on RS and OE cotton yarns.

The RS and OE yarns used for the study were prepared from medium fine Laxmi cotton spun to 14s count with a TM of 4.5 on a ring frame for the ring yarn and on a Reiter Spin Trainer with a rotor speed of 45,000 rpm for the OE yarns. They were scoured and bleached before dyeing.

The dyes used for the experimental work were commercial reactive and direct dyes. They were used as such without purification. The direct dyes, Chrysophenine G (CI Direct Yellow 120) and Incomine Sky Blue 6 B (CI Direct Blue 1) were supplied by M/s Indokem Ltd, and the reactive dye, Amective Golden Yellow IRX (CI Reactive Orange 12) was supplied by Amritlal Chemaux Ltd.

The scoured and bleached yarns were dyed with the above dyes at three temperatures till equilibrium was attained in each case (60 min). Standard dyeing procedure was used in each case.

One gram of the yarn was cut and dyed to 0.5% shade, keeping the material-to-liquor ratio at 1 : 100. RS and OE yarns were dyed separately in conical flasks. A blank dyebath without the yarn was run alongside the actual dyeing. For direct dyes, Glauber’s salt and the material were added to the dye solution when the dyeing temperature was attained. For Chrysophenine G, the dyeing temperatures were 40°, 50° and 60°C and for Incomine Sky Blue 6 BS, the dyeing temperatures were 45°, 55° and 65°C.

For the reactive dye, Glauber’s salt and the material were added to the dye solution when the dyeing temperature was attained. For Chrysophenine G, the dyeing temperatures were 40°, 50° and 60°C and for Incomine Sky Blue 6 BS, the dyeing temperatures were 45°, 55° and 65°C.

The dyebath exhaustion was calculated from
the absorbance values determined periodically using a spectrophotometer after suitable dilution of a small amount of the dye solution taken out from the dyebath. The absorbance value of the blank dyebath was taken as the initial reading. The per cent exhaustion of the dyebath at time 't' was calculated with reference to the absorbance of the blank dyebath. Similarly, the equilibrium exhaustion value was determined from the absorbance values at the end of the dyeing period.

The apparent diffusion coefficient was determined from an approximation of Fick's equation described by Vickerstaff, which can be conveniently applied in the earlier stages of dyeing as:

$$\frac{E_t}{E_\infty} = 2 \sqrt{\frac{Dt}{\pi}}$$

where $E_t$ is the exhaustion of the dyebath at time $t$; $E_\infty$, the equilibrium exhaustion; and $D$, the apparent diffusion coefficient. Setty has used the above equation to calculate $D$ for dyeing Alizarin Saphire BN on wool fibres.

By plotting $E_t/E_\infty$ against $\sqrt{t}$, a straight line is obtained. From the slope $m$ of the line, the apparent diffusion coefficient is calculated as:

$$m = 2 \sqrt{\frac{D}{\pi}}$$

$$D = \frac{m^2 \pi}{4}$$

The apparent diffusion coefficients were determined at different temperatures to calculate the apparent activation energy $(E)$ of the dyeing process using Arrhenius equation:

$$D_T = D_0 e^{-E/R T}$$

where $D_T$ is the apparent diffusion coefficient at $T$(K); $D_0$, a constant; and $R$, the gas constant.

Taking logarithms,

$$\ln D_T = \ln D_0 - \frac{E}{2.303 R T}$$

When $\ln D_T$ is plotted against $1/T$, a straight line is obtained. If $m'$ is the slope,

$$m' = -\frac{E}{2.303 R}$$

$$-E = 2.303 R m'$$

The per cent exhaustion values for each dyeing time at 40°, 50° and 60°C were calculated for dyeing of Chrysophenine G on RS and OE yarns and are shown in Figs 1 and 2 respectively.

It is seen from Figs 1 and 2 that the per cent
exhaustion increases with the increase in dyeing time and temperature. The per cent exhaustion values were used to calculate $E_i/E_\infty$ values, which were plotted against $\sqrt{t}$ values (Figs 3 and 4) using regression equations. From the slope of the straight lines obtained, $D$ was calculated for all the three temperatures (Table 1).

It is observed from Table 1 and Figs 3 and 4 that the values of $D$ increase with the increase in temperature for both RS and OE yarns.

For the dyes Incomine Sky Blue 6 BS and Amective Golden Yellow IRX, similar calculations were made for dyebath exhaustion. Regression lines were drawn for the plots $E_i/E_\infty$ against $\sqrt{t}$. Straight lines were obtained for the plots as in the case of Chrysophenine G.

The values of apparent diffusion coefficient obtained at the three temperatures for the three dyes were used to determine the apparent activation energy by plotting log $D_1$ against $1/T$. The plots for the dyeing of Chrysophenine G on RS and OE yarns are shown in Figs 5 and 6 respectively and the values of the apparent activation energy are given in Table 1.

It is seen from Figs 5 and 6 and Table 1 that the values of $D$ increase with the increase in temperature for all the dyes studied. The activation energies for both RS and OE yarns are comparable. The apparent activation energies of direct dyes are much higher than those of reactive dyes.

References
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