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Effects of solvent properties on cationic dyeing process of acrylic yarn

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Abstract−Cationic dye is a special dye for acrylics, but it is very difficult in dyeing through the core. In practice, the price of a special leveling agent for acrylic fiber is high, and uniform staining is poor. By mixing a number of organic solvents in the dye bath, we can improve the structure of fibers and their deep-dyeing. We used n-propanol, isopropanol and benzyl alcohol as organic solvents, by adjusting the pH value and the appropriate temperature, and with special depth and leveling agent for dyeing soaping fastness contrast, to find economically viable process conditions.

Keywords: Acrylic, Soaping Fastness, pH Value

INTRODUCTION

Acrylic fibers have wide applications in the textile industry, and there is always a continuous increase in the production and consumption of these fibers [1]. Acrylic polymers containing a small amount of anionic centers, such as sulfonic acid or carboxylic acid groups, can be dyed readily with dyes bearing a positive charge, i.e., cationic dyes. The cationic dyes are attracted to and then anchored to the fiber by ionic bonds. The anionic centers arise either from the polymerization inhibitors or from small amount of copolymer added deliberately to introduce the anionic sites. Basic dye is by far the most important class of dye used on acrylic fibers. Basic dyes dissociate in water to yield colored cations and are characterized by their brilliance and very high tinctorial strength. This dye class (Basic dyes), which includes some of the earliest synthetic dyes, was originally used for dyeing wool, silk, and mordanted cotton, but the generally poor light fastness of the dyeing suppressed their use until the introduction of acrylic fibers on which the dyes exhibited higher light fastness and very good fastness to wet treatments [2].

One approach to reducing the environmental impact of acrylic dyeing is to use energy in the form of infrared radiation. And cationic dyeing has been studied for acrylic fiber with some positive results for solvation, with the latter showing particularly significant improvement. Infrared radiation and solvation have also been shown to assist acrylic dyeing.

On the other hand, acrylic yarn easily generates uneven dyeing defects. To solve the problem, we used a leveling agent. As to uneven coloring problem, the most common solution is to add a leveling agent in the process of dyeing. Special additives of dyeing acrylic such as leveling agent AN are expensive. Therefore, we tried conventional solvents to improve the depth of acrylic fiber dyeing.

In this study the dyeing and fastness properties of acrylic fibers using cationic dye were thoroughly investigated. Comparative results of the dyeing acrylic fibers using both three types of organic solvents and leveling agent AN were also presented.

EXPERIMENTAL

1. Materials

Acrylic yarn, n-propanol (analytically pure), isopropanol (analytically pure), benzyl alcohol (analytically pure), acetic acid (analytically pure), sodium carbonate (analytically pure), cationic leveling agent AN, Cationic Red X-GRL, Cationic Yellow X-GL, Cationic Blue X-GRRL, DMF, and soap flakes.

2. Apparatus

The apparatus consisted of BS110S type textile scale, 101A-2Btype electric drying oven, infrared staining instrument (Datacolor, U.S.), color measurement and matching instrument (Datacolor, U.S.).

3. Methods

3-1. Dyeing of Acrylic Fabrics Using Infrared Dyeing Methods

Acrylic fabric samples (2 g each) were dyed with the cationic dyes and different organic solvents at liquor ratio 1 : 50. Dyeing was carried out using infrared dyeing at the same concentrations of dye (5 g/L), organic solvent concentration (2-6% based on fabric weight), pH values (3.5-5.5), dyeing at 25 °C. The temperature increased at 1 °C/min up to 100 °C, and the duration time was 60 minutes.

3-2. Dye Fixation Test

The dye fixation of different dyes on acrylic samples was tested by extraction in 50% aqueous solution of dimethyl formamide (DMF), boiling for 15 min. The extracted samples were then rinsed and dried.

3-3. Comparative Experiments

For the sake of contrast, the same conditions of dyeing were carried out using infrared dyeing at the same concentrations of dye (5 g/L) with leveling agent AN (2% based on fabric weight), pH values (4.5), temperatures (100 °C), and duration time (60 min). Then the dyed samples were rinsed with cold water and washed for 25 min in a bath containing 2 g/*l* of non-ionic detergent (Hostapal CV, Clariant), at 45-50 °C. Finally, the fabrics were rinsed with water and air dried.

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4. Measurements

4-1. K/S Value

The color strength of the dyed samples was evaluated by color measurement and matching instrument, and the relative color strength (K/S values) was automatically assessed using Eq. (1)

$$K/S = \frac{(1-R)^2}{2R} \tag{1}$$

where R is decimal fraction of the reflectance of the dyed fabric, Ro is decimal fraction of the reflectance of the un-dyed fabric, K is absorption coefficient and S is scattering coefficient.

4-2. Leveling Properties [3]

Leveling properties of dyed acrylic fabric using 5 g/L dye applied under the selected dyeing conditions for all dyes were assessed on a color measurement and matching instrument by measuring K/S within each sample at eight separate points and the S(λ) was calculated using Eq. (2)

$$S_{(\lambda)} = \sqrt{\frac{\sum_{i=1}^{n}[(K/S)_{i,\lambda} - \overline{(K/S)}_{\lambda}]^2}{n-1}} \tag{2}$$

$$\overline{(K/S)}_{\lambda} = \frac{1}{n}\sum_{i=1}^{n}(K/S)_{i,\lambda} \tag{3}$$

where: $S_{(\lambda)}$ is the standard deviation of the K/S value and sample mean on each sample point dyed fabric; λ is the wavelength of the measurement; n is the total number of the measurements; $(K/S)_{i,\lambda}$ is the K/S value of i measurement at λ wavelength; $\overline{(K/S)}_{\lambda}$ is the $\overline{(K/S)}_{\lambda}$ was calculated using Eq. (3).

$S_{(\lambda)}$ means the degree of the K/S of the sample points deviating from the average, which is used to characterize the leveling properties of the samples. The smaller the $S_{(\lambda)}$, the better the leveling properties.

4-3. Fastness Properties

The dyeing samples were tested for washing, acid and alkaline perspiration, dry and wet rubbing and light fastness according to AATCC standard methods [4-7].

RESULTS AND DISCUSSION

1. Chemical Formula Analysis

As we know, the smaller the dielectric constant, the smaller the polarity. Table 2 shows that the polarity of benzyl alcohol is minimum among the three kinds of organic solvent. It can be thought that benzyl alcohol could easily enter into acrylic fiber, which is helpful for the expansion of acrylic fiber. On the other hand, benzyl alcohol is compatible with cationic dyes which are enumerated in Table 1. Consequently, it is supposed that the effect of benzyl alcohol on dyeing property of acrylic fabrics is better than the two other organic solvents.

Table 1. Properties of used cationic dyes

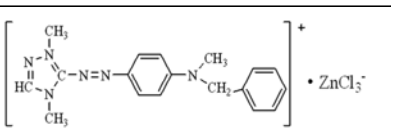
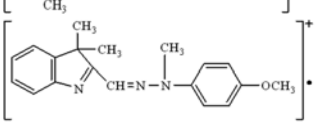
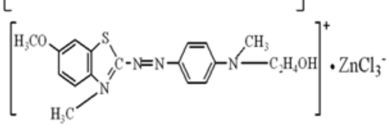
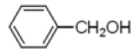
Dyestuff	Chemical formula
Cationic red X-GRL	
Cationic yellow X-GL	
Cationic blue X-GRRL	

Table 2. Properties of organic solvents used

Solvent	Chemical formula	Dielectric constant
n-Propanol	CH_3-CH_2-CH_2OH	20.45
Isopropanol	CH_3-CH(OH)-CH_3	19.92
Benzyl alcohol		13.00

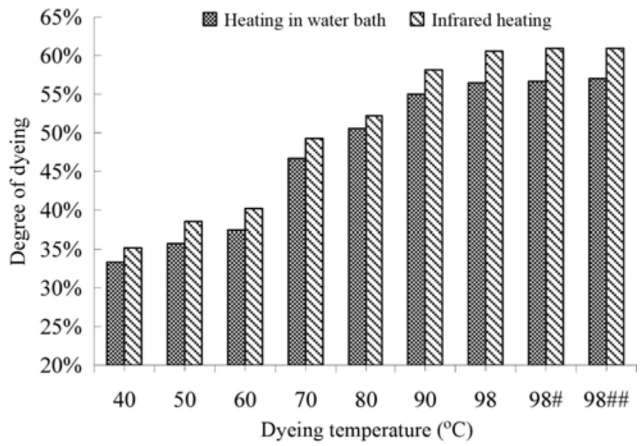


Fig. 1. Effect of different heating mode on the dyeing percentage of acrylic fabric for Cationic Red X-GRL. [a]98#: Heat preservation for 30 minutes in 98 °C; [b]98##: Heat preservation for 60 minutes in 98 °C.

2. Effect of Different Heating Mode

As can be seen from Fig. 1, there is an abrupt enhancement in the K/S values obtained at a benzyl alcohol concentration approximately 3% using infrared heating. It is well known that infrared heating has penetrating power and can heat both inside and outside at the same time, which contributes to increasing the percentages of acrylic disorder, improving the dye absorption and enhancing the degree of dyeing.

3. Effect of Organic Solvent Concentration and pH Value

The following figures show the K/S values of acrylic fabrics dyed with 5 g/*l* of three cationic dyes at various concentrations of organic solvents using infrared heating.

As we know, acrylic fiber shows concrete molecular structure, well developed crystalline region, narrow voids, hydrophobic surfaces, and so on. These characteristics make it hard to be dyed with dyes of large molecular size. Therefore, dyeing of acrylic fiber is generally carried out at temperatures over 95 °C. Organic solvents can lower the dyeing temperature with cationic dye up to about 90 °C by loosening the fiber structure. Infrared heating can rapidly raise the temperature of the dyeing bath to boiling temperature. According to previous studies [8-13], it is essential to investigate the effects

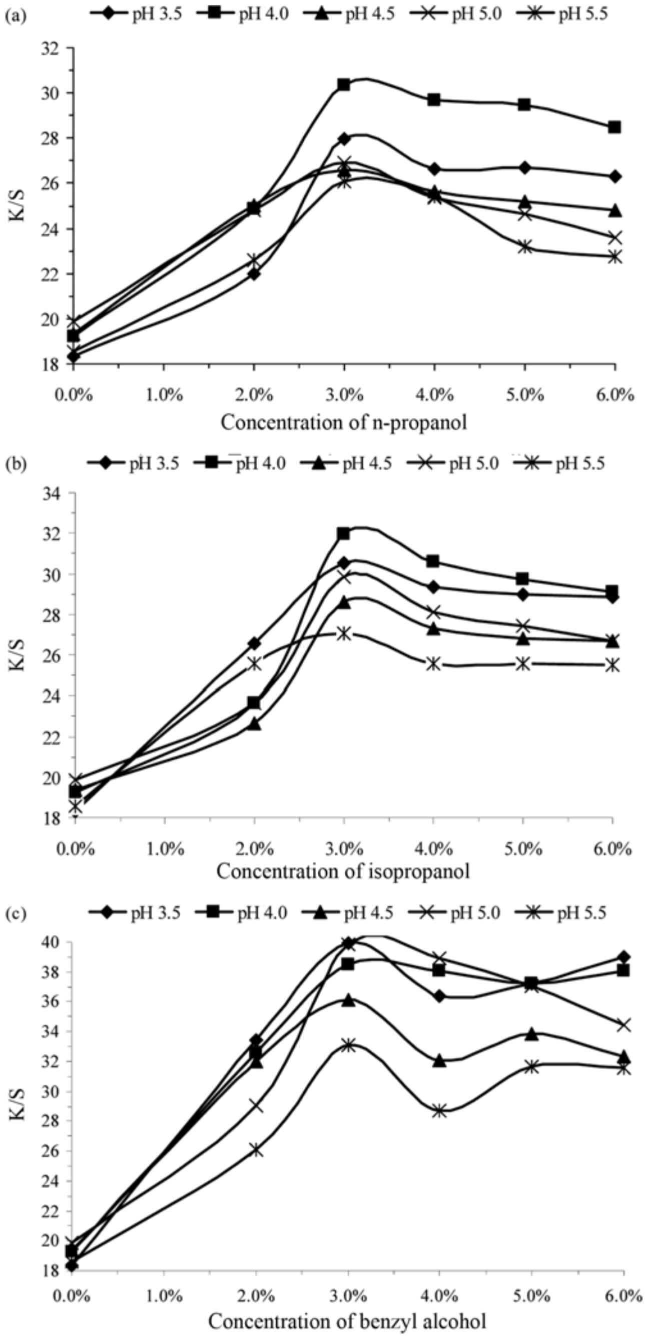


Fig. 2. Effect of concentration of solvent on the K/S values of dyed with Cationic Red X-GRL.

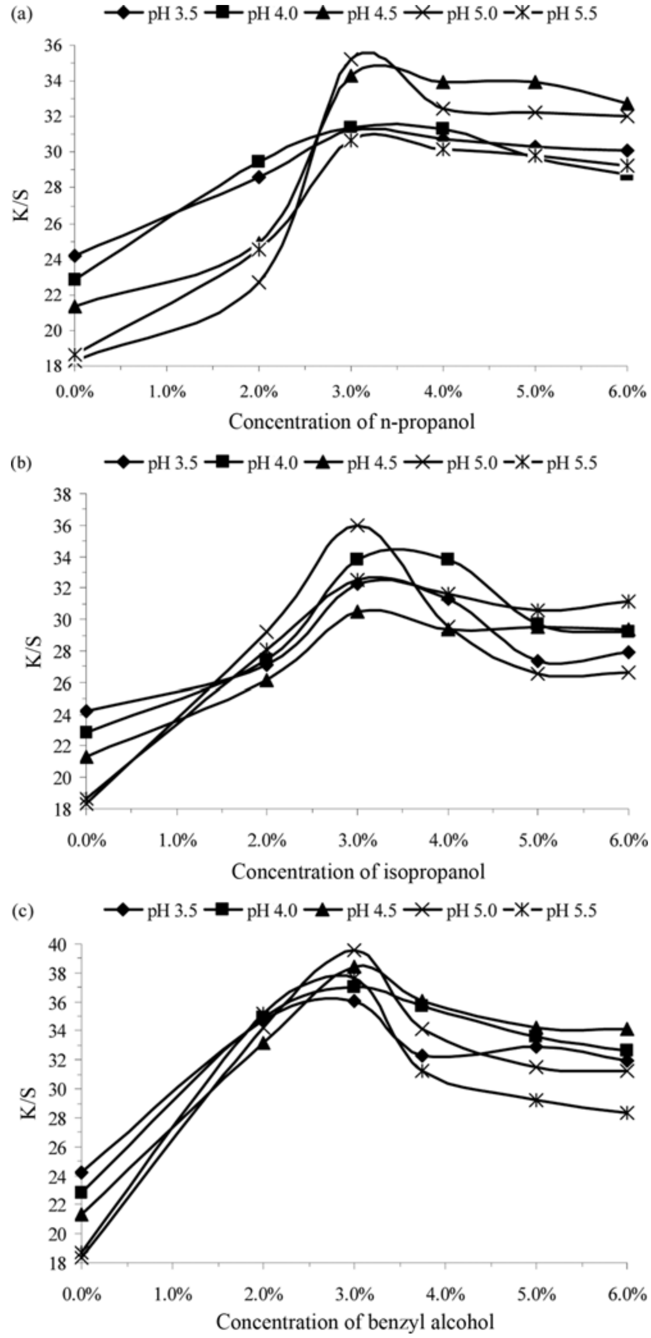


Fig. 3. Effect of concentration of solvent on the K/S values of dyed with Cationic Yellow X-GL.

of added organic solvents on the dyeability of acrylic fibers.

The above three graphs show the effects of concentration of three types of organic solvents on K/S of dyed acrylic fabric. In these figures, the K/S values of dyed fabric are increased with increasing concentration of solvents. That is, the K/S values of dyed fabric with cationic dye at 3% benzyl alcohol within the pH range from 4 to 5 showed rather higher in spite of an increase in the solvent concentration. The increment in dye affinity can be explained as follows: benzyl alcohol is helpful for the expansion of acrylic fiber, so that the resistance of the spatial spread of the dye to the fibers decreases.

On the other hand, the literature [14] reports that dynamic mechanical analysis has been used to demonstrate the plasticizing action of benzyl alcohol on wet fiber. The extent of plasticization which was measured by reduction in T_g of the wet fiber was found to correspond to the amount of benzyl alcohol adsorbed by the fiber. The maximum extent of plasticization coincided with the maximum concentration of benzyl alcohol adsorbed by the fiber. The extent of the enhancement of uptake of cationic dye onto acrylic fiber was found to be proportional to the extent of plasticization.

As shown in Fig. 5, it can be concluded that using benzyl alcohol as solvent can get the best depth of dyeing. However, the dyeing depth of isopropyl alcohol is similar to n-propanol. The special level-

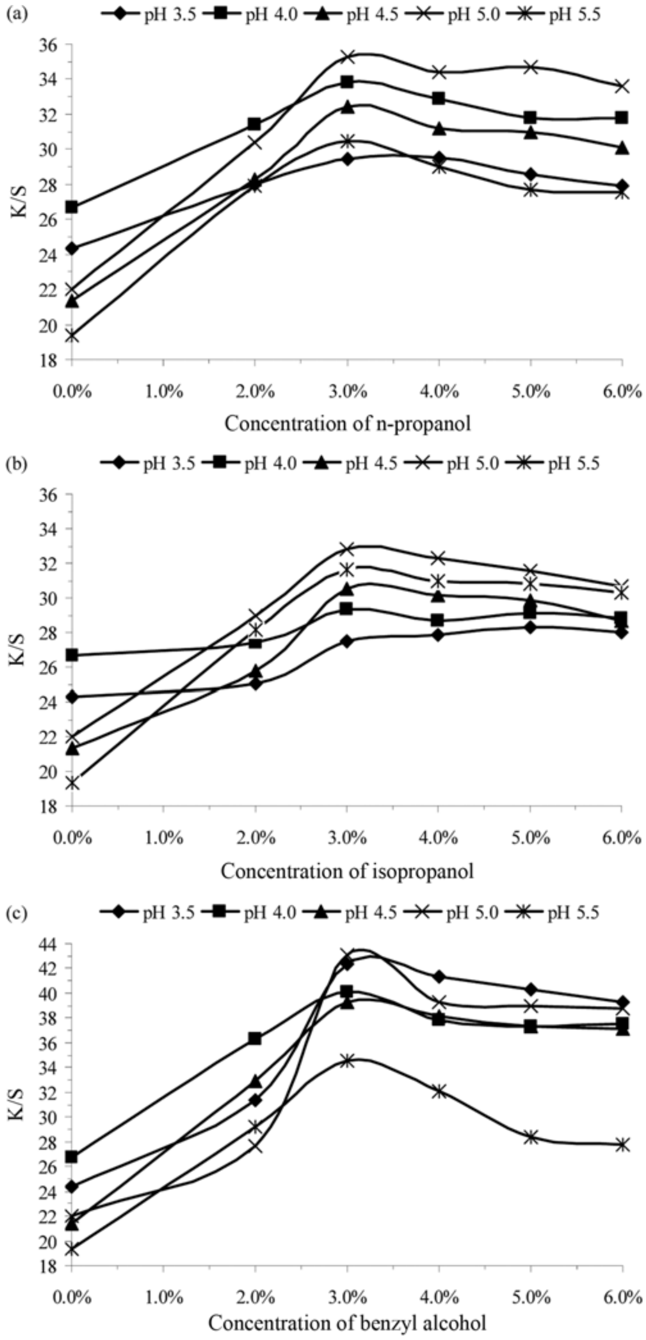


Fig. 4. Effect of concentration of solvent on the K/S values of dyed with Cationic Blue X-GRRL.

ing agent is the worst among the four, and it can be seen from the chart that the apparent color depth was higher when the cationic blue dye staining was employed. Meanwhile, in the best K/S value conditions, the concentration of benzyl alcohol is lower than n-propanol and isopropanol.

4. Leveling Properties Analysis

As seen in Table 3, the leveling properties of the dyeing acrylic using three types of organic solvents are not as good as leveling agent AN, but the difference of the S (λ) is not distinct. However, benzyl alcohol is basically able to meet the actual production applications for its uniform dyeing performance. More importantly, benzyl alcohol can enhance K/S value of the acrylic yarn more powerfully than leveling agent AN.

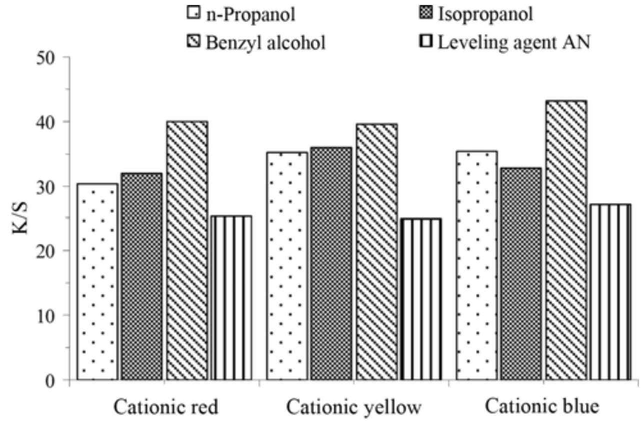


Fig. 5. K/S values of dyed acrylic fabric according to the different kinds of the used solvents.

Table 3. Results of various leveling properties

Dyestuff	λ_{max}/nm	Added components	K/S value	$S_{(\lambda)}$
Cationic red	530	n-Propanol	30.353	1.04
	530	Isopropanol	31.965	1.12
	530	Benzyl alcohol	39.867	0.91
	530	Leveling agent AN	25.556	0.85
Cationic yellow	420	n-Propanol	35.221	0.96
	420	Isopropanol	35.978	0.93
	420	Benzyl alcohol	39.600	0.9
	420	Leveling agent AN	25.013	0.88
Cationic blue	590	n-Propanol	35.290	1.15
	590	Isopropanol	32.800	1.05
	590	Benzyl alcohol	43.100	0.99
	590	Leveling agent AN	26.844	0.96

5. Fastness Properties Analysis

Table 4 presents the fastness properties for washing, perspiration, rubbing and light of acrylic yarn dyed with different cationic dyes with the infrared dyeing technique. The benzyl alcohol and leveling agent AN display similar fastness properties, whereas the other two show lower fastness properties.

CONCLUSIONS

Dyeability of acrylic fibers treated by infrared heat dyeing was investigated and the following conclusions were made: Addition of the organic solvents in dyeing bath increases the dye uptake at a certain concentration. Three organic solvents and leveling agent AN were added in dye bath, and their effects on dyeability were investigated. The K/S values of dyed acrylic fabric increased with increasing concentration of added solvents except for some cases. To obtain higher K/S value in acrylic fibers with infrared dyeing, it is necessary in future studies to investigate the solubility parameter of dye, solvent, fiber, and solubility parameter difference, as well as dipole moment of solvent.

Table 4. Results of various fastness properties

Sample		Washing	Perspiration		Rubbing		Light fastness 35 h
			Acid	Alkaline	Dry	Wet	
Cationic red	n-Propanol	3-4	3	4	4-5	3	6
	Isopropanol	4	4	4	4-5	3	6
	Benzyl alcohol	4	4	4	4-5	3-4	7-8
	Leveling agent AN	4-5	3-4	3-4	4-5	3-4	7-8
Cationic yellow	n-Propanol	4	3	4	4-5	3	6-7
	Isopropanol	4	4	4	4-5	3	7-8
	Benzyl alcohol	4-5	4	4	4-5	4	7
	Leveling agent AN	4-5	3-4	3-4	4-5	4	7-8
Cationic blue	n-Propanol	4	4	4	4-5	3-4	5-6
	Isopropanol	3-4	4	4	4-5	3-4	6-7
	Benzyl alcohol	4-5	4	4	4-5	4	7-8
	Leveling agent AN	4-5	3-4	3-4	4-5	3-4	7

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