Fibers and Polymers 2003, Vol.4, No.4, 204-209

Microwave Heat Dyeing of Polyester Fabric

Sam Soo Kim*, Su Gyung Leem, Han Do Ghim, Joon Ho Kim, and Won Seok Lyoo

School of Textiles, Yeungnam University, Kyongsan 712-749, Korea

(Received June 11, 2003; Revised October 22, 2003; Accepted October 29, 2003)

Abstract: The effect of padding solution on the microwave heat dyeing of polyester fabric was studied extensively. Polyester fabrics were impregnated in aqueous urea solution and aqueous sodium chloride solution for 10 min and then dyed for 7 min by microwave apparatus (2 450 MHz, 700 W) under optimum conditions which provide good exhaustion. Aqueous solutions of urea and sodium chloride showed more effective than water as a padding solution for microwave heat dyeing. The type of solvent added in padding media and its concentration significantly affects the K/S values of dyed polyester fabric. Added solvents such as n-hexane, acetone, and dimethyl formamide were also more effective than 100 % water as padding media for the microwave heat dyeing. It is supposed that the effect of used solvents on dyeing property of polyester fabrics depends on the solubility parameter difference between solvent and polyester fabric.

Keywords: Microwave heat dyeing, Polyester fabric, Dyeing property

Introduction

Dielectric heating by microwave can be explained as the conversion of energy from wave into thermal form in the dielectric materials. Materials with high dielectric constants, such as water, salt, and alcohol, can be self-heated by the rotation and relaxation of dipole during the radiation of microwave. Therefore, microwave heat as a heat source can be used in dyeing. In most dyeing methods, heat is used to increase dyeing rates and to promote dye exhaustion. Because conventional heating system used for dyeing often cause dye migration problems, alternative energy, source such as microwave, has been used.

On the other hand, in the case of dyeing of polyester fabric in water, temperature of dyeing solution cannot reach over 100 °C easily. Thus it is necessary to attempt the dyeing of polyester by using microwave heating. In our previous study [1], the effects of steaming and padding conditions on microwave heat dyeing of polyester fabric were investigated. In this study, microwave heat dyeing of polyester fabric were performed with varying concentrations of urea and sodium chloride (NaCl), and several solvent solutions and their effects on dyeability of polyester fabrics were evaluated.

Experimental

Materials

Polyester fabric (warp/weft 75d/72f SD) was pretreated and weight-reduced by general method. Disperse dyes used in this study were C. I. Disperse Orange 1, Yellow 7, and Red 13 (Aldrich Chemical Co. Inc., dye content 25 %) as shown in Table 1. Table 2 shows the characteristics of first-grade organic solvents used in this study.

*Corresponding author: sskim@yu.ac.kr

Microwave Heat Dyeing

Microwave Range RE-440 (Samsung Electronics Co., 2 450 MHz, 700 W) was adopted to radiate microwave. Padding of fabrics was conducted using Mathis laboratory padder (CH-8156, Oberhasli). Several researchers [2,3] have already confirmed the importance of steaming for the even heating in microwave heat dyeing. To introduce the even steaming into fabrics, 800-1 000 m*l* of water was preheated by microwave in specially designed beaker before taking place of dyeing. Relative humidity was controlled about 100 % by positioning three beakers of 150 m*l* of water in the rotational panel of the range during the process. Polyester fabric, padded by the condition indicated in Table 3, was fixed over the preheated device with cover preventing the loss of vapor. Dyeing was performed for 7 minutes using microwave radiation and followed by reduction cleaning.

Characterization

K/S values of polyester fabrics dyed by microwave heat were measured at maximum absorption wavelength of each dye using Computer Color Matching (Color Eye 3100, Macbeth).

Results and Discussion

Effect of Urea

Microwave heat dyeing can effectively lower energy and cost of dyeing because of short heating time. But it is hard to heat over 100 °C during the dyeing of polyester fabric with disperse dye in 100 % water dye bath. In this study, urea was added into water to increase the boiling point of dye liquor and the effect of dyeability.

Figure 1 shows the K/S values of polyester fabrics dyed with 5 g/*l* of three disperse dyes at various concentration of urea using microwave heating for 7 min. K/S values of fabrics dyed in urea-added bath were higher than those in

Table 1. Properties of used disperse dyes

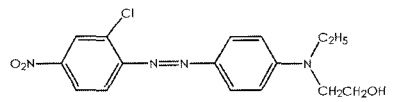
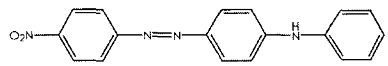
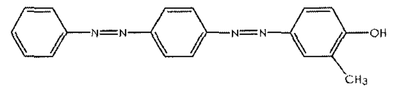
C. I. Name	Formula	FW	Dipole moment (D)	Solubility parameter (δ)
C. I. Disperse Red 13		348.79	7.710	8.963
C. I. Disperse Orange 1		318.34	7.389	8.441
C. I. Disperse Yellow 7		316.37	1.257	8.175

Table 2. Properties of used organic solvents

Solvent	Formula	Solubility parameter δ	B. P. (°C)	Dipole moment (D)
Hexane	$CH_3(CH_2)_4CH_3$	7.2	68.7	0.00
Acetone	CH_3COCH_3	9.8	56.2	2.88
N. N. Dimethyl formamide	$HCON(CH_3)_2$	12.1	152.8	3.82
Methyl alcohol	CH_3OH	14.3	64.5	1.70
Ethylene glycol	CH_2OHCH_2OH	16.3	197.2	2.28

cf. Polyethylene terephthalate δ: 10.7.

Table 3. Conditions of microwave heat dyeing

Padding	Pick up (%)	70 ± 5
	Speed of rotation of mangle (m/min)	2
Microwave generation	Frequency (MHz)	2,450
	Output (W)	700
Padding liquor for microwave treatment	Conc. of solvent (%)	0, 10, 30, 50
	Conc. of dye (g/*l*)	5
	Conc. Of urea (wt%)	0,10,20,30,40,50
	Conc. Of NaCl (mol%)	0, 1, 2, 5, 7, 9
	Time of treatment (min)	7
	Conc. of antimigrant (g/*l*)	2
	Conc. of dispersing agent (g/*l*)	2
	Time of dipping (min)	10
	pH of dye liquor	5.5
Reduction cleaning	$Na_2S_2O_4$ (g/*l*)	2
	NaOH (g/*l*)	2
	Nonionic surfactant (g/*l*)	2
	Temperature and time of treatment (°C × min)	80 × 20

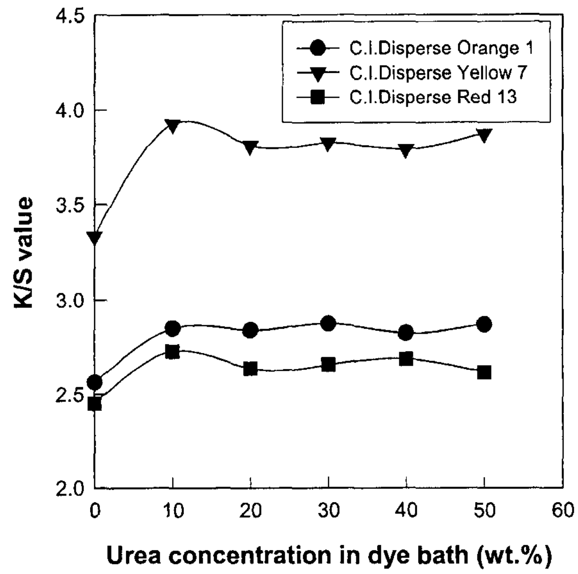


Figure 1. K/S values of dyed polyester fabric according to the urea concentration in dye bath; dye concentration 5 g/*l*.

100 % water bath for all three disperse dyes used in this study. Microwave heating in aqueous dye solution with urea can introduce the elevated boiling point of dye liquor due to urea of high dipole moment, as well as heat generation of dye-liquor by dipole rotation. Therefore, added urea is suspected to introduce high temperature and pressure surroundings in

microwave dyeing apparatus. This is in good accordance with much of other fundamental researches [4,5]. These researches indicated that microwave heating has an effect on the fine structure of various textile fibers, especially thermoplastics. Wakida *et al.* [6] reported that microwave heating of nylon and polyester fibers in aqueous solutions for 2 min increased crystallinity and crystal size. Aqueous urea and various glycols had an even pronounced effect. Needle *et al.* [7] reported changes in properties including textile strength and dye receptivity when nylon, wool, cotton and polyester fabrics were heated in various polar solvents for 1-2 minute using microwave heating.

It is generally accepted that urea used as a leveling agent of reactive dyes during the cold pad batch (CPB) dyeing of cotton fabrics could give a boiling point elevation of dye liquor and swelling of fiber in microwave heat dyeing. Dipole moments of materials, such as fiber, dye, agents, solvent, and so on, were appreciated as important parameters of microwave heat dyeing. Higher dipole moment of urea (4.07 D), therefore, can increase in boiling temperature of dye liquor. Chiao-Cheng and Reagan [8] have also showed urea added in dye liquor gave high dye uptake due to its higher dipole moment than that of water.

On the other hand, the dipole moment of used dye as well as urea addition effect also could effect on dyeing property. In fact, the C. I. Disperse Yellow 7 which has lower dipole moment (1.257 D) than Orange 1 (7.389 D) and Red 13 (7.710 D) showed higher K/S value. This results might be explained by the dipole moment difference between used dye and urea. Besides the dipole moment, the solubility parameter of dye and solvent, dye structure, and so on are also important considering factors in microwave heat dyeing.

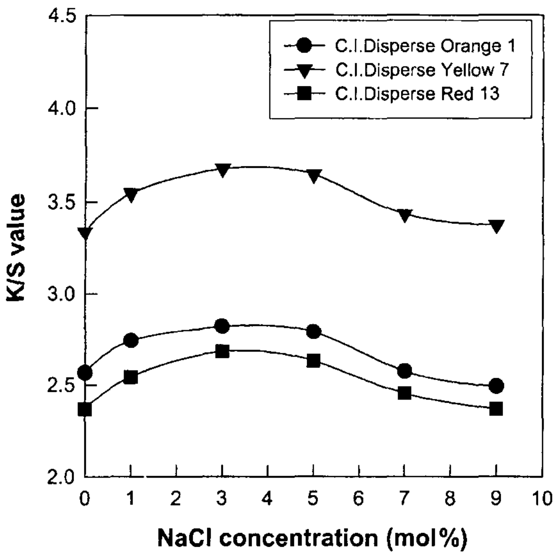


Figure 2. K/S values of dyed polyester fabric according to the NaCl concentration in dye bath; dye concentration 5 *g/l*.

Effect of Sodium Chloride

K/S values of microwave heat dyed polyester fabrics with the concentration of NaCl added to dyeing solution were shown in Figure 2. In connection with salt addition effect, it was reported that the rate and amount of evaporation, as well as dielectricity increased with increasing the amount of salt added to dyeing bath of microwave heat dyeing [9,10]. 1-9 mol% of NaCl was added to the dyeing bath in expectation of increasing of the rate of temperature increment and dielectricity. The K/S value of dyed fabric increases slightly with added NaCl concentration until about 1-5 mol% and then decrease at 7-9 mol%. This results were in good agreement with that of Furuya [10] which addition of NaCl in water increased the rate of temperature increment from 20 °C/sec to 30.5 °C/sec. Therefore, it can be deduced that microwave heating shows that solvent-specific heating characteristics and exothermic characteristics of matrices affect the heating temperatures of substrates. NaCl over 5 mol%, however, induces lowered K/S values similar to those of untreated cases. This was ascribed to the low evenness of fabric dyed with excess amount of NaCl having much of white spotting. In fact, the white spotted unlevel dyed fabric often occurred at over 5 mol%, and this led to occur high reflectance and exhibit low K/S value of dyed fabric.

Effect of Organic Solvents

Polyester 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, such as direct and acid dyes. Therefore, dyeing of polyester fiber is generally carried out at high temperature over 120 °C. Carrier could descend the dyeing temperature with disperse dye up to about 100 °C by loosening the fiber structure. Microwave heating can raise the temperature of dyeing bath to boiling temperature rapidly, but cannot achieve high dye uptake with 100 % water bath. According to the previous studies [11-16], it is essential to investigate the effects of added organic solvents on dyeability of polyester fiber. Figure 3 shows the effects of concentration of organic solvent on K/S of dyed polyester fabric with three types of disperse dyes. In our previous paper [1], microwave heat dyeing with 10, 20, 30, and 40 % (v/v) of ethylene glycol (EG), dimethylformamide (DMF), and urea solutions was performed and dyeing property in the respect of level dyeing were reported at about 30 % of solvent. In these figures, the K/S values of dyed fabric was increased with increasing concentration of solvents except for some cases. That is, the K/S values of dyed fabric with C. I. Disperse Orange 1 and Red 13 at 50 % DMF showed rather lower K/S value in spite of an increase in the solvent concentration.

These results cannot be explained clearly by only dipole moments (D) or boiling points (°C) of solvents. Dipole moments and boiling temperatures of solvents are as follows; D:

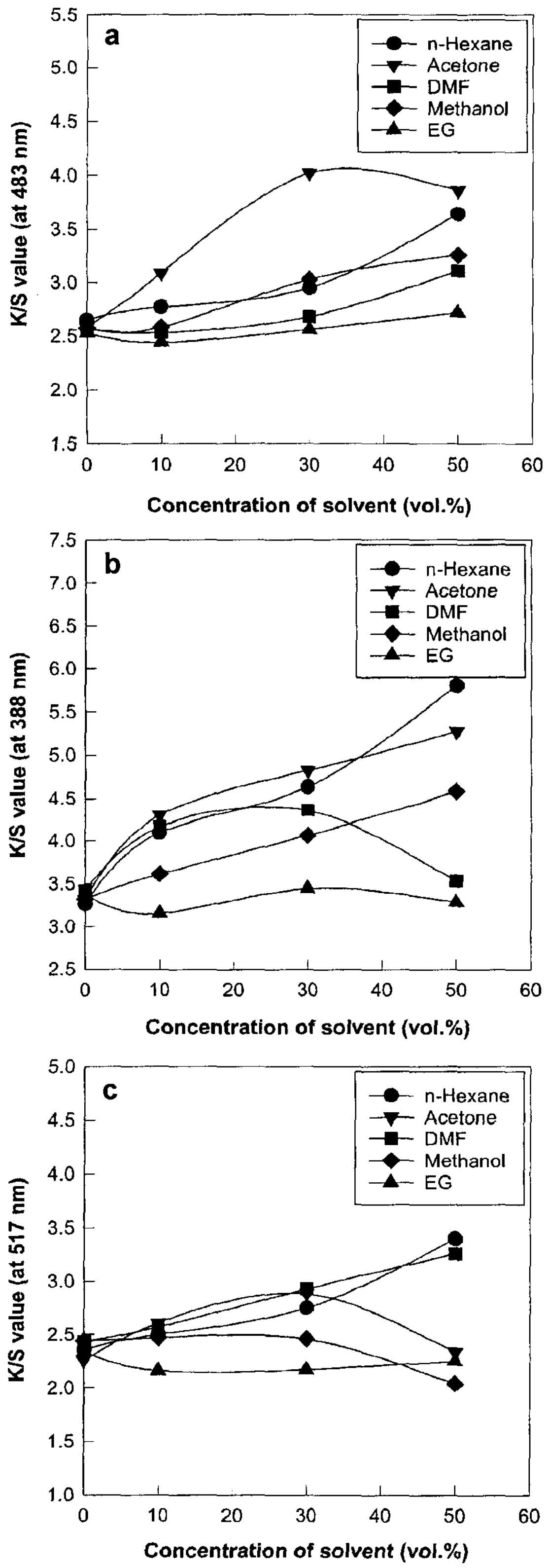


Figure 3. Effect of concentration of solvent on the K/S values of dyed polyester fabric: a, C. I. Disperse Orange 1; b, C. I. Disperse Yellow 7; c, C. I. Disperse Red 13.

DMF(3.82) > acetone(2.88) > EG(2.28) > methanol(1.70) > n-hexane(0.00); boiling temperature(°C): EG(197.2) > DMF (152.8) > n-hexane(68.7) > methanol(64.5) > acetone(56.2). In cases of DMF and acetone, increasing dye uptakes can be explained by higher dipole moments. For n-hexane, on the other hands, it cannot be explained by dipole moment only and deduced that there are other factors except dipole moment. The K/S value decreasing at even 50 % solvent concentration was attributed to the deficiency of level dyeing property. As confirmed [6,17,18], solvents of high dipole moments and boiling temperatures increase the dyeability of polyester fiber by affecting heating temperature, changing in microstructure of fiber, and resulting fast dye transfer. In this study, however, it was found that extent of the boiling temperature of added solvent did not affect the dyeability. Therefore, it is necessary to choose comparatively high dipole moment having solvent to obtain high K/S value. But as shown in case of n-hexane in this study, it is necessary to investigate the other factors except dipole moment.

Effect of Solubility Parameter

Simply solubility parameter, unfortunately, cannot explain the exceptional higher K/S value of fabric having none dipole moment n-hexane, added 50 % in dyeing bath. Hansen [19] divided the mixing energies as disperse force, dipolar Van der Waals force, and hydrogen bonding and defined three solubility parameters as δ_d, δ_p, and δ_h for disperse force, dipolar Van der Waals force, and hydrogen bonding energy solubility parameter, respectively. Ibe [13] introduced the associated solubility parameter δ_a. Therefore, precise interpretation of interaction between solvent and polyester fiber can be achieved by considering these four solubility parameters as well as total difference of solubility parameter [13,16,20]. But according to the simply solubility parameter concept in this discussion, we could infer that the used dyes in this study should have greater solubility in 50 % solvent solution than in 10 % or 30 % solutions. This tendency could be understood from the solubility parameters difference ($\Delta\delta$) between used dyes and solvents as indicated in Table 4. With increase in solvent content, the solubility parameter difference of the dyes and the solvents should decrease, and C. I. Disperse Red 13 should possess low solubility parameter difference in dye liquor followed by C. I. Disperse Orange 1 and C. I. Disperse Yellow 7.

On the other hand, the effect of used solvents on K/S value of dyed fabrics, unfortunately, cannot explain simply. However, we considered the solubility parameter of solvent to know the effect of added solvent on K/S values. According to Harris and Guion [21] when the solvent and fiber have about same solubility parameter, the dye has little preference for either dye bath phase or fiber phase. In addition to the similar solubility parameter effect, the less $\Delta\delta$ difference between dye and solvent is, like as in case of high concentration in same solvent, the higher K/S of dyed fabric is. From these

Table 4. Solubility parameters of Dyes, Solvents, Solvent concentrations and Solubility parameter difference between dye and solvent

Dyes	Solvents	Solvent addition concentrations			$\Delta\delta_1$			$\Delta\delta_2$			$\Delta\delta_3$		
		10 %	30 %	50 %	10 %	30 %	50 %	10 %	30 %	50 %	10 %	30 %	50 %
C. I. Disperse Red 13 (A) (δ: 8.963)	Hexane (δ = 7.2)	22.14	18.82	15.50	13.18	9.86	6.54	13.70	1038	7.06	13.97	10.65	7.33
C. I. Disperse Orange1 (B) (δ: 8.441)	Acetone (δ = 9.8)	22.40	19.60	16.80	13.44	10.64	7.84	13.96	11.16	8.36	14.23	11.43	8.63
C. I. Disperse Yellow17(C) (δ: 8.175)	N.N-Dimethyl formamide (δ = 12.1)	22.63	20.29	17.95	13.67	11.33	8.99	14.19	11.85	9.51	14.46	12.12	9.78
	Methyl alcohol (δ = 14.3)	22.85	20.95	19.05	13.89	11.99	10.09	14.41	12.51	10.61	14.68	12.78	10.07
	Ethylene glycol (δ = 16.3)	23.05	21.55	20.05	14.09	12.59	11.09	14.61	13.11	11.61	14.88	13.38	11.88

*solubility parameter of water δ = 23.8, $\Delta\delta_1 = \delta_{solvent} - \delta_{A\ dye}$, $\Delta\delta_2 = \delta_{solvent} - \delta_{B\ dye}$, $\Delta\delta_3 = \delta_{solvent} - \delta_{C\ dye}$.

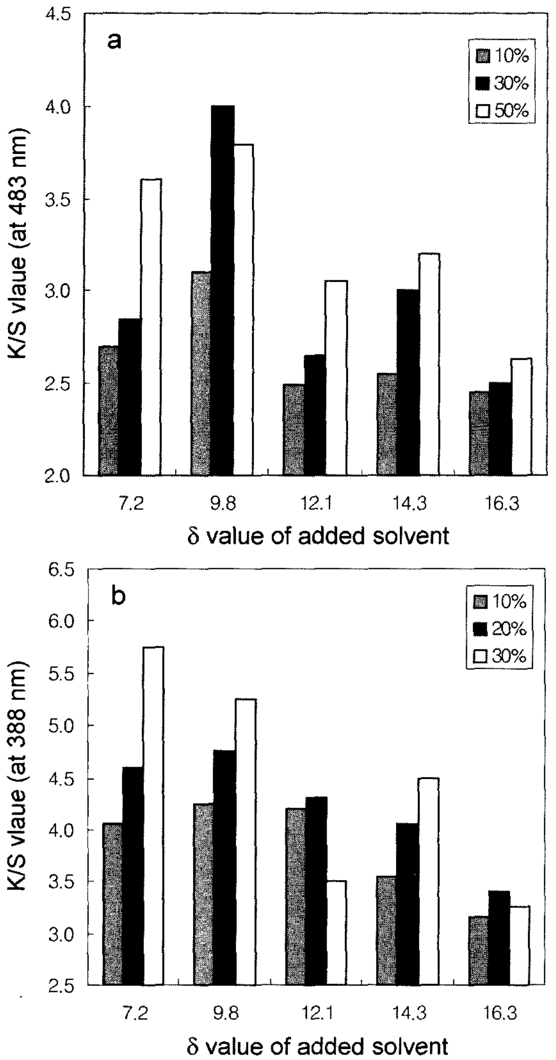


Figure 4. K/S values of dyed polyester fabric according to the solubility parameter of the used solvents : a, C. I. Disperse Orange 1; b, C. I. Disperse Yellow 7; c, C. I. Disperse Red 13. (δ: n-Hexane (7.2), Acetone (9.8), DMF (12.1), Methanol (14.3), EG (16.3)).

results, it can be concluded that higher K/S can be obtained at the solubility parameter similar to that of polyester fiber, 10.7, and these similar solubility parameters mean the maximum interaction between polyester fiber and solvents [22]. The K/S of dyed fabric according to the added solvent amount in same solvent is shown in Figure 4. The dyed fabric had high K/S at 50 % solvent concentration except for some cases. Although many researchers [15,16,20,23-26] have studied the effects of solubility parameters of dye, fiber, and solvent on dyeability, it is quite difficult to apply exact solubility theory with dyeability. Therefore, it is necessary to select the solvent which gives a minimum solubility parameter difference between polyester fiber and solvent in order to obtain high K/S values of dyed polyester in microwave heat dyeing.

Conclusions

Dyeability of polyester fiber treated by microwave heat dyeing was investigated. From these results, it can be concluded as follows. Addition of urea in dyeing bath increases the dye uptake at all concentration. For NaCl, slight increase in the dye uptake was observed at 1-5 mol% but white spotting induced by excess amount of NaCl decreased evenness of dyed fabric. Five organic solvents were added in dye bath and their effects on dyeability were investigated. The K/S values of dyed polyester fabric increased with increasing concentration of added solvents except for some cases. To obtain higher K/S value in polyester microwave dyeing, it is necessary to investigate the solubility parameter of dye, solvent, fiber, and solubility parameter difference, as well as dipole moment of solvent.

Acknowledgement

This work was supported by Research Grant of Advanced Research Center (105095) and Regional Research Center in Yeungnam University.

References

1. S. J. Seo, S. G. Im, and S. S. Kim, *J. Kor. Soc. Dyers. Finishers*, **10**, 4 (1998).
2. J. G. Belton, *Int. Dyer. Text. Printer*, **15**, 5 (1970).
3. R. R. D. Holt and J. F. Graham, *Text. Veredulung*, **14**, 508 (1979).
4. M. J. Delaney, *Text. Chem. Colorist*, **4**, 119 (1972).
5. M. J. Delaney and Seltzer, *J. Soc. Dyers Colour.*, **88**, 55 (1972).
6. T. Wakida, Y. Tomihara, I. Aoki, and N. Kuroki, *Sen-i Gakkaishi (Japan)*, **31**, 9 (1975).
7. H. L. Needle, A. Tai, R. S. Berns, and K. W. Alger, '*Book of Papers 1977*', N.T.C., A.A.T.C.C., p.201.
8. J. W. Chiao-Cheng and B. M. Reagan, *Text. Chem. Colorist*, **15**, 1 (1983).
9. M. J. Delaney, *Text. Chem. Colorist*, **4**, 5 (1972).
10. Masazo Furuya, *Dyeing industry, Jpn.*, **28**, 9 (1980).
11. S. Kuwabara, *Sen-i Gakkaishi (Japan)*, **34**, 9 (1978).
12. S. A. Siddiqui, *Text. Res. J.*, **52**, 6 (1982).
13. E. C. Ibe, *J. Appl. Polym. Sci.*, **14**, 837 (1970).
14. D. M. Koenhrn and C. A. Smolders, *J. Appl. Polym. Sci.*, **19**, 1163 (1975).
15. W. C. Ingamells, *J. Soc. Dyers Colour.*, **96**, 9 (1980).
16. S. R. Park, K. S. Yang, and J. W. Kim, *J. Korean Fiber Soc.*, **28**, 40 (1991).
17. R. S. Berns and H. L. Needles, *J. Soc. Dyers Colour.*, **95**, 6 (1979).
18. G. J. Kim, P. K. Park, I. J. Gwag, and M. R. Park, *J. Korean Fiber Soc.*, **32**, 46 (1995).
19. C. M. Hansen, *J. Paint Technol.*, **39**, 505 (1967).
20. R. B. Chavan, J. V. Rao, and H. Ahmad, *Text. Res. J.*, **6**, 347 (1983).
21. F. O. Harris and T. H. Guion, *Text. Res. J.*, **42**, 626 (1972).
22. Y. M. Lee and S. S. Im, *J. Korean Fiber Soc.*, **32**, 697 (1995).
23. Y. M. Lee, K. W. Lee, and S. S. Im, *J. Korean Fiber Soc.*, **33**, 412 (1996).
24. P. Y. Wang and J. F. Ma, *Text. Res. J.*, **68**, 8 (1998).
25. W. C. Ingamells and M. N. Thomas, *Text. Chem. Colorist*, **16**, 3 (1984).
26. D. W. Van Krevelen, "Properties of Polymers", pp.189-225, Elsevier, Amsterdam, 1990.