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Dyeing Polyester and Cotton-Polyester Fabrics by Means of Direct Dyestuffs after Chitosan Treatment

Abstract
Research into the process of dyeing polyester and cotton-polyester fabrics using direct dyestuffs was carried out. In order to improve the adhesion of chitosan to the surface of polyester fibres, pre-treatment in NaOH solutions was performed. The colour and rubbing fastness properties of the chitosan-deposited fabrics were assessed. The colour difference between the dyed blank samples and samples dyed after alkaline and/or chitosan treatment was estimated using spectrophotometer evaluation. The data obtained shows that it is possible to dye polyester and cotton-polyester fabrics finished by chitosan with only one direct dyestuff, which normally shows substantivity to cellulose fibres. The dyed samples showed good rubbing and washing colour fastness properties within the range of colour change. The colour strength of the dyed samples increased with the increased deposition of chitosan on the fabric.

Key words: *dyeing process, direct dyestuff, polyester fabric, cotton-polyester fabric, chitosan, alkaline treatment.*

Introduction

Consumers generally accept cotton-polyester textile fabrics. The selection of these fibres ensured sufficient comfort resulting mainly from the use of cotton fibres, as well as suitable mechanical properties such as the tensile strength characteristic of synthetic fibres. However, the presence of both components (polyester and cotton) in textiles causes some difficulties in the dyeing process [1].

Polyester fibres show a hydrophobic character, and swell to a very small extent in the water bath. Hence, the access of the dyestuff molecules to the fibre's inside is very difficult. This fact, together with an absence of active chemical groups in polyester's macromolecules makes it impossible to apply the majority of dyestuffs apart from disperse dyes.

On the contrary, hydrophilic cellulose fibres may easily undergo swelling in water. Owing to this phenomenon, the dyestuff molecules first adsorbed on the fibre surface may diffuse into the fibre interior. Subsequently, the bonding interactions between the dyestuff and cellulose may be formed.

In spite of their advantages, polyester fibres are difficult to dye. The often applied pressure method requires a suitable, intricate apparatus which causes great energy consumption.

In order to obtain an intensive colour strength of polyester fibres, auxiliary agents are often added to the dye bath. These agents can often cause sensitisation of the human skin. Moreover, the small amount of them left on the polyester fibres reduces colour fastness to light [2,3].

It is possible to eliminate disperse dyestuffs and the detrimental auxiliary agents by the application of natural polymers such as chitin or chitosan in the textile finishing processes.

Chitosan is the deacetylated form of chitin. It is a long, unbranched polysaccharide like cellulose, with an aminoacetyl group instead of a hydroxyl group in the C-2 carbon position [4-12].

Materials and Methods

Two different fabrics were used:
- polyester fabric (90 g/m^2), containing

__Table 1.__ The chitosan samples' characteristics; the viscosity was determined for a 1% solution of chitosan in a 1% solution of acetic acid at a temperature of 25°C, by means of a Brookfield viscometer at 30 r.p.m.

Property	Unit	Chitosan I	Chitosan II	Chitosan III
Dry mass	%	96.9	89.0	89.6
Ash content	%	1.31	0.29	1.2
Deacetylation degree	%	83	65.5	77.7
Viscosity	mPa s	20	1230	245

Table 2. Changes in dry-rubbing, wet-rubbing (PN-EN ISO 105-X12:1999) and washing fastness (PN-EN 20105-C01:1997) properties of cotton-polyester fabric samples dyed using Solophenyl Blau TLE after treatment with chitosan I, 0 - without alkaline pre-treatment, and A - with alkaline pre-treatment, NaOH 10 g/dm^3.

Pretreatment	Chitosan deposition, %	Colour fastness to:		
		rubbing		washing
		dry	wet	
0	0.0	4-5	3-4	4-5
	0.5	4	3	4
	1.0	4-5	3	4-5
	1.5	4-5	3	4-5
	2.0	4	3	4-5
	2.5	4-5	3	4-5
	3.0	4	3	4
A	0.0	4-5	3-4	4-5
	0.5	4-5	3	4-5
	1.0	4-5	3	4-5
	1.5	4	3	4-5
	2.0	4	3	4-5
	2.5	4	3-4	4
	3.0	4-5	3	4-5

Table 3. Changes in dry-rubbing , wet-rubbing (PN-EN ISO 105-X12:1999) and washing fastness (PN-EN 20105-C01:1997) properties of cotton-polyester fabric samples dyed using Solophenyl Blau TLE after treatment with chitosan II, 0 - without alkaline pre-treatment, and A - with alkaline pre-treatment, NaOH 10 g/dm^3.

Pretreatment	Chitosan deposition, %	Colour fastness to:		
		rubbing		washing
		dry	wet	
0	0.10	4	3	4-5
	0.25	4-5	3	4-5
	0.50	4	3	4-5
	0.75	4	3	4-5
	1.00	4	3	4-5
	1.50	4	3	4-5
A	0.10	4-5	3	4-5
	0.25	4-5	3	4-5
	0.50	4-5	3	4-5
	0.75	4-5	3	4-5
	1.00	4-5	3	4-5
	1.50	4-5	3	4-5

in warp and weft yarns of linear density 8.4 tex, (PE100);

- polyester-cotton fabric, PE/CO - 67/33, (115 g/m^2), containing in warp and weft directions PE/CO - 67/33 yarns of linear density 10×2 tex.

The samples were washed for 45 min in an aqueous solution containing 2 g/dm^3 of wetting agent Rokafenol N-8 (produced by Organika-Rokita, Poland) with a liquor ratio of 1:25 at 60°C, and then rinsed twice in cold tap water and dried at the room temperature.

Table 4. Changes in dry-rubbing, wet-rubbing (PN-EN ISO 105-X12:1999) and washing fastness (PN-EN 20105-C01:1997) properties of cotton-polyester fabric samples dyed using Solophenyl Blau TLE after treatment with chitosan III, 0 - without alkaline pre-treatment, and A - with alkaline pre-treatment, NaOH 10 g/dm^3.

Pretreatment	Chitosan deposition, %	Colour fastness to:		
		rubbing		washing
		dry	wet	
0	0.10	4-5	3	4-5
	0.25	4	3	4-5
	0.50	4	3	4-5
	0.75	4-5	3	4-5
	1.00	4	3	4-5
	1.50	4	3	4-5
A	0.10	4-5	3	4-5
	0.25	4-5	3	4-5
	0.50	4-5	3	4-5
	0.75	4-5	3	4-5
	1.00	4-5	3	4-5
	1.50	4	2-3	4-5

In order to improve the adhesion of chitosan to the smooth surface of polyester fibres, an alkaline pre-treatment in water solution containing 10, 20, 30 g/dm^3 of NaOH for 30 min at 98°C with a liquor ratio of 1:15 was performed. Subsequently, the samples were rinsed twice in cold tap water and dried at room temperature.

Three chitosan samples of different viscosity and different deacetylation degree, produced by the Chiton Co. Ltd., Gdynia, Poland, were used. The properties of the samples are shown in Table 1.

The chitosan flakes were dissolved in an aqueous 1% acetic acid. After adding a cross-linking agent (glutar aldehyde, 5% w/w, calculated to the weight of pure chitosan) the samples were immersed in the chitosan solutions in the special laboratory padding-squeezing machine, made by E. Benz, Switzerland. This process was repeated several times to ensure the even deposition of chitosan on the fabric surface. Then the samples were dried at 90°C for 40 s and subjected to a thermofixation process at 130°C for 20 s.

The chitosan amount deposited on the fabric surface was determined according to the equation:

Table 5. Changes in dry-rubbing , wet-rubbing (PN-EN ISO 105-X12:1999) and washing fastness (PN-EN ISO 20105-C01:1997) properties of cotton-polyester fabric samples dyed using Solophenyl Rot 4GE after treatment with chitosan I, 0 - without alkaline pre-treatment, and A_1 - with alkaline pre-treatment, NaOH 10 g/dm^3, A_2 - with alkaline pre-treatment, NaOH 20 g/dm^3, and A_3- with alkaline pre-treatment, NaOH 30 g/dm^3.

Pretreatment	Chitosan deposition, %	Colour fastness to:		
		rubbing		washing
		dry	wet	
0	0.0	4-5	3-4	4-5
	0.5	4-5	3	4
	1.0	4-5	3	4
	1.5	4-5	3	4-5
	2.0	4-5	3	4
	2.5	4-5	3	4
	3.0	4-5	3	4-5
A_1	0.0	4-5	3-4	4-5
	0.5	4-5	3	4
	1.0	4-5	3	4
	1.5	4-5	3	4
	2.0	4-5	3	4
	2.5	4-5	3	3
	3.0	4-5	3	4
A_2	0.0	4-5	3-4	4-5
	0.5	4-5	3	4-5
	1.0	4-5	3	4-5
	1.5	4-5	3	4-5
	2.0	4-5	3-4	4-5
	2.5	4-5	3	4-5
	3.0	4-5	3	4-5
A_3	0.0	4-5	3-4	4-5
	0.5	4-5	3	4
	1.0	4-5	3	4
	1.5	4-5	3	4-5
	2.0	4-5	3	4
	2.5	4-5	3	4
	3.0	4-5	3	4

$$p = \frac{T \cdot a}{d} \qquad (1)$$

where:

p - the chitosan amount deposited on the fabric, in %, calculated in relation to the weight of fabrics,

a - the chitosan concentration in the padding solution, in g/dm^3,

T - the chitosan pick-up, in % (50% for polyester fabric and 80% for cotton-polyester blend).

d - the density of the chitosan solutions, approximately 1 g/cm^3 for all chitosan solutions.

A chitosan solution of concentration 20 g/dm^3 was used for deposition. For example, at T=80%, a=20 g/dm^3, and d=1 g/cm^3, the chitosan amount p=1.6%.

Table 6. Changes in dry-rubbing, wet-rubbing (PN-EN ISO 105-X12:1999) and washing fastness (PN-EN 20105-C01-1997) properties of cotton-polyester fabric samples dyed using Solophenyl Blau TLE after treatment with chitosan I, 0 - without alkaline pre-treatment, and A_1 - with alkaline pre-treatment, NaOH 10 g/dm^3, A_2 - with alkaline pre-treatment, NaOH 20 g/dm^3, and A_3- with alkaline pre-treatment, NaOH 30 g/dm^3.

Pretreat-ment	Chitosan deposition, %	Colour fastness to:		
		rubbing		washing
		dry	wet	
0	0.5	3-4	1-2	4
	1.0	3-4	1-2	4-5
	1.5	3-4	1-2	4-5
	2.0	3-4	1-2	4-5
	2.5	3-4	1-2	4-5
	3.0	3-4	1-2	4-5
A_1	0.5	3	2	4-5
	1.0	3-4	2	4-5
	1.5	3-4	2	4-5
	2.0	3-4	2	4-5
	2.5	4	2	4-5
	3.0	4-5	2	4-5
A_2	0.5	4	1-2	4-5
	1.0	4	1-2	4-5
	1.5	4-5	1-2	4-5
	2.0	4-5	1-2	4-5
	2.5	4	1-2	4-5
	3.0	4	2	4-5
A_3	0.5	3-4	2	4-5
	1.0	4-5	1-2	4-5
	1.5	4	1-2	4-5
	2.0	4-5	1-2	4-5
	2.5	4-5	1-2	4-5
	3.0	4	2	4-5

The polyester and cotton-polyester fabrics samples were dyed after or without chitosan deposition, using one direct dyestuff showing substantivity only to cellulose, in the Linitest (Hanau GmbH) laboratory dyeing-washing machine, Germany. The Solophenyl Rot 4GE and Solophenyl Blau TLE direct dyestuffs, kindly supplied by Swisscolor, were applied according to the following procedure: temperature in the dye bath (dyestuff - 1% o.w.f., Glauber's salt - 15 g/dm^3, liquor ratio - 1:15) was raised from 40°C to 95°C at 1°C/min, maintained for 45 min, then decreased to 80°C and maintained at the final temperature for 20 min.

After dyeing, the samples were fixed in an aqueous solution containing 3% fixative Tinofix Eco (without formaldehyde) for 40 min at 40°C , then rinsed and dried at room temperature.

The colour difference between the dyed blank samples and samples dyed after the alkaline and/or chitosan treatment was monitored with a Macbeth Color Eye 3000 diffusion reflectance spectrophotometer, made in the USA, under illuminant D_{65} using a 10° observer. The colour and rubbing fastness properties were estimated according to Polish standards. The results were assessed in ratings from grade 1 (very poor) to grade 5 (excellent). The colour change was assessed according to the grey scale from grade 1 (much altered) to grade 5 (unaltered).

Results and Discussion

The dyeing with direct dyestuffs obtained on chitosan-deposited polyester fabric samples is even, independent of earlier alkaline pre-treatment. The dyeing uniformity depends on the uniformity of chitosan deposition. The dyed cotton-polyester samples are characterised by better dyeing uniformity and melange effect, which decreases with an increased amount of chitosan.

The data obtained shows that after chitosan treatment it is possible to dye polyester and cotton-polyester fabric with only one direct dyestuff, which shows substantivity only to cellulose fibres. The dyed textiles are characterised by good dry-rubbing and fastness properties (3-4 to 4-5 grades), as well as good washing fastness properties in the range of the colour change (4 to 4-5 grades), apart from the polyester fabric samples dyed with the Solophenyl Rot 4GE dyestuff, for which 2 to 2-3 grades were obtained. However, all dyed samples show a low level of wet-rubbing fastness properties: 1 to 2-3 grades for the polyester samples and 2-3 to 3-4 grades for the blend samples.
(Tables 2-6).

An alkaline pre-treatment of fabric samples has practically no essential consequence for changes in colour fastness to rubbing and washing, but causes a slight increase in the depth of shade. In order to improve the adhesion of chitosan to the surface of polyester fibres, the pre-treatment in an alkaline solution containing 10 g/dm^3 of NaOH is permitted.

The colour strength increases with an increase in chitosan deposition independent of the degree of deacetylation. The colour difference between the dyed blank samples and the samples with an increased chitosan amount grows significantly, and has a similar character for both polyester and cotton-polyester fabric samples. (Figures 1-5).

The deacetylation degree of chitosan does not essentially affect either the strength of colour of textiles or the colour fastness to rubbing and washing. The viscosity of chitosan (which depends on the molecular weight) decides its application properties. The stiffness of the chitosan-deposited samples increases with an increase in the chitosan deposition on textiles.

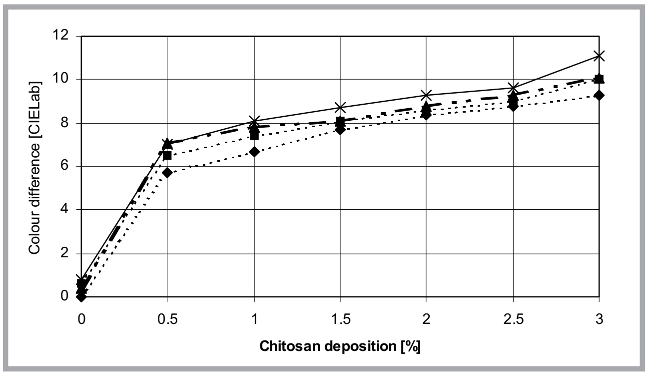

Figure 1. Changes in colour difference of cotton-polyester fabric samples dyed using Solophenyl Blau TLE after chitosan (I) deposition; NaOH concentration: ◆ 0 g/dm^3, ■ 10 g/dm^3, ▲ 20 g/dm^3, × 30 g/dm^3.

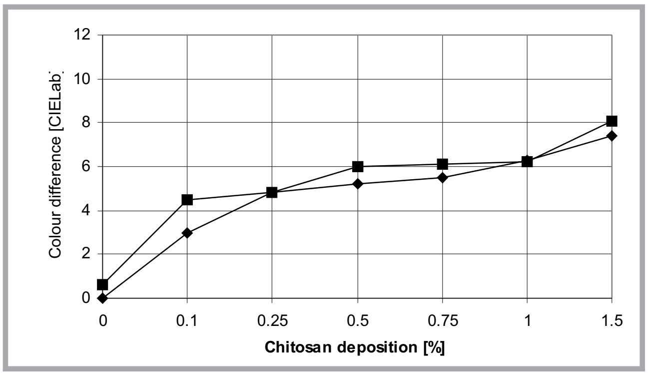

Figure 2. Changes in colour difference of cotton-polyester fabric samples dyed using Solophenyl Blau TLE after chitosan (II) deposition; NaOH concentration: ◆ 0 g/dm^3, ■ 10 g/dm^3.

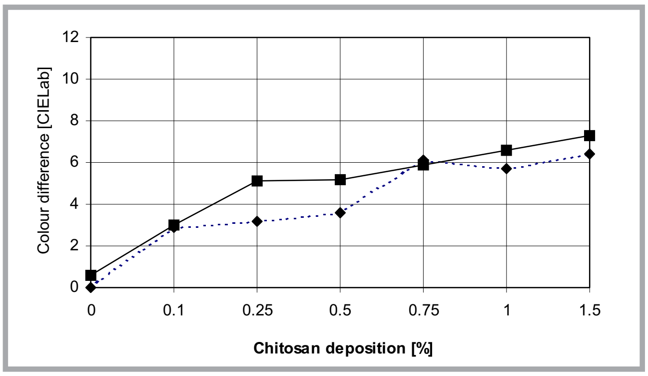

__Figure 3.__ Changes in colour difference of cotton-polyester fabric samples dyed using Solophenyl Blau TLE after chitosan (III) deposition; NaOH concentration: ◆ 0 g/dm^3, ■ 10 g/dm^3.

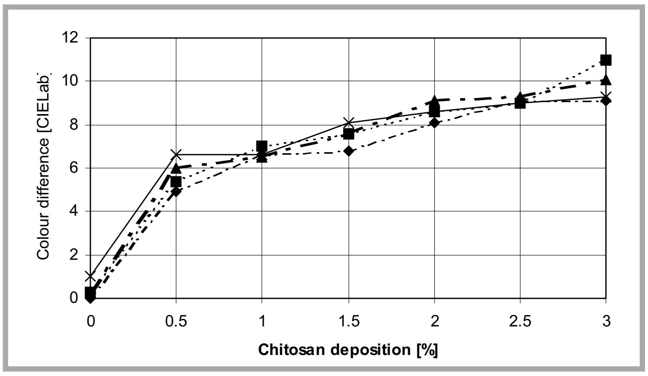

__Figure 4.__ Changes in colour difference of cotton-polyester fabric samples dyed using Solophenyl Rot 4GE after chitosan (I) deposition; NaOH concentration: ◆ 0 g/dm^3, ■ 10 g/dm^3, ▲ 20 g/dm^3, × 30 g/dm^3.

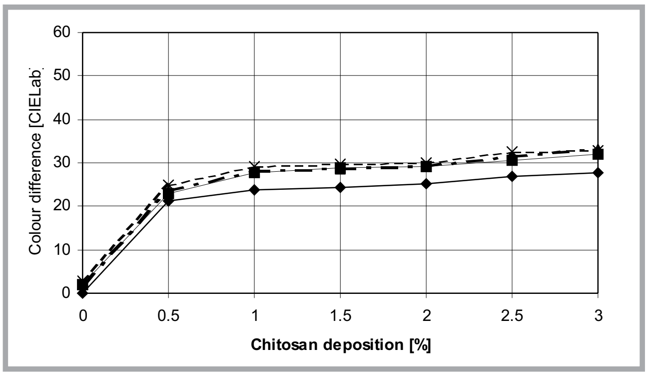

__Figure 5.__ Changes in colour difference of polyester fabric sam-ples dyed using Solo-phenyl Blau TLE after chitosan (I) deposition; NaOH concentration: ◆ 0 g/dm^3, ■ 10 g/dm^3, ▲ 20 g/dm^3, × 30 g/dm^3.

According to the data obtained, the polyester and cotton-polyester fabrics are best finished by means of direct dyestuffs after an alkaline pre-treatment in solution containing 10 g/dm^3 of NaOH and followed by impregnation with chitosan solution with concentration below 1% w/v, independent of the chitosan characteristic.

Conclusions

- It is possible to polyester and cotton-polyester fabrics with direct dyestuffs after chitosan treatment.
- Dyed textiles are characterised by good dry-rubbing and washing fastness but medium wet-rubbing fastness properties.
- The alkaline pre-treatment affects the greater adhesion of chitosan to the surface of polyester fibres, which is manifested by the greater colour strength. Pre-treatment in an alkaline solution containing 10 g/dm^3 NaOH is permitted.
- The achievement of good effects depends mainly on the amount of chitosan deposited and its characteristic (deacetylation degree, molecular weight). The greater the molecular weight (viscosity) of chitosan used, the worse effects in application are observed.

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References

1. *Z. Świderski: 'The modern dyeing systems for blends of polyester and cellulose fibres', Przegląd Włókienniczy, No 2, 87-91, 1981 (in Polish).*
2. *B. Gajdzicki: 'The dyeing process of textiles made from polyester-cellulose blended yarn', Proceedings of the Conference of Dyers and Colourists, Zakopane,1998 (in Polish).*
3. *J. Szadowski, W. Malinowski: 'The dyestuffs for simultaneous dyeing of polyester and cellulose fibres', Przegląd Włókienniczy, No 2, 1979, (in Polish).*
4. *'Biodegradable Non-wovens from the Sea', INDA JNR, Vol. 5, No 1.*
5. *W.H. Daly, J. Macorsay: 'An Overview of Chitin and Derivatives for Biodegradable Materials Applications', Fibers & Textiles in Eastern Europe, No 7/8, 1997.*
6. *J.H. Kim, S.Y. Lee: 'Surface Modification of Polymer Films by Treatment of Chitosan', Proceedings of the Conference, Tesaloniki, Greece, 1997.*
7. *Nousiainen, H. Struszczyk, O. Kivekas: 'Application of Chitosan as a Modern Non-woven Binding Agent', INDEX 93 CONGRESS.*
8. *D.J. Yoo, Y. Shin, K. Min, J.J. Jang: 'Functional Finishing of Cotton Fabrics by Treatment with Chitosan', Advances in Chitin Science, vol. II, eds. A. Domard, G.A.F. Roberts and K.M. Varum, EUCHIS'97, Lyon, September, 1997.*
9. *Davidson R.S., Xue Y.: 'Improving the Dyeability of Wool by Treatment with Chitosan', JSDC vol.110, January, pp. 25-29, 1994.*
10. *S. M. Hudson: 'Application of Chitin and Chitosan as Fiber and Textile Chemicals', Advances in Chitin Science, vol. II, eds. A. Domard, G.A.F. Roberts and K.M. Varum, EUCHIS'97, Lyon, September 1997.*
11. *E. Rybicki, A. Walawska, Z. Adamski: 'Studies on the optical brightening of polyester and polyester-cotton blends impregnated with chitosan', Proceedings of the Conference of the Polish Chitin Society: Progress on chemistry and application of chitin and its derivatives. Łódź,10-12 October 10-12, 1995.*
12. *Walawska A., Filipowska B., Rybicki E.: 'The dyeing process of polyester and cotton-polyester fabrics by means of direct dyestuff after chitosan treatment', 4th International Conference TEXSCI'2000, Liberec, June 12-14, 2000.*

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