

Fluorescent Naphthalimide Dyes for Polyester Fibres

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Abstract

Several fluorescent and mostly newly-prepared dyes, derivatives of 4-aminonaphthalimide, were synthesised. The structures of the dyes prepared were confirmed by ^1H NMR analysis, and their properties were characterised by thin layer chromatography (TLC) and measurement of the melting points. Fluorescence emission spectra in various solvents were measured, and the quantum & relative fluorescence yield values were determined. All the dyes prepared were used in the coloration of polyester fabrics. The fastness properties of the resultant dyeings were determined, and their chromaticity coordinates and luminance coefficient β values were measured.

Key words: disperse dyes, polyester fibres, dyeing fluorescent dyes, naphthalimide.

hibit properties similar to typical organic pigments, due to strong aggregation. Products where R is an alkyl group can be converted into disperse dyes, which are used in the coloration of synthetic fibres. However, this kind of dyeing, with products of short carbon chains ($\text{R} = \text{CH}_3$ and $\text{R} = \text{C}_2\text{H}_5$), show insufficient sublimation fastness. On the other hand, very long or branched alkyl residues considerably lower the melting points of final products, which can then be used as solvent-type dyes.

The purpose of the present work was to synthesise and estimate the application properties of two groups of dyes with the structure presented in *Figure 1*, in which R is n-butyl or benzyl residue.

Introduction

The continuous development of automobile traffic and the safety regulations connected to it has resulted in an increasing demand for highly visible textiles. Polyester fibres play important role in the manufacture of such textiles due to their good mechanical and exploitation properties. In the present work, an attempt was made to synthesise fluorescent dyes to polyester fibres which could also meet all the requirements laid down in the relevant European Standards.

Data from the literature [1] and the results of our earlier works [2, 3] have shown that imides of naphthalene-1,8-dicarboxylic acid which include an electron-donating group in position 4 of their molecule exhibit good luminescent properties. In this work, our interest is directed towards dye derivatives of 4-aminonaphthalimide, the general structure of which is presented in *Figure 1*.

It has been already established that when R is an aryl residue, most of the dyes ex-

were standardised by precipitation from DMF solutions in the presence of NNO Disperser. A dye bath module of 1:40 was used, with a dyeing time of 1 hr. at 130 °C. Application and fastness tests were carried out according to the Standard PN-ISO. The results of these tests are presented on a five-point scale, where 1 is the lowest grade and 5 the highest. The light fastness on the polyester fibres was measured on Hanau 1500 Xenotest apparatus, and the results are presented on an eight-point scale, where 1 is the lowest graded and 8 the highest. Other colour parameters, such as the chromaticity coordinates and luminance coefficient β of the textiles dyed, were measured on a Minolta CM-508c spectrophotometer with a measuring geometry of 45/0. All the synthesis and purification processes were monitored by TLC chromatography with the use of Silicagel Merck 5554 plates and a 254/365nm UV lamp.

Synthesis of intermediate products

Preparation of all the dyes obtained in this work may be illustrated by the scheme in *Figure 2* (see page 92).

According to this scheme, an appropriate amine **3** is usually acylated by a derivative of naphthalene-1,8-dicarboxylic acid (naphthalic acid), which in position 4 of its skeleton contains a mobile group susceptible to reacting to nucleophilic substitution ($\text{X} = \text{Cl}, \text{Br}, \text{NO}_2, \text{SO}_3\text{H}$). In earlier works, 4-nitronaphthalic acid

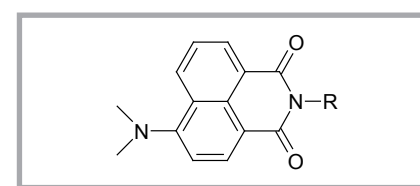


Figure 1. General structure of 4-aminonaphthalimide dyes.

Experimental

Characterisation of products and equipment

The melting points were determined with Boethius PHMK-05 apparatus, and the values were corrected. The structures of the dyes prepared were confirmed by ^1H NMR analysis with a Bruker DPX-250 Avance spectrometer at a frequency of 250 MHz. Absorption measurements in the UV-VIS range were taken on a Varian CARY 400 spectrophotometer. Emission spectra were recorded on a Hitachi 450 spectrofluorimeter (λ_{exc} 426 nm, cuvette 1 cm \times 1 cm, geometry 90°). The quantum fluorescence yield was assessed according to a Coumarin 602, with a concentration of 2.4×10^{-5} mole/dm³ in water-ethanol 1:1 solutions [4].

Application tests were carried out on the polyester fabrics using a Rotec (Roaches) laboratory dyeing machine according to a process typical for disperse dyes. Directly before application, the dyes

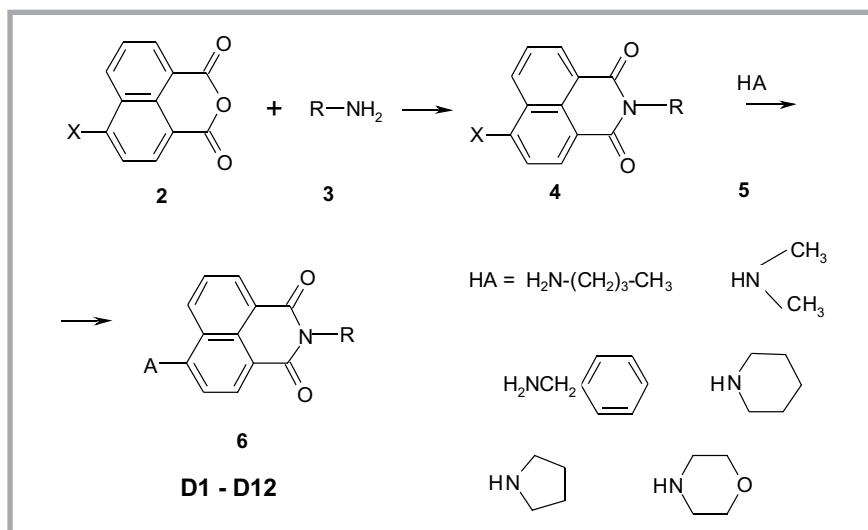


Figure 2. Scheme of the preparation of all the dyes.

Table 1. Chlorinating of naphthalene-1,8-dicarboxylic acid anhydride with sodium hypochlorite – hydrochloric acid mixture (best results): *A = 1,8-naphthalic anhydride substrate, B = anhydride of 4,5-dichloro-1,8-naphthalic acid, C = oxidation products.

No	Sodium hypochlorite - naphthalic anhydride proportions, mole/mole	Time in hrs and HCl concentration	Yield of crude product, %	Melting point of crude product, °C	Impurities (TLC)*
1.	3.0	4 h 30% HCl	68	185 - 200	A
2.	3.2	4 h 30% HCl	73	189 - 201	A (traces)
3.	4.0	4.5 h 30% HCl	76	204 - 206	B, C
4.	3.2	2 h 15% HCl + 3 h 8% HCl	78	206 - 208	A (traces)
5.	3.6	2 h 15% HCl + 3 h 8% HCl	79	206 - 209	B, C
6.	4.0 (2,5 +1,5) (added in two portions)	2 h 15% HCl + 3 h 8% HCl	79	204 - 208	B, C

anhydride [2] was used as a substrate in synthesising derivatives of 4-aminonaphthalimide. This compound is very convenient when used on a laboratory scale, but due to its specific preparation, it has no technical importance. From a technical point of view, anhydride of 4-chloronaphthalic acid seems to be the most effective substrate because its precursor, naphthalene-1,8-dicarboxylic acid anhydride, may easily be obtained by vapour-phase oxidation of naphthalene. In recent literature, four methods of preparing 4-chloronaphthalic acid anhydride are described: by chlorinating naphthalic acid anhydride in an aqueous medium using gaseous chlorine at pH = 7.3 - 7.7 and a temperature of -2 to 5 °C [5], or at pH 7 - 9 and a temperature of 10 - 20 °C [6], as well as by the action of gaseous chlorine on potassium salts of 1,8-naphthalic acid in a water/chloroform emulsion [7]. In our work, we chose the chlorinating method using a sodium hypochlorite/hydrochloric acid mixture. The latter chemical was progressively introduced to the reaction mixture at a pH

of 7.3-7.8 [8]. In order to obtain a product of good quality, a number of optimisation trials were performed. The most important results from these trials are listed in Table 1.

Further purification of the sample obtained in trial 4 (Table 1) gave a 4-chloro-1,8-naphthalic acid anhydride with a melting point of 212 - 214 °C (literature data 216 - 217 °C [9]) and total reaction yield of 71.8%. This anhydride was used in the acylation of the above-mentioned amines 3, which resulted in the preparation of two 4-chloro-1,8-naphthalimides: 4a (R = butyl, X = Cl) and 4b (R = benzyl, X = Cl). These products were then used to synthesise the dyes D1 - D6 (R = butyl) and D7 - D12 (R = benzyl).

Preparation of 4-chloronaphthalene-1,8-dicarboxylic acid anhydride (2, X = Cl)

99.1 g of naphthalene-1,8-dicarboxylic acid anhydride was dissolved in a solution of 50.0 g sodium hydroxide in 2.4 dm³ of water at 60 °C. After cooling to 15 °C,

390 cm³ of sodium hypochlorite containing 164.5 g Cl/dm³ was added. Over the next 2 hours, 160 cm³ of 15% HCl was added dropwise below the reaction mixture's surface at such a rate as to keep the reaction pH within the 7.3 - 7.5 range. Over the next 3 hours, another 80 cm³ of 8% at pH = 7.8 was added.

The reaction product was separated by adding 50 cm³ of 30% HCl to the bath, which was then filtered out. The wet paste was dissolved in a warm aqueous solution of sodium carbonate, filtered with active carbon and precipitated by salting out with sodium chloride. The separated disodium salt of 4-chloronaphthalene-1,8-dicarboxylic acid was dissolved in water and acidified with hydrochloric acid. The precipitated 4-chloronaphthalene-1,8-dicarboxylic acid was filtered out, washed with water and dried at 120 °C to obtain 83.5 g of 4-chloronaphthalene-1,8-dicarboxylic acid anhydride, which was 71.8% of the theoretical yield. The melting point of the product prepared was 208 - 209 °C (literature melting point 216 - 217 °C) [9].






Preparation of N-n-butyl-4-chloro-1,8-naphthalimide (4a, R = n-butyl, X = Cl)

23.2 g 4-chloronaphthalene-1,8-dicarboxylic acid anhydride and 7.7 g n-butylamine in 400 cm³ water were refluxed for 16 hrs. After treatment of hot aqueous sodium carbonate solution, a solid precipitate was re-crystallised from ethanol after drying. (14 cm³/1g). The final product has a melting point of 95 - 96 °C (in the literature, 93 - 94 °C) [10].

Preparation of N-benzyl-4-chloro-1,8-naphthalimide (4b, R = benzyl, X = Cl)

23.2 g of 4-chloronaphthalene-1,8-dicarboxylic acid anhydride, 10.5 g of benzylamine, 50 cm³ of 2-methoxyethanol and 200 cm³ of water were refluxed for 16 hrs. After cooling, the product precipitated was filtered out, powdered in mortar and treated with boiling aqueous sodium carbonate of 2%. The reaction yield of the crude product, 29.5 g (92% theory), showed a melting point of 134 - 135 °C. After crystallisation from ethanol (30 cm³/1g), the product's melting point was 138 - 140 °C (in the literature 168 - 170.7 °C) [11]. The structure was confirmed by ¹H NMR spectra: s 5.37 N-CH₂-Ph, 2H; m 7.2 - 7.57 Ph-H, 5H; d 7.29 Nf3-H, 1H, J=8.0; d 8.40 Nf2-H, 1H, J = 8.0; dd 8.39 Nf5-H, 1H, J = 8.5, J = 1.25; t 7.84Nf6-H, 1H, J = 8.5; dd 8.59Nf7-H, 1H, J = 8.5, J = 1.25.

Table 2. Synthesis data and some properties of dyes D1-D12; * Silicagel, UV 366, eluents – a) cyclohexane:dioxane 2:1, b) cyclohexane:dioxane 4:1, c) ethyl acetate:acetic acid:toluene 5:2:20, d) toluen:dioxane 9:1.

A	R=CH ₂ (CH ₂) ₂ CH ₃					R=—CH ₂ — 				
	Dye	Yield, %	m.p. of crude dye, °C	Melting point, (°C)	TLC* R _F	Dye	Yield, %	m.p. of crude dye, °C	Melting point (°C)	TLC* R _F
	D1	97	129-134	132-133 dioxane lit. m.p. 118-120 [12]	0.70 b	D7	98	130-134	135-136 dioxane no lit. m.p.	0.71 a
	D2	93	131-134	135-136 methanol lit. m.p. 125 [12]	0.74 c	D8	98	90-100	134-135 dioxane no lit. m.p.	0.69 a
CH ₃ (CH ₂) ₃ NH—	D3	96	121-126	127-129 methanol lit. m.p. 127-128 [13]	0.49 d	D9	78	121-126	125-126 dioxane no lit. m.p.	0.48 a
(CH ₃) ₂ N—	D4	80	110-112	114-116 CH lit m.p. 114-115[13]	0.70 a	D10	79	118-124	119-121 ethanol no lit. m.p.	0.49 a
	D5	98	130-134	138-140 ethanol lit. m.p. 138-140[14]	0.46 d	D11	98	133-138	137-138 ethanol no lit. m.p.	0.47 d
	D6	84	oily	169-170 dioxane no lit. m.p.	0.55 a	D12	94	oily	208-209 dioxane no lit. m.p.	0.62 a

General method for the preparation of dyes D1-D12

A typical reaction of aromatic nucleophilic substitution is the replacement of the chlorine atom in 4-chloro-1,8-naphthalimides **3** by an amine residue. The relatively strong-basic amines **HA** used to an excess of a 4 - 5 mole/mole act as nucleophilic agents. The excess of amine also takes the role of a hydrochloride neutralising agent. In our work, these reactions were carried out in N-methyl-2-pyrrolidone (90 °C, 4 - 12 hrs) or dimethylsulphoxide (70 °C, 2 - 12 hrs). Replacement reactions and final purification of the dyes were monitored by TLC chromatography. The structures of the dyes prepared were confirmed by ¹H NMR analysis.

Preparation of N-n-butyl-4-N'-piperidine-1,8-naphthalimide (D1, R = butyl, A = 1-piperidylyl).

2.9 g of **4a**, 3.5 g of piperidine and 25 cm³ of DMSO were heated at 70 °C for 2 hours. The dye was separated by dropping 15 cm³ of 10% HCl followed by 20 cm³ of water. Afterwards was the filtration of the product separated, then it was washed with 1% HCl and finally dried drying. The yield of the crude dye was 3.3 g (97.3% theory), with a melting point of 129 - 134 °C. After crystallisation from dioxane (5 cm³/1 g), pale yellow crystals with a melting point of 127 - 129 °C (in the literature, 118 - 120 °C [12]) were obtained.

Results and discussion

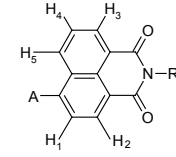
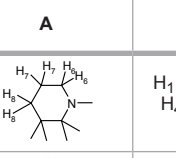
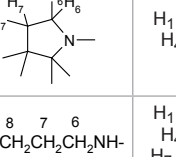
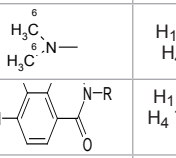
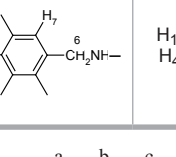
In **Table 2** some properties of dyes D1-D12 and details of their synthesis are list-

ed. The spectroscopic (VIS) and ¹HNMR data of these dyes are collected in **Table 3**.

In order to examine the fluorescent properties of all the dyes prepared, D1-D12, the emission spectra of the dye solutions

in organic solvents were measured. Especial interest was directed towards the emission spectra in ethyl acetate and ethyl benzoate solutions, because these solvents have a similar chemical character to the polyester fibre for whose

Table 3. Selected spectral properties of dyes D1-D12.

No	Dye	VIS : ethanol λ _{max} , nm, ε _{mol}	A	¹ H NMR *
1	D1 D7	411 11,500 411 13,310		H ₁ 7.18 d 1H; H ₂ 8.50 d 1H; H ₃ 8.39 dd 1H; H ₄ 7.67 t 1H; H ₅ 8.57 dd 1H; H ₆ 3.23 t 4H; H ₇ 1.89 m 4H; H ₈ 1.67-1.76 m 2H
2	D2 D8	450 19,500 451 19,900		H ₁ 6.82 d 1H. H ₂ 8.43 d 1H. H ₃ 8.56 dd 1H. H ₄ 7.67 t 1H. H ₅ 8.59 dd 1H; H ₆ 3.77 t 4H. H ₇ 2.07-2.13 m 4H
3	D3 D9	423 14,150 424 14,350	9 8 7 6 CH ₃ CH ₂ CH ₂ CH ₂ NH-	H ₁ 6.73 d 1H; H ₂ 8.70 d 1H; H ₃ 8.07 dd 1H; H ₄ 7.62 t 1H; H ₅ 8.58 dd 1H; H ₆ 3.41 t 2H; H ₇ 69-1.86 m 2H; H ₈ 1.46 s 2H; H ₉ 0.97 t 3H
4	D4 D10	444 15,900 444 17,300		H ₁ 7.12 d 1H; H ₂ 8.48 d 1H; H ₃ 8.44 dd 1H; H ₄ 7.66 t 1H; H ₅ 8.57 dd 1H; H ₆ 3.10 s 6H
5	D5 D11	395 10,700 395 11 200		H ₁ 7.24 d 1H; H ₂ 8.50 d 1H; H ₃ 8.42 dd 1H; H ₄ 7.71 t 1H; H ₅ 8.59 dd 1H; H ₆ 4.03 t 4H; H ₇ 3.27 4H
6	DB6 D12	438 16,000 438 16,700		H ₁ 6.78 d 1H; H ₂ 8.46 d 1H; H ₃ 8.11 dd 1H; H ₄ 7.64 t 1H; H ₅ 8.60 dd 1H; H ₆ 4.62 s 2H; H ₇ 7.19-7.57 m 5H

In D1-D6 present in all spectra R=—CH₂—CH₂—CH₂—CH₂—CH₃: H_a 4,17 t 2H, H_b 1,65-1,77 m 2H, H_c 1,37-1,52 m 2H, H_d 0,97 t 3H.


In D7-D12 present in all spectra R=—CH₂— H_b 7,22-7,57 m 5H, H_a 5,37 s 2

Table 4. Fluorescent properties of dyes D1 ÷ D12 in selected organic solvents; λ_{\max} F - maximum of the fluorescence peak (nm), Φ - fluorescence quantum yield, F - relative fluorescence intensity (D12 dye taken as standard).

Dye	96% ethanol			ethyl acetate			ethyl benzoate		
	λ_{\max}	Φ , nm	F	λ_{\max}	Φ , nm	F	λ_{\max}	Φ , nm	F
D1	534	0.02	0.020	512	0.47	0.484	512	0.55	0.464
D2	525	0.03	0.040	508	0.50	0.550	506	0.59	0.788
D3	527	0.62	0.968	504	0.69	0.911	500	0.68	0.865
D4	525	0.01	0.016	508	0.48	0.352	508	0.58	0.502
D5	529	0.06	0.063	509	0.70	0.442	509	0.67	0.690
D6	521	0.48	0.871	500	0.80	0.868	500	0.69	0.966
D7	537	0.02	0.017	514	0.46	0.358	512	0.58	0.426
D8	527	0.03	0.043	505	0.50	0.649	507	0.66	0.847
D	529	0.65	0.968	500	0.78	0.918	503	0.70	0.851
D10	529	0.01	0.018	509	0.32	0.348	508	0.57	0.677
D11	531	0.06	0.057	509	0.77	0.358	508	0.75	0.451
D12	522	0.76	1.000	497	0.84	1.000	499	0.76	1.000

Table 5. Chromaticity co-ordinates and luminance coefficients of dyes D1 ÷ D12 before and after exposure to xenon lamp (polyester fabric, 0.5% dyeings); Underlined samples were exposed to xenon lamp, Ch - chromaticity co-ordinates outside marked area.

Dye	Before exposition				After exposition			
	x	y	β	notices	x	y	β	notices
D1	0.372	0.504	0.811		0.368	0.493	0.801	
D2	0.397	0.549	0.899		0.370 ⁵	0.472	0.777	Ch
D3	0.382	0.531	0.736					
D4	0.369	0.526	0.875		0.360	0.486	0.779	Ch
D5	0.346	0.472	0.830	Ch*				
D6	0.376	0.521	0.801		0.372	0.485	0.742	
D7	0.368	0.511	0.899		0.373	0.505	0.865	
D8	0.401	0.540	0.712					
D9	0.402	0.518	0.706					
D10	0.374	0.527	0.860		0.371	0.496	0.770	
D11	0.346	0.467	0.776	Ch				
D12	0.368	0.515	0.839		0.381	0.479	0.762	

substrate these dyes were intended. The results of these measurements are listed in **Table 4**.

The data of individual dyes presented in **Table 4** depends on the solvent used. This is understandable because both the absorption and emission spectra peaks in the case of 4-amino-1,8-naphthalimides are connected with charge transfer and are strongly influenced by the polarity of the solvent used, the possibility of hydrogen bonds forming, etc. [15].

In 96% ethanol solutions, the maximum fluorescence peaks are bathochromically shifted approximately 20 nm compared with other solvents; this phenomenon is not influenced by the nature of the amine substituent present in the naphthalene skeleton. On the other hand, the fluorescence intensity and its quantum yield is strongly dependent on the nature of this substituent. A good fluorescence quantum yield ($\phi = 0.48 - 0.76$) can only be

observed in the case of primary amines. Dyes with a naphthalene skeleton substituted by secondary amines exhibit very low fluorescence parameters.

All the dyes prepared exhibit good fluorescence properties in more aprotic solvents such as ethyl acetate and ethyl benzoate. Fluorescence quantum yields (ϕ) in ethyl benzoate are within the range of 0.58 - 0.76, and the differences in fluorescence intensity (F), which characterise the brightness of the sample (solution, fabric etc.), do not exceed 50% of the range.

All the dyes prepared, D1 - D12, were subjected to dyeing tests, during which polyester fabric was used. During preliminary dyeings, a dye concentration of 0.5% of the weight of the fabric used was specified. The results of the application and fastness tests are presented in **Table 5**.

Most of the dyes examined give very brilliant colours on polyester fibres, with the exception of dyes D5 and D11 (derivatives of morpholine). The latter substances exhibit light absorption peaks in the short-wave region of the visible range (see **Table 3**), which results in weak colour saturation of the fabric. The fastness properties of the textiles dyed (washing, rubbing) are very good. The sublimation fastness of the dyeings in the case of dyes D1 to D6 is within the range of 4 - 5 at the 5th point of the scale. Dyes D7 to D12 (benzyl derivatives) give even better results; their properties are ranked 5 on the same scale. The light fastness of the dyeings is influenced by the nature of amino residue A in the dye molecule. It is already known that most of the fluorescent dyes used in practice are characterised by a moderate light fastness as well as by values of 3 and 4 at the 8th point of the blue lightfastness scale, which are usually accepted as good results. Such properties were displayed in our work by dyes D1 and D7 (lightfastness 4 - 5 (derivatives of piperidine)), dyes D2 and D8 (lightfastness 4 (derivatives of pyrrolidine)), and also by dyes D5 and D11 (lightfastness 3 - 4 (derivatives of morpholine)). However, as mentioned above, the latter have poor colouristic properties.

In order to determine the possibility of practically applying the synthesised dyes to high-visibility textile garments, the chromaticity co-ordinates (x, y) and luminance coefficient (β) of the dyed fabric samples were measured both before and after being exposed to a xenon lamp. According to the requirements defined by the International Standard [16], textiles designed for manufacturing high visibility garments must conform to certain values specified for a particular colour. The chromaticity co-ordinates x and y should fall within a specified area, and the luminance coefficient β for yellow colours should be equal to or higher than 0.700. Coefficient β is measured as Y/Y_0 in the trichromatic XYZ system, where $Y_0 = 100\%$ is for ideally scattering a substance.

The results of these measurements are given in **Table 6** and also presented in **Figures 3** (all dyes before exposure to the xenon lamp) and **4** (selected dyes after exposure to the xenon lamp). It can be seen that all the dyes, except the derivatives of morpholine (D5, D11), are located within the marked area on the

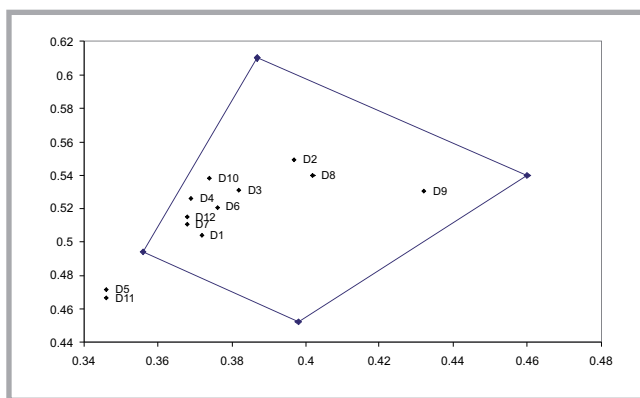


Figure 3. Chromaticity co-ordinates of dyes D1-D12 on polyester fabric.

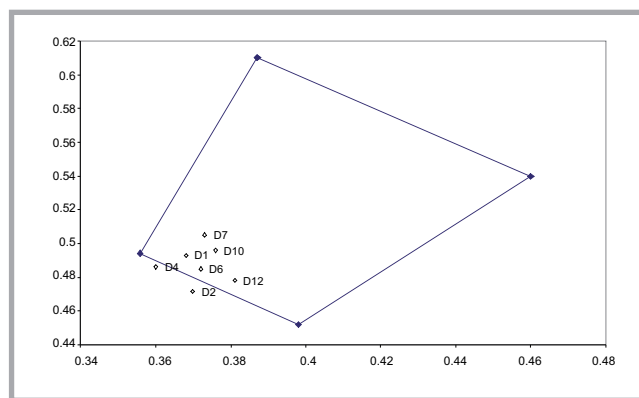


Figure 4. Chromaticity co-ordinates of selected dyes on polyester fabric after exposure to a xenon lamp.

Table 6. Application properties of dyes D1 - D12 (polyester fabric, 0.5% dyeings).

	R=CH ₂ (CH ₂) ₂ Cl						R= —CH ₂ —					
	Dye	Colour	Washing 60°C	Sublimation	Rubbing	Light	Dye	Colour	Washing 60°C	Sublimation	Rubbing	Light
	D1	Brilliant yellow G	5,5,5	4-5,4,4	5,5,5	4 - 5	D7	Brilliant yellow G	5,5,5	5,5,5	5,5,5	4 - 5
	D2	Brilliant yellow G	5,5,5	↑4-5,3-4,3-4	5	4	D8	Yellow	5,5,5	5,4-5,5	5,5,5	4
CH ₃ (CH ₂) ₃ NH—	D3	Brilliant yellow G	5,5,5	4-5,4,4	5,4,5	3	D9	Brilliant yellow G	5,5,5	5,4-5,5	5,4,4	3
(CH ₃) ₂ N-	D4	Brilliant yellow	5,5,5	4,3,3-4	5,4-5,4-5	3 - 4	D10	Brilliant yellow	5,5,5	↑4-5,4,4-5	5,5,4	3
	D5	Weak yellow	5,5,5	4,4,4	5,5,5	4	D11	Weak yellow	5,5,5	↑4-5,4-5,4-5	5,5,5	3 - 4
	D6	Brilliant yellow G	5,5,5	5,4-5,4-5	5,5,5	3	D12	Brilliant yellow G	5,5,5	↑5,5,5	5,5,5	3

chromaticity diagram. According to the Standard, after exposure to the xenon lamp, all but two of the dyes (D2 and D4) fulfil the requirements of the Standard.

It can be noticed that dye D3 (known in practice as C.I. Solvent Yellow 116 ; C.I. 561930) shows weaker application properties in dyed fabric in comparison with other dyes. However, due to their high fluorescence, both this substance and other dyes were used for visualization of phenomena occurring in Langmuir-Blodgett's thin layers [17].

Conclusions

Considering all the spectral, fastness and chromaticity data, dye D7 seems to be the most promising product for the coloration of high-visibility polyester fabrics. Dye D1 has similar properties but also shows a greater affinity to organic solvents, and therefore it should be consid-

ered as a colorant for fluorescent paints, inks etc.

Acknowledgment

This work was partially supported by the Polish Committee of Scientific Research (No 3 T09B 04516)

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Received 04.01.2008 Reviewed 08.01.2009