Treatment of Polyamides Fabrics with Cyclodextrins to Improve Antimicrobial and Thermal Stability Properties

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Abstract: Treatments of polyamide 6, Quiana and Nomex fabrics with β- Cyclodextrin(CD) or monochlorotriazinyl β-Cyclodextrin(CD-T) were investigated. Significant improvements in antimicrobial and thermal stability uniformity were observed. The colour values and fastness of the coloured fabrics to washing and perspiration were given. The untreated and treated fabrics were characterized by infrared spectroscopy (FTIR), differential thermal analysis (DTA) and thermogravimetric analysis (TGA). The changes in yellowness, moisture regain, roughness, tensile strength, elongation and antimicrobial activity have been studied. The TGA indicated that the temperature of burning T_b value lies at 471^{o}C-472^{o}C for CD treated polyamide 6 while it lies at 475^{o}C-490^{o}C for CD-T treated one. This may afford the use of CD-T in treatment of polyamide 6 to attain also some heat resistance than untreated one.

Keywords: Polyamide 6, Quiana, Nomex, Reactive dyes, β- cyclodextrin, monochlorotriazinyl, Antimicrobial Infrared, DTA, TGA, and T_b.

1. INTRODUCTION

Cyclodextrins are cyclic oligosaccharides. These molecules are able to form inclusion complexes with a large number of organic molecules. The properties of cyclodextrins enable them to be used in a variety of different textile applications. Owing to the complexing abilities of cyclodextrins, textiles with new functional properties could be made available [1].

β- Cyclodextrin (CD-T) was used as a low environmental impact additive in dyeing processes of polyamide fibres with azo disperses dyes [2]. Efficient pretreatments of the textile fibres, temperature, pH and addition of electrolytes can influence the uniformity of their dyeing. Auxiliaries act with dye solution on the fibre interface or act as resolving of the dye molecules interface [3].

The amount of remaining dyes in the waste water is significantly reduced when CD/dye complexes are formed [4].

Cyclodextrins have a hydrophobic internal cavity so that they can improve the dye up take of azoic disperse dyes by polyester fibres [5].

CD serves as a host in the formation of both soluble and solved crystalline inclusion complexes with large variety of non- covalently included guest molecules [6]. Four- to 10-fold improvement of colour uniformity and minor changes of colour yield have been found upon dyeing Nylon 66 and microfiber Nylon 6 fabrics in the presence of cyclodextrin compared to dyeing without it. ^{1}H NMR data supported the role of cyclodextrin as dye complexing agent. Product quality, however, was also dependent on fabric nature, since for conventional Nylon 6, color uniformity was not improved by the presence of cyclodextrin systems [7, 8]. Retarder/leveling effect of β -cyclodextrin in dyeing process has been studied and the results were compared with that of a commercial product. In general, cyclodextrins were used in washing processes to remove the absorbed surfactants [9]. β-Cyclodextrin was tested as a dye complexing agent – as a dye retardant in the dyeing of PAN fibres with cationic dyes. Significant improvement of colour uniformity and some improvements in colour depth were observed when PAN fibres were dyed in the presence of β-cyclodextrin as compared to dyeing in the presence of a commercial retardant [10].

The finishing process involved polymerization between citric acid and CDs, which yielded a cross-linked polymer that physically adhered to the surface of PA fibers. This permanent functionalization was characterized by evaluating the damping property with a polar liquid (glycerol) *via* the drop contact angle method for various rates of modification of the fabrics. The biological and microbiological effects of the PA, which were functionalized with hydroxypropylated derivate of γ-CD (HP-γ-CDs) and charged with ciprofloxacin (CFX), were evaluated by cell culture assays [11].

In the future cyclodextrins might play a significant role in the textile industry and might be used: (1) to remove surfactants from washed textiles; (2) to substitute surfactants; (3) in finishing textiles; (4) when bound chemically to fibers, to provide enhanced hydrophilicity and first of all, inclusion complex forming ability to immobilize perfumes, insect repellents, antimicrobial agents, etc [12].

ß-cyclodextrin (CD)-based linear water-soluble polymers were synthesized. The synthesized water-soluble polymer was covalently fixed onto cotton surfaces by a polycondensation reaction at controlled conditions. The grafting occurred through the formation of a crosslink between hydroxyl groups of cotton and CD polymer.This was confirmed using FTIR spectroscopy and DSC [13].

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It is aimed in this investigation to carry out a systematic study on the pretreatment of polyamide 6, Nomex and Quiana fabrics with CD or CD –T derivative to prepare antimicrobial polyamide fabrics. The effect of variation of the treatment conditions, such as concentration of CD and CD-T, and thermo fixation temperature is studied. The changes in the dyeing properties (colour value and fastness) of the treated polyamides fabrics are evaluated.

2. EXPERIMENTAL

2.1. Materials

2.1.1. Fabrics

Knitted Polyamide 6 (aliphatic PA) was supplied from El-Shourbagy Co., Cairo, Egypt. Quiana (cyclic PA) and Nomex (aromatic PA) fibres were supplied by PCUK (Produits Chemiques Ugine Kuhlmann, Creil Cedex, France). The fabrics were scoured in aqueous bath for 30 minutes, at 60°C using 2% nonionic detergent (o.w.f.) liquor ratio 1:50. The scoured fabrics were washed with warm water followed by rinsing for 5 minutes in cold water, and air dried.

2.1.2. Chemicals

β-Cyclodextrin hydrate (CD), monochlortriazinyl β-cyclodextrin Na-salt (CD-T) are products of Wacker – Chemie GmbH, Munich, Germany. Quaternary ammonium salt (3-chloro-2-hydroxypropyl trimethylamonium chloride) was supplied from Floka (Germany).

2.1.3. Dyes

The commercial dye samples. C.I. Reactive Red 84 (Ciba Specialty Chemicals), C.I. Reactive Blue 203 (Egypt Colours) and C.I. Reactive Yellow 1(Isama Dye. Egypt) were used.

2.2. Treatments

The polyamides fabric were immersed in a solution containing 10-50 g/l (o. w .f) of β-Cyclodextrin hydrate (CD), or monochlortriazinyl β-cyclodextrin Na-salt (CD-T) which adjusted to pH 4 using acetic acid or citric acid at room temperature for 1h, then padded to pickup 100 %, dried at 80°C for 10 min. and then fixed at 160°C for 5 min. Finally the fabric is washed thoroughly with tap water and air dried. Also, polyamides fabrics were treated with solution containing 30g/l (o.w.f) of CD-T and 2g/l quaternary ammonium salt at the same conditions.

2.3. Dyeing

The dye bath was prepared by accurately weighing the dyestuff to give the prescribed shade. The dye was pasted with small amount of water and wetting agent. The paste was then dissolved by adding hot boiling water. The dye solution was then added to the dyeing bath, adjusted to pH 4.5 using acetic acid. The dye bath was heated to 80°C, then added the sample to the dyeing bath and continued for 1 h. The dyed samples were then thoroughly washed in warm and cold water and air-dried.

2.4. Measurements

2.4.1. Colour Value

Spectral reflectance measurements of the dyed fabrics were carried out using a recording filter Spectrophotometer Hunter lab (The Colour Management Company, USA). The colour value expressed as K/S of the dyed samples was determined by applying the Kubelka-Munk equation [14].

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

Where R: is the decimal fraction of the reflectance of the dyed substrate.

R_o: is the decimal fraction of the reflectance of the undyed substrate

S: is the scattering coefficient

K: is the absorption coefficient

2.4.2. Yellowness Index

Measurement of the yellowness index was carried out by using Hunter lab (The Colour Management Company, USA). Yellowness Index (YI) was determined using ASTM method E (313).

$$YI\ (E313) = 100[1-(0.847\ Z/Y)]$$

Y, Z are the first numerical scale offered to quantify colour.

YI: Yellowness Index of treated polyamide 6 sample.

2.4.3. Washing Fastness

The colour fastness to washing was determined according to the AATCC test method 61–1994 using a laundrometer. The soaped specimen (5x5cm) was sewed between two pieces of bleached wool and polyamide 6 in case of dyeing with reactive dyes. The composites were immersed into an aqueous solution containing 5 g/l soap and 2 g/l sodium carbonate, liquor ratio of 1:50 at 40°C. The test was run for 40 minutes. The samples were then removed, rinsed twice in 100 ml of water at 40°C for 15 minutes with occasional stirring and hand squeezing. This was followed by scouring in 100 ml of 0.014 % solution of acetic acid for one minute at 27°C rinsing again for one minute in 100 ml water at 27°C, followed by drying. Evaluation of the wash fastness was carried out using the Gray Scale reference for colour change [15].

2.4.4. Perspiration Fastness

Alkaline Solution

0.25 g/l L-histidine monohydrochloride monohydrate. 10g/l of sodium chloride, 1g/l sodium hydrogen phosphate were dissolved in one litre of distilled water. Finally the pH was adjusted to 8 by sodium hydroxide solution (0.1N) [15].

Acidic Solution

The Histidine monohydrochloride monohydrate0.25g/l., sodium chloride 10g/l, and sodium dihydrogen phosphate 1g/l were dissolved in one litre of distilled water. The pH was adjusted to 4.3 by acetic acid solution (10%). The

coloured specimen 5x4 cm was sewed between two pieces of uncoloured specimens to form a composite specimen. The composite sample was then immersed for 15-30 minutes in each solution with occasional agitation and squeezing to ensure complete wetting. The test specimen was placed between two glass plates under force of about 4-5 kg. The plates containing the composite specimen were then held vertical in an oven at 37°C for 4 hours [15].

2.4.5. Tensile Strength and Elongation

The tensile properties of polyamide fibres before and after treatment with CD or CD-T were evaluated using a Instron Tensile Tester (USA) according to ASTM D 76 Standard Specification for Textile Testing Machines. The average was taken for samples (5x 20 cm).

2.4.6. Roughness

Surface roughness was measured according to JIS 94 Standard, using Surface Roughness Measuring Instrument, SE 1700 α (Kosaka Laboratory Ltd. Japan).

2.4.7. Moisture Regain

The measurement of the moisture regain of the polyamide sample was performed according to ASTM Standard 2654-76 [16]. The moisture regain of the samples were calculated according to:

$$\text{Moisture regain } \% = \frac{W_1 - W_2}{W_2} \text{ x } 100$$

Where W_1: Weight of sample after saturation in the standard humidity atmosphere.

W_2: Constant weight of dried sample.

2.4.8. Thermogravimetric Analysis (TGA)

Thermogravimetric analysis (TGA) was carried out using thermal analyzer 7 series (Perkin Elmer, USA) with attached TG unit. A movable thermostatically controlled electric furnace was used to heat the sample at the desired rates. The sample was heated under normal atmosphere at a rate of 10°C/ min, and the loss in the weight of the samples was recorded against temperature from 30° to 500°C.

2.4.9. Differential Thermal Analysis (DTA)

Differential thermal analysis (DTA) was carried out using thermal analyzer 7 series (Perkin Elmer, USA). Thermographs were recorded from 25°C to 250 °C under normal atmosphere.

2.4.10. Infrared Spectral Analysis

Infrared spectra were recorded on FT-IR Nicolet 5 DX Spectrophotometer. The samples were examined as 1.5% KBr pellets.

2.4.11. Antimicrobial Activity

The antibacterial activity of the NMA-HTCC was evaluated against the Gram positive - Staphylococcus aureus (ATCC 6538) [17].

The fungus activity was evaluated against Candida albicams (Flamentous fungus) (ATCC 6275) [18].

3. RESULTS AND DISCUSSION

3.1 Dyeing Characteristics

3.1.1. The Effect of Concentration of CD and CD-T

The effect of concentration of CD or CD-T on the attained colour values of the dyed polyamide 6 fabrics are given in Table **1**. The treatment carried out with (10-50 g/l) of CD or CD-T, It can observe that pretreatment with 30g/l CD gave higher colour values than the untreated one. But 30g/l of CD-T gave same result of the untreated one. The increase in colour value may be attributed to the possibility of capturing the dye moiety by the CD. It was found that the concentration of 50g/l of CD-T decrease the colour values than untreated sample.

Table 1. Colour Value of Untreated and Pretreated Polyamide 6 Fabric with CD or CD-T

Concentration g /l	Colour Value (K/S)
Untreated: 0	12.1
CD : 10	12.2
30	12.3
50	12.2
CD-T : 10	12.2
30	12.1
50	12.0

Treatment: Immersion in CD or CD-T solution (xg/l), liquor ratio 1:20, 1h, pH 4 (citric acid), padding, pick up 100 %, dry 10 min and fixation at 160 °C, 5 min. **Dyeing:** 1% (o.w.f) C.I. Reactive Red 84, 85 °C, pH 4.5, 1h, liquor ratio 1:50.

3.1.2. Effect of Liquor Ratio of Dyeing Bath

Polyamide fabrics pretreated with CD or CD-T was dyed with C.I. Reactive Red 84 using different liquor ratios. Fig. (**1**) presents the dependence of the attained colour values (K/S) on liquor ratio of the dyebath. It can seen that increasing the liquor ratio to 1:50 gave relatively higher K/S values for dyed pretreated polyamide fabrics with either CD or CD-T. But, when dyed the treated polyamide fabrics with C.I. Reactive Yellow 1 there is no affected the different liquor ratio.

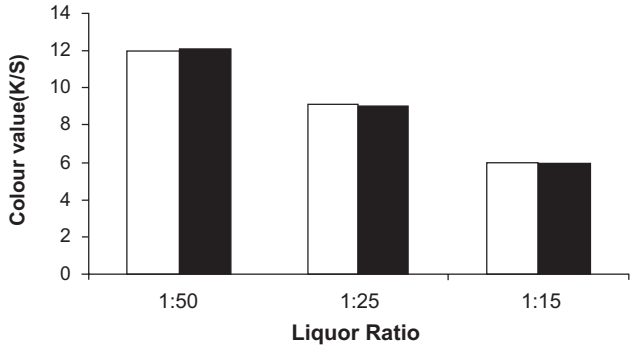

Fig. (1). Dependence of the colour value of the dyed polyamide 6 fabrics on the liquor ratio of the dyebath.

Treatment: Immersion in CD or CD-T solution (30g/l), liquor ratio 1:20, 1h, pH 4 (citric acid), padding, pick up 100%, dry at 80 °C, 10 min and fixation at 160 °C, 5min. **Dyeing:** 1% (o.w.f) C.I. Reactive Red 84, 85 °C, pH 4.5, 1h, liquor ratio 1:50 ■: untreated fabric □: treated fabric.

3.1.3. Effect of Acidification

Fig. (**2**) presents the effect of acidification of the treatment solutions on the attained colour values of the dyed polyamide fabrics pretreated with either CD or CD-T. The adjustment of the treatment solutions to pH 4 was performed with either acetic acid (pk_a 4.78) or with citric acid (pk_a 4.77), has imparted nearly the same colour values on the dyed pretreated polyamide fabrics. Citric acid my be led to made crossliking with polyamide fabrics and CD-T which decrease the colour values as compared with treated with CDl. This attributed to block the active sides of the treated fabrics.

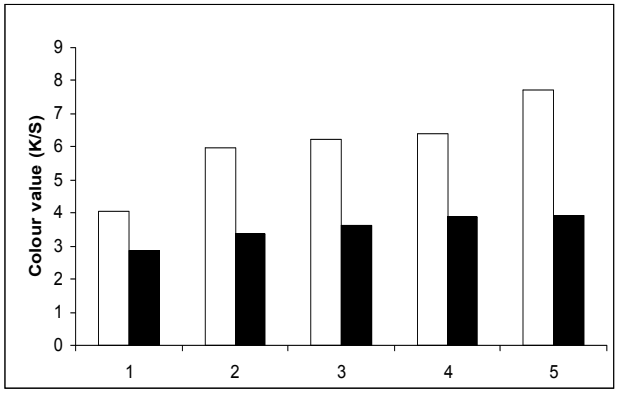

Fig. (2). Dependence of the colour value of the dyed polyamide 6 fabric on the acidification of the treatment solution.

Treatment: Immersion in CD or CD-T solution (30 g/l), liquor ratio 1:20, 1h, padding, pick up 100 %, dry at 80 ^{o}C, 10 min and fixation at 160 ^{o}C, 5min. 1-Untreated polyamide 6; 2-Treated polyamide 6 with (CD) pH 4 (citric acid); 3- Treated polyamide 6 with (CD) pH 4 (acetic acid); 4-Treated polyamide 6 with (CD-T) pH 4 (citric acid); 5-Treated polyamide 6 with (CD-T) pH 4 (acetic acid). **Dyeing:** 1% (o.w.f) C.I. Reactive Yellow 1, or C.I. Reactive Blue 203, 85 ^{o}C, pH 4.5,1h, liquor ratio 1:50.

■ C.I. Reactive Blue 203 □C.I. Reactive Yellow 1.

3.2. Moisture Regain, Yellowness and Roughness

The moisture regain, yellowness and roughness of the untreated and pretreated polyamide 6, Quiana and Nomex fabrics are given in Table **2**. The treatments with CD –T gave rise to better results than those of the untreated ones. The treated polyamide 6 fabrics with either CD–T or CD gave moisture regain of 4. 7 % and 5.97 % respectively, as compared with 1.7 % for untreated ones. This may be attributed to an increase in the hydrophilic nature of the treated fabric. Yellowness index of polyamide 6, Quiana and Nomex fabrics are given in Table **3**. It can be observed that treatments with either CD or CD-T did not change the Yellowness index for the mentioned three substrates.

The roughness property given in Table **3** illustrates that the treatment of polyamide 6, Quiana and Nomex fabrics with CD or CD-T causes a decrease in the roughness property as compared to the untreated fabrics.

3.3. Washing and Perspiration Fastness

Table **3** shows that the washing and perspiration fastness of the dyed fabrics with C.I. Reactive Blue 203, C.I. Reactive Red 84 and C.I.

Reactive Yellow 1 of the untreated and pretreated polyamide 6, Quiana and Nomex fabrics with 30g/l CD or CD-T. It can be seen that the treatment with CD-T has relatively improved the washing fastness of Quiana and Nomex than that of the pretreated samples with CD and untreated ones. The perspiration fastness of the dyed polyamide 6 fabrics pretreated with CD gave higher values than the perspiration fastness in both alkaline and acidic solutions of the polyamide 6 fabrics pretreated with CD-T dyed using C.I. Reactive Yellow 1. The perspiration fastness in acidic solution of the dyed pretreated Quiana and Nomex fabrics were found to be relatively improved.

3.4. Tensile Strength and Elongation

The results of tensile strength and elongation of the treated and untreated polyamide 6 fabrics are given in Table **4**. The results show that the tensile strength and elongation of the untreated fabric are 0.405 (Kg/cm) and 126 % respectively. The treatments affect both the tensile strength and elongation. It can be seen that the treatments with CD or CD-T led to a decrease in the tensile strength to 0.345 and 0.324 (Kg/cm^2) respectively. The treated fabrics with CD or CD-T showed approximately 17.8 % and 31.6 % increase in their elongation property, respectively.

Table 2. Moisture Regain, Yellowness and Roughness of Untreated and Treated Polyamide Fabrics

Roughness	Yellowness Index	Moisture Regain %	Samples
25.9	2.15	2.25	Untreated Polyamide 6
20.5	2.35	5.9	Treated with (CD)
20.7	2.5	4.7	Treated with (CD-T)
25.58	3.1	2.3	Untreated Quiana
13.25	4.00	5.3	Treated with (CD)
12.02	3.91	5.4	Treated with (CD-T)
22.01	23.85	2.7	Untreated Nomex
19.8	22.92	5.9	Treated with (CD)
18.72	21.87	5.2	Treated with (CD-T)

Treatment: Immersion in CD or CD-T solution (30g/l), liquor ratio 1:20, 1h, pH 4 (citric acid), padding, pick up 100%, dry at 80 ^{o}C, 10 min and Fixation at 160 ^{o}C, 5 min.

Table 3. Washing and Perspiration Fastness of Dyed Untreated and Pretreated Polyamides Fabrics

Dyed Samples	k/s	Washing Fastness			Perspiration Fastness					
					Alkaline			Acidic		
		Alt	St_n	St_w	Alt	St_n	St_w	Alt	St_n	St_w
C.I. Reactive Blue 203										
Untreated polyamide 6	2.7	4	4-5	4	4-5	4-5	4-5	4-5	4-5	4-5
Pretreated with CD	3.4	4-5	4-5	4-5	4	4-5	4-5	4-5	4-5	5
Pretreated with CD-T	3.3	5	5	5	5	4-5	5	4-5	5	4-5
C.I. Reactive Red 84										
Untreated polyamide 6	12.1	4-5	4-5	4-5	4	4-5	4-5	4	4	4
Pretreated with CD	12.3	5	5	5	4-5	4-5	4-5	4-5	4-5	4-5
Pretreated with CD-T	12.1	4-5	4-5	5	4-5	4-5	4-5	4-5	4-5	5
C.I. Reactive Yellow 1										
Untreated polyamide 6	4.1	4-5	4-5	4-5	4	4	4-5	4	4-5	4-5
Pretreated with CD	6.2	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5
Pretreated with CD-T	6.1	4-5	4-5	5	4-5	4-5	4-5	4-5	4-5	5
C.I. Reactive Yellow 1 Untreated Quiana	8.2	4	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5
Pretreated with CD	8.6	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4
Pretreated with CD-T	8.6	4-5	5	4-5	4-5	4-5	5	4-5	5	5
C.I. Reactive Yellow 1										
Untreated Nomex	8.6	4	4-5	4-5	4-5	4-5	4-5	5	4-5	4-5
Pretreated with CD	8.8	4-5	4-5	5	4-5	4-5	4-5	4-5	4-5	4-5
Pretreated with CD-T	8.7	4-5	5	5	4-5	4-5	4-5	4-5	5	4-5

Treatment: Immersion in CD or CD-T solution (30g/l), liquor ratio 1:20, 1h, pH 4 (citric acid), padding, pick up 100%, dry at 80 ^oC, 10 min and Fixation at 160 ^oC, 5 min. **Dyeing:** 1% (o.w.f), 85 ^oC, pH 4.5, 1h, liquor ratio 1:50.

3.5. Thermogravimetric Analysis (TGA)

The differential thermogravimetic graphs (TGA) of the untreated and treated polyamide 6 fabrics are shown in Fig. (**3**). The first mass loss at around 107^{o}C is due to the loss of moisture, the second and third mass loss at 284^{o}C and 505^{o}C due to a start of melting and decomposition.

The onsets of degradation from the untreated sample were 284^{o}C, and the loss in weight was 89.3 %. The treated samples with CD started degradation at 284 ^{o}C, and 279.5^{o}C respectively. The end of degradation temperature was slightly increased to 505^{o}C and 548^{o}C respectively. On the other hand, the degradation of the treated CD-T polyamide 6 started at temperature of 312^{o}C and 325.5^{o}C respectively, and the end of degradation temperature was shifted from 511^{o}C to 541^{o}C and 559^{o}C. These results indicate that the treatment of polyamide 6 with CD-T led to confirm stability than the treatment with CD. It can be noticed that treating polyamide 6 fabrics with CD or CD-T imparts relatively high burning temperature (T_b) values. The first derivation of the thermogravimetic analysis curves of polyamide samples treated with CD or CD-T versus the temperature of heating indicates that T_b value lies at 471^{o}C -472^{o}C for CD treatment, while it lies at 475^{o}C -490^{o}C for CD-T treatment. These results suggest that the use of CD-T in treatment of polyamide 6 showed better heat resistance.

3.6. Differential Thermal Analysis (DTA)

The thermal behaviour of the untreated and treated polyamide 6 fibres are given in Table **5**. The glass transition temperature of the fibre in dry state (Tg) and the melting temperature (T_m) were measured by differential thermal analysis DTA. The diagrams of both untreated and treated polyamide 6 fibres show two endothermic peaks, the first characterise the glass transition temperature (Tg) and the second belongs to the melting temperature (T_m). It was also found that the treatment with CD gave some decrease in the glass transition temperature (Tg) of the treated polyamide 6 fibres than the untreated one.

The glass transition temperature of the treated fabicrs with CD-T increased from 69^{o}C for untreated one to 73^{o}C

Table 4. Tensile Strength and Elongation of Untreated and Treated Polyamide 6 Fabric

Change in Elongation %	Change in Tensile Strength %	Elongation %	Tensile Strength (kg/cm^2)	Samples
0	0	126.5	0.405	Untreated
31.15	-20.4	166.5	0.324	Treated with (CD)
17.8	-14.5	149.0	0.345	Treated with (CD-T)

Treatment: Immersion in CD or CD-T solution (30g/l), liquor ratio 1:20, 1h, pH 4 (citric acid), padding, pick up 100%, dry at 80 ^oC 10 min and fixation at 160 ^oC, 5 min.

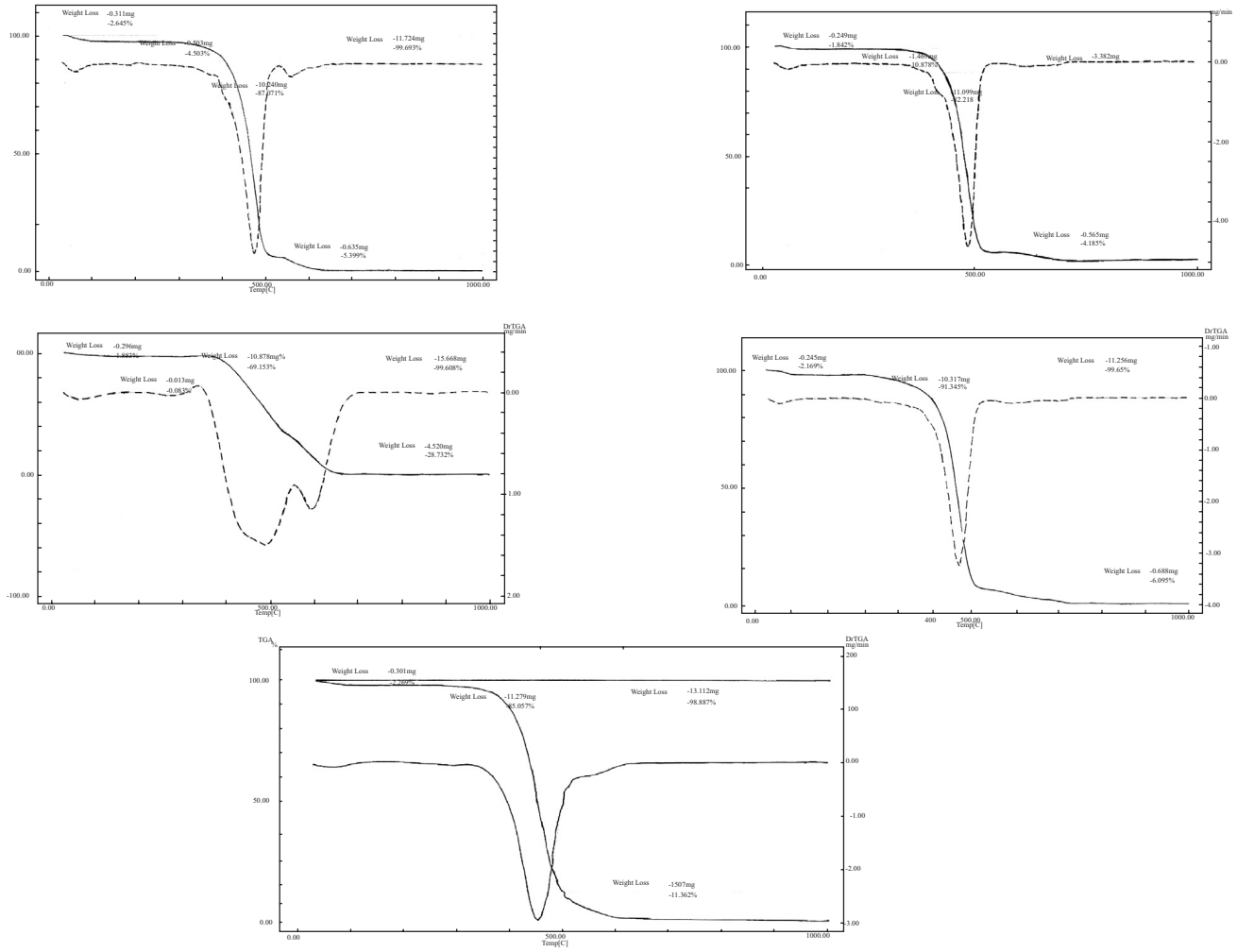

Fig. (3). Thermogravimetric analysis (TGA) of polyamide 6 fabric. **a**) Untreated **b**) Treated with CD 30g/l **c**) Treated with CD 50g/l **d**) Treated with CD-T 30g/l **e**) Treated with CD-T 50g/l.

Table 5. Glass Transition Temperature (Tg) and Crystallization Temperature (Tc) of Untreated and Treated Polyamide 6 Fabric

Polyamide 6	Glass Transition Temperature ^{o}C (Tg)	Crystallization Temperature ^{o}C (Tc)
Untreated	69.4	465.3
Treated with (30g/l CD)	64.1	459.5
Treated with (50g/l CD)	66.2	465.1
Treated with (30g/l CD-T)	73.1	465.9
Treated with (50g/l CD-T)	69.8	473.4

Treatment: Immersion in CD or CD-T solution, liquor ratio 1:20, 1h, pH 4 (citric acid), padding, pick up 100 %, dry at 80 ^{o}C, 10 min and fixation at 160 ^{o}C, 5 min.

and 69.8^{o}C respectively. The melting temperatures of the untreated and treated polyamide 6 fabrics increase upon treatment with CD-T from 465^{o}C to 465.8^{o}C and 473^{o}C, but gave slight decrease with treatment with CD to 459^{o}C. The results in table 6 showed that thermal stability was improved treatment with CD-T. Treatment: immersion in CD or CD-T solution, liquor ratio 1:20, 1h, pH 4 (citric acid), padding, pick up 100 %, dry at 80 ^{o}C, 10 min and fixation at 160 ^{o}C, 5 min.

3.7. Infrared Spectra

Infrared spectra of the treated and untreated polyamide 6, Quiana and Nomex fabrics are shown in Figs. (**4-6**). The treatment with CD or CD-T show some changes in the absorption band between 3200 cm^{-1} and 3600 cm^{-1} for all fabrics peaks are at 3421 cm_1(OH stretching H-bonded). Fig. (**4**) shows a band shift from 1523 cm^{-1} to 1533 cm^{-1}. The infrared spectra of Nomex fabrics given in figure 5 shows

new peaks at 1007 cm^{-1} and 816 cm^{-1} upon its treatment with CD-T, but the treatment with CD shows a shoulder at 517 cm^{-1}. Fig. (**6**) shows the infrared spectra of Quiana fabrics treated with CD or CD-T. New peaks at 3873 cm^{-1} and 3823 cm^{-1} appear for the treated fabrics with CD-T. A peak at 1031 cm^{-1} has disappeared. The treatment of Quiana with CD led to appearance of a week peak at 586 cm^{-1}.

Fig. (4). Infrared spectra of untreated and treated polyamide 6 fabric with CD-T or with CD-T.

Treatment: Immersion in CD or CD-T solution (30g/l), liquor ratio 1:20, 1h, pH 4 (citric acid), padding, pick up 100 %, dry at 80 ^{o}C 10 min and fixation at 160 ^{o}C, 5 min.: 1. Untreated polyamide 6; 2. Treated with CD; 3. Treated with CD-T.

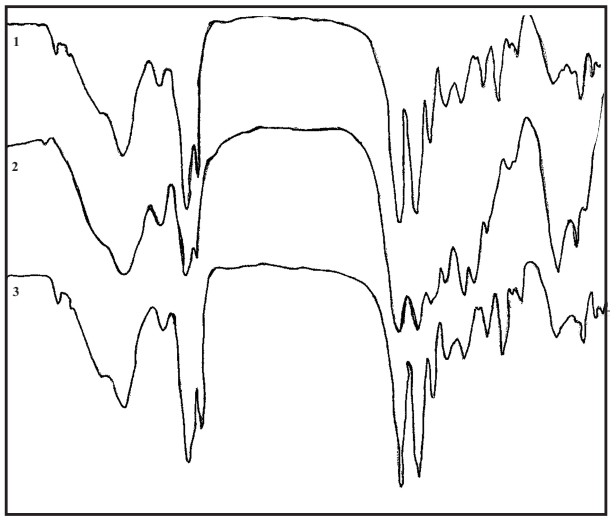

Fig. (5). Infrared spectra of untreated and treated Quiana fabric with CD-T or CD-T.

Treatment: Immersion in CD or CD-T solution (30g/l), liquor ratio 1:20, 1h, pH 4 (citric acid), padding, pick up 100 %, dry at 80 ^{o}C 10 min and fixation at 160 ^{o}C, 5 min.: 1. Untreated Quian; 2. Treated with CD; 3. Treated with CD-T.

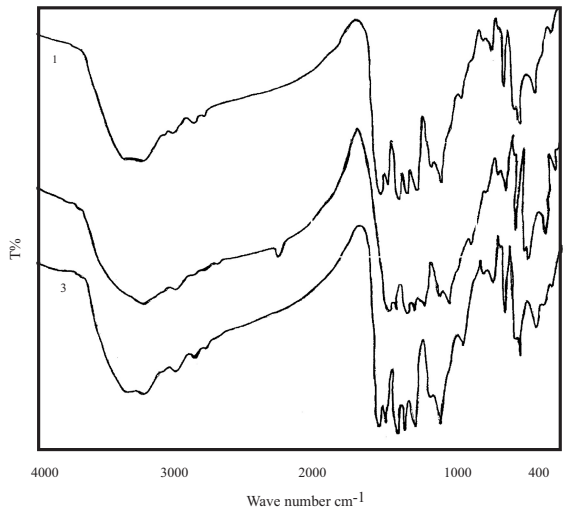

Fig. (6). Infrared spectra of untreated and treated Nomex fabric with CD-T or CD-T.

Treatment: Immersion in CD or CD-T solution (30g/l), liquor ratio 1:20, 1h, pH 4 (citricacid), padding, pick up 100 %, dry at 80 ^{o}C 10 min and fixation at 160 ^{o}C, 5 min.: 1. Untreated Nomex, 2. Treated with CD, 3. Treated with CD-T.

3.8. Antimicrobial Activity

Table **6** shows the inhibition zone diameter (mm/1 cm sample) for Esherichia Coli (G-ve), staphylococcus aureus (G+ ve) and Candida albicams (Filamentous fungus) on the polyamide fabrics. The antimicrobial activity was observed with the treated polyamide fabrics than the untreated fabrics. It was found that the treatment with 30-50 g/l CD or CD-T has enhanced the antimicrobial activity, the highest antimicrobial activity was imparted upon treatment with CD. The treatment with CD or CD-T gave antimicrobial activity on both Quiana and Nomex fabrics. It was found that washing led to some decrease in antimicrobial activity of the treated fabrics as compared with the untreated fabrics. The treatment with CD or CD-T has improved the resistance against Candida albicams (Filamentous fungus). It was found that addition of quaternary ammonium salts increase antimicrobial activity as compared with all treatment. Antimicrobial activity was imparted upon treatment.

CONCLUSION

The colour leveling is improved. The fastness to washing and perspiration are also given. Characterization by FTIR, DTG, TGA and T_b are performed. The treatment with CD or CD-T show some changes in the absorption band between 3200 cm^{-1} and 3600 cm^{-1} for all fabrics peaks are at 3421 cm_1.New peaks at 3873 $cm^{-1}$and 3823 cm^{-1} appear for the treated fabrics with CD-T. Yellowness index, moisture regain and roughness show some improvements.

These results suggest that the use of CD-T in treatment of polyamide 6 showed better heat resistance. The results of thermal behaviour of the treated polyamide 6 fabrics showed that thermal stability was improved with treatment with CD-T. Heat resistance to burning indicted by T_b shows some

Table 6. Antibacterial Activity of Untreated and Treated Polyamide Fabrics

Samples	Inhibition Zone Diameter (mm/1 cm sample)		
	Escherichia coli (G^-)	*Staphylococcus aureus* (G^+)	*Candida albicams* (fungus)
Untreated polyamide 6	0	0	0
Treated with (30g/l CD-T)	8	7	9
Treated with (30g/l CD)	7	6	8
Treated with (50g/l CD-T and quaternary salt)	9	9	9
Untreated Quiana	3	2	2
Treated Quiana with (30g/l CD-T)	8	8	8
Treated Quiana with (30g/l CD)	9	8	9
Treated Quiana with (50g/l CD-T and quaternary salt)	7	5	6
Untreated Nomex	2	3	2
Treated with Nomex (30g/l CD-T)	7	5	7
Treated Nomex with (30g/l CD)	7	6	6
Treated Nomex with (50g/l CD-T and quaternary salt)	9	8	7

Treatment 1: immersion in CD or CD-T solution, liquor ratio 1:20, 1h, citric acid pH 4, Padding, pick up 100 %, dry at 80 ^oC, 10 min and fixation at 160 ^oC, 5 min.

Treatment 2: immersion in CD-T and quaternary salt (2g/l) solution, liquor ratio 1:20, 1h, citric acid pH 4, Padding, pick up 100 %, dry at 80 ^oC, 10 min and fixation at 160 ^oC, 5 min. Standard Ampicillin 7.

prevelage of using CD or CD-T treatments of polyamides fabrics.

It was found that the treatment with 30-50 g/l CD or CD-T has enhanced the antimicrobial activity; the highest anti-microbial activity was imparted upon treatment with CD-T.

Also, the treatment with CD or CD-T has improved the resistance against *Candida albicams* (Filamentous fungus). It was found that addition of quaternary ammonium salts inc-rease antimicrobial activity as compared with all treatment. Antimicrobial activity was imparted upon treatment.

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