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Use of Sustainable Energy as a Heating Source to Improve Dyeability and Other Properties of Wool and Polyamide-6 Fabrics with Nano-Silica

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THIS study deals with the utilization of silicon dioxide nanoparticles (SiO_2 NPs) to treatment of wool and polyamide 6 fabrics. The fabrics treated with different concentrations of SiO_2 NPs (5- 20 g/l) using pad-dry- cure technique. The size of nano silicon dioxide particles measured with TEM. The surface morphology and surface chemical elements of treated and untreated fabrics were characterized through high-resolution Scanning Electron Microscopy (SEM) and Dispersive X-Ray spectroscopy (EDX), respectively. The untreated and treated wool and polyamide fabrics were characterized by FTIR. The effect of the treatment on dyability of both wool and polyamide 6 fabrics using different dyestuffs such as acid, basic and direct dyes is studied with applying innovation technique to save energy, water and time. For comparison, the same dyeing technique was carried out by using conventional heating technique. The colour strength and the fastness tests of the untreated and treated wool and polyamide 6 fabrics were evaluated. The effects of SiO_2 NPs on the physical and multifunctional properties of the treated sample such as weight, thickness, UPF, antibacterial activity and moisture regain % were determined. The obtained results indicate that the optimization of dyeing process parameters as well as optimized treatment of both wool and polyamide fabrics with SiO_2 NPs has a significant influence on the obtained shades and fastness properties.

Keywords: Wool and polyamide 6 fabrics, Nano- silica, UPF, antibacterial and Microwave dyeing.

Introduction

Wool as well as polyamide 6 fibres are the important fibres and utilizing in many textile industry such as carpets, sportswear and clothing [1, 2]. Bendak et al. reported that the treatment polyamide 6 with ß-cyclodextrin or monochlorotriazinyl ß-cyclodextrin were improved the antibacterial activity and thermal stability of the treated fabrics [3]. Also, polyamide fabrics treated with tannic acid to improve the dyeability of polyamide towards cationic dyes as well as fastness properties using different conditions [4]. Nano silicon dioxide was applied in textile industry to incorporate multifunctional properties such as increase the tensile strength, tear strength, antipilling, UPF protection and antimicrobial activity of viscose, polyester, nylon and wool fibres [5-8]. Liu et al studied the preparation and characterization of PET/Silica or polyamide/ Silica nano composites and they found that the purchased organic modified silica was dispersed in ethylene glycol by sonication at room temperature. The addition of nano-particles increases the crystallizing temperature and melting point [9, 10].

Wool fabrics were treated with different compounds such as keratin to enhanced the dyeing with acid and reactive dyestuffs under different conditions[11]. The wool fabrics was treated with

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pentaerytheritol using ultrasonic radiation bath to reducing the temperature of conventional wool dyeing with an acid dye, as well as the treatment enhanced many physical and mechanical properties of wool fabrics [12]. The bio-carbonization on coarse wool fibers led to the enhancement the dyeability both acid and metal 1:1 dyestuff [13]. Wool fabrics dyed with new dyed prepared from polyester and polyamide azo dyes [14].

At the time being, there were many research concerned with modifications, drying and dyeing of some fabrics have been conducted under the effect of microwave irradiation to reducing the temperature, water and time [15]. Microwave irradiation is one of the powerful techniques of non-contact heating, and used for accelerating chemical reacting, dye extraction, and dyeing of different type of fabrics and fibers. The old processing of fabric consumed a large amount of energy, water, as well as time. Many researchers deliberated some new techniques and methods for saving time, water as well as energy[16,17]. Microwave irradiation, has been confirmed to be more rapid, uniform, efficient, and it can be used as alternative to conventional heating source[18,19]. Microwave irradiation can implement easily inside the fabric's particles, can be heated simultaneously, consequently reducing heat transfer problems. It presumed that the microwave irradiation modification could affect on dyeability of textile fiber. However, the study on the effect of different conditions of dyeing of treated wool and polyamide fabric with SiO_2 NPs coupled with microwave irradiation is scanty [20-22].

The purpose of our attempt is aiming to develop the novel textile treatment through SiO_2 NPs for the improvement of polyamide and wool fabrics dyeability under the combined effects of microwave irradiation to reducing time, temperature and water. In addition to carried out comparative studied between dyeing with microwave irradiation method and dyeing with conventional method. The influence of various dyestuffs namely basic, acid and direct dyestuffs have been investigated. Quantitative analysis of the treated dyed sample is performing in order to shed insights vis-à-vis the untreated one. The multi-functions of the treated fabrics with SiO_2 NPs including colouration as well as fastness properties UV protection and antibacterial activity are investigated. Moreover, the fastness properties to rubbing, washing, perspiration and light are evaluated.

Experimental

Material

Fabrics

Knitted polyamide 6 (200 g/m^2) was supplied from El-Shourbagy Co., Cairo, Egypt. Wool fabrics were supplied by Misr for Spinning and Weaving Co., El Mehalla El Kobra, Egypt, and Plan weaved (25 yarns/cm in both weft and warp directions).

Chemicals

The SiO2 NPs obtained from Sigma–Aldrich, Germany. Its average diameter was less than 20-30 nm. Ethyl alcohol and acetic acid of laboratory grade used.

Dyestuffs

C.I. Acid red 1 (Fast red G) dyes, C.I. Basic red 18 (Remacryl®Red TGL) dyes, and Direct dyes (Solophneyl orange T4R) were used. The chemical structures of these dyes shown in Table 1.

Methods

Scouring

The polyamide fabric was treated with a solution containing 2 g/l non-ionic detergent (Triton X-100), at 45 °C for 30 min. Then the fabric was thoroughly washed with water and dried at ambient temperature.

Wool fabrics were scoured for 30 min at 30 °C in a 2% nonionic detergent (based on weight of fabric), fabric: liquor ratio, 1:5, rinsed with warm water and finally dried at ambient temperature.

Treatment with SiO_2 NPs

Wool and polyamide 6 fabrics were treated by different concentrations (5-20 g/l) of SiO_2 NPs solution, which were prepared by stirring the material in distilled water containing ethyl alcohol/water (10% v/v) using ultrasonic homogenizer for 15 min. at ambient temperature. Both wool and polyamide 6 fabrics were immersed at ambient temperature in the SiO_2 NPs solution at liquor ratio 1:10, then padded to pick up of 80% using a laboratory padder, the treated fabrics were dried at 80 ^oC for 5 min. for wool fabrics 2 min for polyamide fabrics, then curing treated wool and polyamide fabrics at 150 ^oC, for 3 min. Table 2 describes the Samples labeling of treated polyamide 6 and wool fabrics with SiO_2 NPs.

Dyeing Methods

The treated, as well as untreated fabrics dyed using two different heating methods, (conventional heating and microwave irradiation).

TABLE 1: Chemical structures of the used reactive, basic and Direct dyes

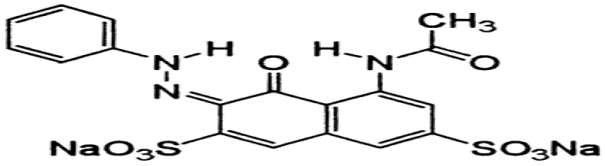
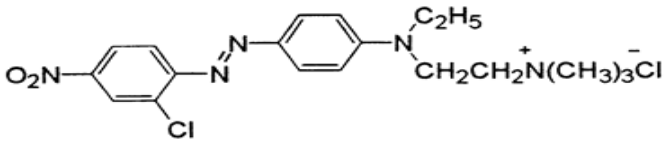
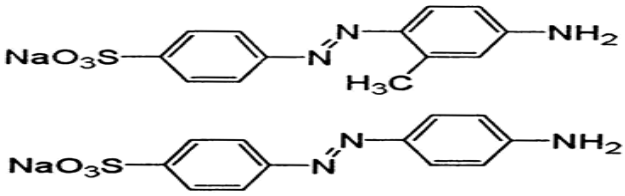
Dye	Chemical structure
C.I. Acid red 1	
C.I. Basic red 18 (Remacryl®Red TGL)	
C.I. Direct orange 34 Direct dyes (Solophneyl orange T4R	

TABLE 2: Samples labeling of nylon and/or wool fabrics with SiO2 NPs

Sample cod	Specification
UW	Untreated wool
W1	Treated wool with 5 g/l SiO_2 NPs
W3	Treated wool with 10 g/l SiO_2 NPs
W5	Treated wool with 15 g/l SiO_2 NPs
W6	Treated wool with 20 g/l SiO_2 NPs
UN	Untreated nylon
N1	Treated nylon with 5 g/l SiO_2 NPs
N3	Treated nylon with 10 g/l SiO_2 NPs
N5	Treated nylon with 15 g/l SiO_2 NPs
N6	Treated nylon with 20 g/l SiO_2 NPs

Dyeing using conventional method

Dyeing with Acid dyes

The dye bath was prepared by accurately weighing the dyestuff to give the prescribed shade. The C.I. Acid Red 1 (2% o.w.f) was pasted with small amount of warm water then dissolved by adding water to completely soluble. The dye solution was adjusted to pH 4-4.5 using acetic acid. The dyeing bath was heated to 60 ^oC and added the sample (polyamide 6 and/or wool sample) to the dyeing bath, the temperature of the dyeing bath was then raised gradually up to 90 ^oC then continued for 60 min, at liquor ratio 1:50. The dyed sample was thoroughly washed in warm and cold water then dried at air.

Dyeing with direct dyes

The required amount of (1 % o.w.f) direct dyes was prepared by pasting in warm water. The dyeing bath was completed to a liquor ratio of 1:50. The pH of dyeing bath was adjusted to 8. The dyeing was started at 90ºC after 20 min sodium chloride salt (10 g/l) was added to the dyeing bath and dyeing procedure continue to 60 min. The dyed samples were withdrawn, rinsed with water and air-dried.

Dyeing with basic dyes

The dye bath solution was prepared by pasting required amount of dyes C.I. Basic red 18 or C.I. Basic Blue with water to give the prescribed shade (1% o.w.f) and diluting with water to completely soluble dye. The dye solution was adjusted at pH 4.5 using acetic acid. The dye bath was heated to 85°C and added the sample (acrylic fibers) to the dye bath and the dyeing continued for 60 min., at liquor ratio 1:50. The dyed sample was thoroughly washed in warm and cold water and air- dried.

Dyeing using microwave irradiation

The dyeing process was applied to the fabric via exhaustion technique by using microwave irradiation. The same dyeing bath solution was prepared as described above with liquor ratio 1:50 for 2 min. After dyeing, the fabrics were removed, rinsed, and dried at room temperature.

Analyses and Testing

Bending stiffness

Measurements of bending stiffness of the fabrics were performed using the standard method according to (ASTM - D 1388-96) Shirey stiffness tester.

Thickness (mm)

Measurements of Thickness of the fabrics were performed using the standard method according to (ASTM-D1777).

Weight

Measurements of weight (gm./m²) of the fabrics were performed using the standard method according to (ASTM-D3776).

Moisture Regain %

Measurements of moisture regain of the fabrics were performed using the standard ASTM method 2654-76 (West, 1981). Moisture regain of the samples was calculated in accordance with the equation 1:

$$Moisture\ regain\ \% \ = \ \frac{W_1 - W_2}{W_1}\ x\ 100 \ldots\ldots\ldots (1)$$

Where: W_1 is the weight of sample after saturation in the standard humidity atmosphere

W_2: is the constant weight of dried sample.

Colorimetric measurements

The colorimetric analysis of the dyed fabrics was recorded using a spectrophotometer with pulsed Xenon lamps as light source (Ultra Scan Pro, Hunter Lab, USA) 10° observer with D65 illuminant, d/2 viewing geometry and measurement area of 2 mm. All measurements were occurred at λ_{max} wavelength. The corresponding color strength value (K/S) was assessed by applying the Kubelka-Munk (Eq. 2)[23].

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

Where R is the decimal fraction of the reflection of the colored fabric, K is the absorption coefficient and S is the scattering coefficient.

Fastness Properties

Fastness properties of the dyed samples were determined according to ISO standard methods. The specific tests were ISO 105-C06 (2010), color fastness to washing; ISO 105- E04:2013, color fastness to perspiration (acid and alkaline); and ISO 105-B02 (2014), color fastness to light and rubbing[24-27].

Field Emission Scanning Electron Microscopy (FE-SEM)

The surface morphology structure of unmodified as well as the modified both polyamide and wool fabrics were investigated by FE-SEM Quanta FEG 250. All samples were tested without pre-gold sputtering.

Transmission electron microscope

Shape, size and distribution of nano silicon dioxide were imaged using high-resolution transmission electron microscopy (JEOL-JEM-1200) operating at an accelerating voltage of 100 kV.

UV-Protection

The transmission of ultraviolet (UV) radiation through fabrics was evaluated using Varian Cary 300 ultraviolet visible spectrophotometer (Mulgrave, Victoria 3170, Australia) at a wavelength range of 320- 400 nm.

Evaluation of antibacterial activities

The antibacterial activity of untreated and treated fibers were tested against Klebsiella Pneumoniae (AATCC 2666) as gram-negative bacteria and Staphylococcus aureus as gram-positive bacteria. The antibacterial test was performed quantitatively using the standard test method according to the AATCC test method 100–1999 for Bacterial Counting. The method was described in the literature [28-30]

Infrared Spectra (FTIR)

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

Results and Discussion

The main target of this search was to improve the multifunctional properties of wool as well

as polyamide 6 fabric surfaces by incorporating the functionally important SiO_2 NPs. Many researchers worked on the modified textile with different metal type but there are no reports about the modification with SiO_2 NPs to improve wool and polyamide fabric surfaces via treatment with SiO_2 NPs. The untreated and treated of both fabrics were characterized by SEM, EDX, as well as FTIR analysis to verify the presence of SiO_2 NPs. The multifunctional properties such as colouration, and UV protection of wool, as well as polyamide-6 fabrics were successfully obtained after treatment and dyed using microwave heating. Microwave heating is better than the oil heating bath (traditional heating), where the microwave heating diminishing the reaction time besides reducing the water and energy consumption.

Results obtained along with those brought about by alteration of the magnitude of the parameters controlling the conditions of treatment and dyeing of the wool and polyamide-6 fabrics are given under.

Transmission Electron Microscopy

To gain insight into exact form of the SiO_2 nanostructures, the transmission electron microscopic (TEM) analysis was performed (Fig. 1). The TEM images showed that, the SiO_2 NPs were uniformly rhombohedral morphology with an average diameter of about (20-30) nm.

Characterization of SiO2 NPs Incorporated wool and polyamide-6 fabrics

The morphological, chemically and physically alterations on the wool and polyamide-6 fabrics surface caused by SiO_2 NPs incorporated fabrics surfaces were observed under different technical method with comparison between untreated and treated fabrics at 10% SiO_2 NPs , liquor ratio 1:10, padded to pick up of 80 %, dried at 80 ^oC 5 min for wool and 2 min for polyamide 6. curing at 150 ^oC, for 3 min.

To get insights into the morphologies of the treated Polyamide-6 and wool fabrics with SiO_2 NPs, the scanning electron microscopy (SEM) as well as (EDX) characterization were performed to observe the incorporation of SiO_2 NPs on the fabric's surfaces.

The SEM micrographs are shown in Figure 2 (a-d). Images of the UW (fig.2 a) and UN (Fig.2 c) show a typically clear and smooth longitudinal fibril structure surface for polyamide 6 fibres, and any change in structure surface of wool fibres. The surface of the fabric in presence of SiO_2 NPs is covered by SiO_2 NPs and submicron aggregates of it. However, W5 (Fig.2 b) illustrated a sufficient amount of SiO_2 NPs on the surface, while N5 (Fig. 2 d) illustrated the low amount of SiO_2 NPs on the surface of polyamide 6.

The successful SiO_2 NPs incorporated both fabrics were further confirmed by the energy dispersive spectrum (EDX). Fig.3 shows EDX spectra for treated and untreated of both fabrics. The signals at 2KeV for elemental silicon in the EDX spectra (Figure 3b&c) demonstrated that the SiO_2 NPs were immobilized onto W5 as well as N5. So, we can conclude that the SEM and EDX results are the evidence of the presence of SiO_2 NPs in the W5 & N5 samples.

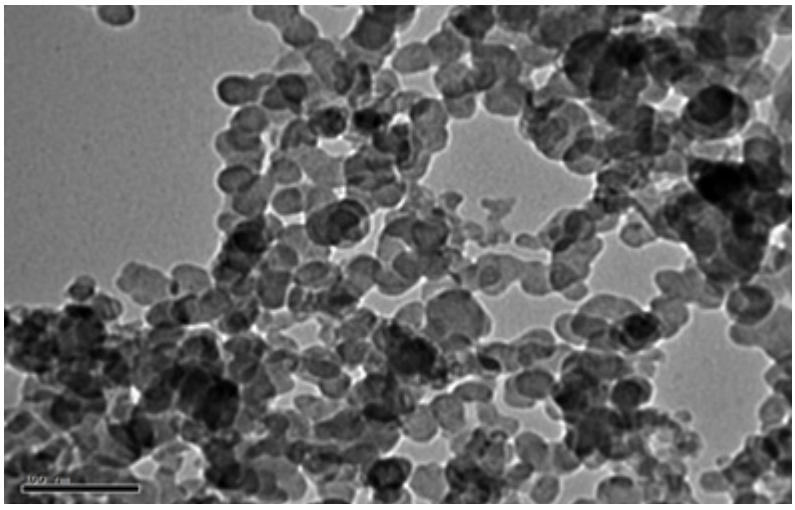


Fig. 1: TEM graph of the supernatant SiO_2 NPs

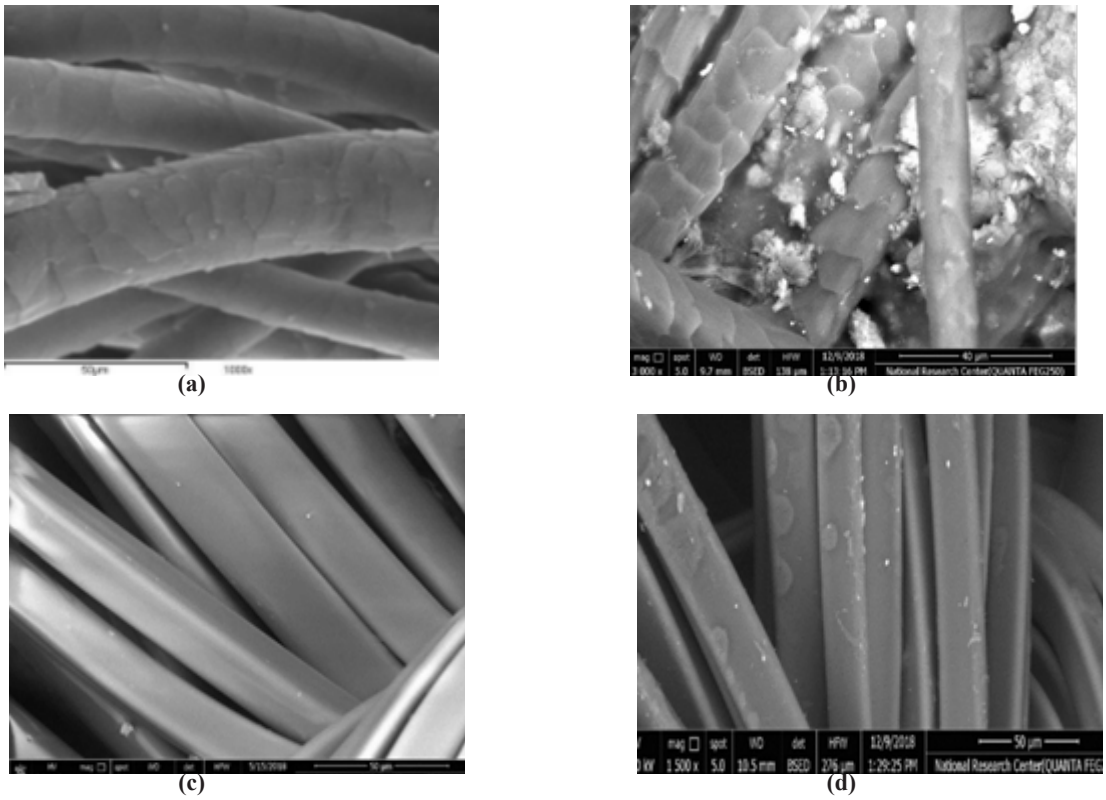


Fig. 2 (a- d): Scanning Electron Microscopy (FE-SEM) for untreated wool, untreated polyamide 6, treated wool and treated polyamide 6 with SiO_2 NPs

(a) UW: untreated wool , (b) W5: treated wool 5% SiO_2 NPs,
(c) UN: untreated polyamide 6, (d) N5: treated polyamide 5% SiO_2 NPs

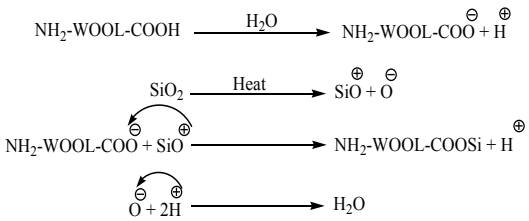
Effect of treatment on Mechanical Properties of the treated wool and polyamide-6Fabrics

Mechanism of SiO2 NPs incorporation into wool fabric

The chemical reduction of Si salts in aqueous solutions was the most preferred method. In the redox reaction system, the values of the standard reduction potentials (E^0) determine the pairs of reactants required for successful chemical reactions. This means that the free energy change in the reaction, ΔG^0, must be negative or equivalent $\Delta E^0 > 0$.

The formation of Si NPs incorporated wool fabrics can be divided into two stages; 1) pre-nucleation, and 2) nucleation

In the first stage, the Wool fabrics are protonic materials which have a negative zeta potential in neutral solutions owing to the carboxyl groups in their chemical structure. After the wool fabric immerged into SiO_2 solution, the Si^+ ions adsorb and diffuse into the fabric's molecules due to the electrostatic interaction between Si^+ ions and negatively charged of carboxylate groups in the end chain of wool structure.



Weight, thickness, moisture regain and UPF of untreated and treated polyamide 6 and wool fabrics

The investigation into the mechanical properties (weight and thickness) and physical properties (moisture regain as well as UPF) of the control and SiO_2 NPs incorporated wool and polyamide fabrics were examined (Table 3 and Fig. 4). The results show that: i) the incorporation of SiO_2 NPs on the wool and polyamide 6 fabrics surfaces leads to a great enhancement on weight and thickness overall. The increase in both weight and thickness for treated fabrics is due to

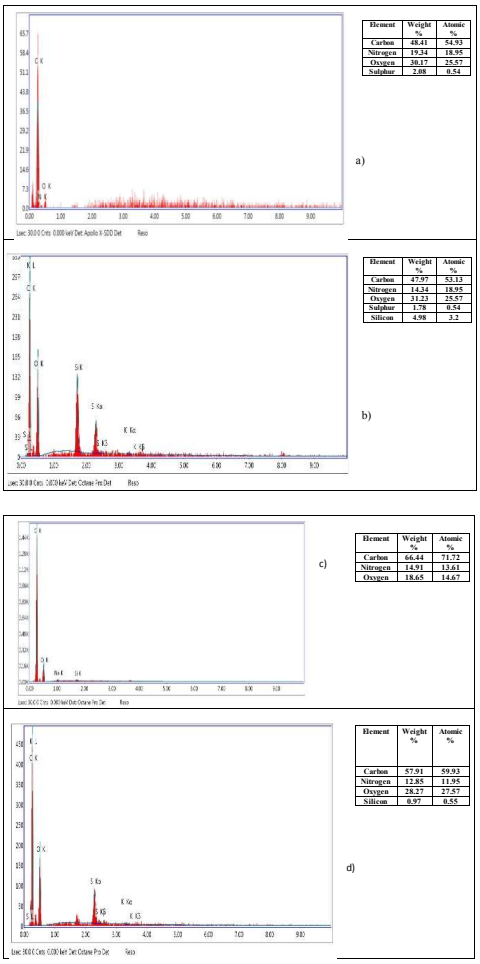
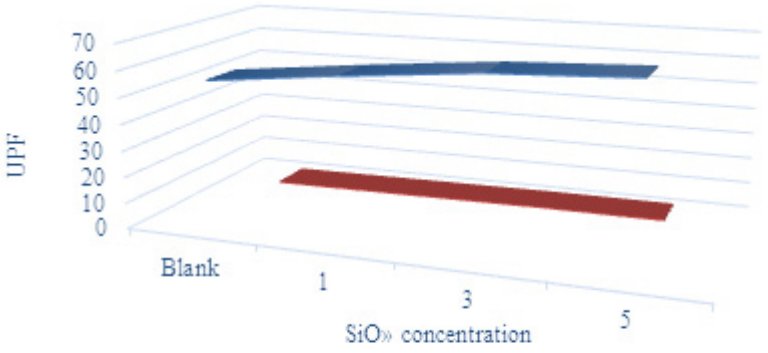


Fig 3: EDX Disperse X-Ray Spectroscopy for untreated wool, untreated polyamide, treated wool and treated polyamide with SiO_2 NPs
(a) UW: untreated wool, (b) W5: treated wool 5% SiO_2 NPs,
(c) UN: untreated polyamide 6, (d) N5: treated polyamide 5% SiO_2 NPs

TABLE 3: Weight, Thickness, moisture regain % as well as UPF of control and treated polyamide and wool fabrics

Sample labeling	Weight (g/m^2)	Thickness (mm)	Moisture regain %	UPF
UW	242.4	0.69	10.6	60.6
W1	256.5	0.75	10.7	105.2
W3	268.2	0.78	10,9	106.8
W 5	268.5	0.79	10.9	107.2
W 6	268.8	0.79	10.8	112.7
UN	175	0.42	2.14	1.6
N1	175.5	0.44	2.4	22.1
N3	176	0.46	2.45	23.4
N5	176.5	0.47	2.41	24.1
N6	176.6	0.48	2.41	24.5



	Blank	1	3	5
Wool fabric	55.3	60.6	65.2	67.2
Polyamide fabric	1.6	2.1	2.7	2.8

Fig. 4: UPF of untreated and treated wool as well as polyamide-6 fabric with different concentration of SiO_2 NPs

the presence of the SiO_2 NPs inside and outside the treated fibres. This increase may be attributed to the small particles of nano molecule covered the surface of the treated fibres.

The results of UPF protection of the treated fabrics with SiO_2 NPs as well as untreated samples were tabulated in Table 3. It was found that increase in concentration SiO_2 NPs led to more increased the UPF value for treated wool fabric than treated polyamide fabrics. The UPF rating for wool fabrics ranged from 60 to + 95, the rustles give a significant increase UV protection compared to untreated wool one. The results show that wool fabrics provide very excellent protection to the human body when they exceed 95 UPF. This increase may be due to the small particles of nano molecule which make easily to penetrate into the fiber molecules and more dispersion of SiO_2 NPs throughout the fabrics, leading to an increase in the interfacial adhesion between the nano and the fabric filaments. Also, this covering polyamide 6 fabrics with SiO_2 NPs act as protective layer and prevents the penetration of UVR through the fabrics and, thus, causes skin damage. Also, it is known that the increasing the weight and thickness of fabrics lead to increase the resistance ultraviolet radiation. [31, 32]

From the data of the moisture regain %, in Table 3 the SiO_2 NPs concentration increased the moisture regain give little increase. It was found that the moisture regain %, increased from 10.6 for untreated wool to be 10.9 for treated wool with SiO_2 NPs, as well as increased from 2.14 for untreated polyamide 6 to be 2.45 for treated polyamide 6 fabrics. This may be due to the corporation hydrogen bond and Van der Waal forces between the treated fibres and nano silicon dioxide.

Bending length and bending rigidities

The bending length and bending rigidities of untreated and treated wool as well as polyamide-6 samples are presented in Table 4. Data of table 4 show that the bending length of untreated and treated wool sample ranges from 2.5 cm to 4.1 cm in warp while it ranges from 3.0 to 4.9 cm in weft and bending rigidity ranges from 426.0 to 1473.3 mg/cm in warp and it ranges from 654.5 to 2446.7 mg/cm in weft. In addition, it can be noticed that the bending length ranges from 1.8 to 2.6 and from 1.9 to 3.1 cm for untreated and treated polyamide-6 in warp and weft respectively, while bending rigidity ranges from 102.1 to 2.3.5 and from 120 to 313.9 mg/cm in warp and weft respectively. It is expected to note here that fabric sample W5 and N5 possesses the highest bending length and binding rigidities, whereas untreated sample possesses the lowest values, but, the increase in the binding rigidities values of the treated fabric dose not greatly affect or hinder the uses of the fabrics. The increase in bending rigidity of both treated fabrics may be attributed to increase the weight and thickness of treated fabric than the untreated samples.

Tensile strength (Kg), Elongation % and Burst of treated and untreated wool and polyamide- 6 fabrics

Table 5 are clearly observed that as the SiO_2 NPs concentration increases there are a slightly

TABLE 4: Effect of SiO_2 NPs concentration on bending length as well as Binding rigidities of treated and untreated wool and polyamide-6 fabrics

Sample cod.	Bending length (cm)		Bending Rigidity (mg/ cm)	
	Warp	Weft	Warp	Weft
		Wool		
UW	2.5	3.0	426.0	654.5
W1	3.6	4.3	1196.7	2039.4
W3	3.8	4.5	1230.5	2201.2
W5	4.1	4.9	1473.3	2446.7
		Polyamide-6		
UN	1.8	1.9	102.1	120
N1	2.1	2.6	162.1	307.6
N3	2.3	2.6	200.5	309.3
N5	2.6	3.1	205.3	313.9

TABLE 5: Tensile strength and Elongation % of treated wool fabrics as well as burst of Polyamide 6

Sample cod.	Tensile strength (Kg f/mm²)	Elongation %
	Wool	
UW	0.9146	16.6
W1	0.962	18.7
W3	0.98	18.95
W5	0.981	19.3
	Burst of Polyamide 6 **(Kpa)**	
UN	410.7	
N1	413.9	
N3	418.6	
N5	419.7	

increase in tensile strength for wool fabric as well as burst for polyamide-6 fabric. Increase in tensile strength is usually accompanied by an increase elongation %. This increase may be attributed to the treated with nano silicon dioxide led to make new ionic link between the chin of the both treated fibres and SiO_2 NPs as shown in mechanism, as well as may be to found physical bonds such as hydrogen bond and van der Waals forces.

Colour measurements

The colour strength (K/S) value is usually used to point out the dye content of the dyed textile fabrics as; the higher K/S value exhibit the greater colour absorption and hence the desirable of the dyes amount on the fabric surfaces. The colour strength (K/S) value of the treated wool and polyamide 6 fabrics were measured at a wavelength of a round 525 nm in dependence on the applied different heating source conditions and showed in Table 6.

Result of tables 5 show the K/S value of treated and untreated wool as well as polyamide 6 fabrics dyed with (C.I. Basic Red 18) as a basic dye, C.I. Acid Red 1 as an acid dye and C.I. Direct Orange 34 as a direct dye by applying different heating source (microwave irradiation as well as traditional heating).

Results obtained reveal that: i) All the colour strength

(K/S) values of the treated polyamide 6 fabrics with SiO_2 NPs incorporated are significantly higher than the untreated polyamide 6 fabrics using microwave irradiation or traditional heating method, however treated wool fabrics give significantly increase when dyeing with basic dyes by microwave irradiation method than traditional heating method. ii) The K/S value of the treated fabric increases with increasing SiO_2 NPs concentration, indicating a higher amount of SiO_2 NPs incorporated into the both fabrics, iii) With increasing the SiO_2 NPs concentration, more Si^+ absorbed to the treated fabrics which lead to the increased the Si^+ on the fiber surfaces and the depth of colour became stronger, iv) The basic dye achieved traditional heating.

The increasing of SiO_2 NPs concentration of treatment leads to a higher K/S value while the direct dye is the lower value and follow the order: basic Red 18 > Acid Red 1 > Direct Orange. This may be attributed to the net negative charge in the structural lattice of nano silicon dioxide SiO_2 NPs ascribes to the isomorphous replacement of Si^{4+} in the tetrahedral layer in the octahedral layer, result in enhancing adsorbing of cationic substances [33] . v) Furthermore, the K/S values of dyed samples by using microwave irradiation as a heating source are significantly higher if compared with the using oil bath.

The enhancement of K/S value of treated fibers, it may be concluded that, the more enough concentration is a basic requirement for the completion of the silicon particle incorporated into both fabrics. Also by using microwave irradiation, the K/S increased, this may be the microwave irradiation leading to the rapid initial heating and generation of localized heat at reaction sites increases the rate of reaction and the conglomeration of dye molecules reduced, leading to easy and rapid diffusion of dye into the fabrics and more color uptake at higher concentration.

The fastness properties of coloured wool and polyamide 6 fabrics were further evaluated and reported in Tables (7-10). In all treatment conditions, the SiO2 NPs incorporated both fabrics showed fastness results ranged from well to very well when using conventional heating and from very well to excellent when using microwave irradiation which is referred to the chemically stable of SiO_2 NPs on the fabrics and it follows the following order: Basic dyes > Acid Dyes > Direct dyes, Polyamide 6 > wool fabric, Microwave irradiation > traditional heating.

Antibacterial activity

The important characteristic of the material that is purposed for biomedical applications is the antibacterial property. Silicon atom as well as silicon NPs are very poisonous to the microorganisms and they show strong antibacterial effects toward the gram-positive and gram-negative bacteria. In addition, the SiO_2 NPs incorporated into the wool as well as nylon-6 fabrics can endow these fabrics with antibacterial activity. From data in table 11, for all fabrics (untreated and treated wool and polyamide 6 fabrics), showed better antibacterial activity comparing to the untreated one. Comparing between the two fabrics, wool fabric exhibited the best antimicrobial reduction. For the treated wool samples, percentage of reduction were 88% for Staphylococcus aureus as gram-positive (G+) bacteria, and 76% for Escherichia coli (G-)

TABLE 6: Colour strength of untreated and treated wool and polyamide 6 fabrics dyed with different dyestuffs.

Sample labeling.	Conventional method			Microwave method		
	C.I. Basic Red 18	C.I. Acid Red 1	C.I. Direct Orange 34	C.I. Basic Red 18	C.I. Acid Red 1	C.I. Direct Orange 34
UW	8.18	5.54	3.21	18.51	4.93	3.9
W1	8.54	4.74	3.23	22.5	5.77	3.8
W3	8.67	4.90	3.29	23.9	5.97	4.32
W 5	8.87	4.95	3.36	24.1	6.18	4.78
UN	10.96	4.44	5.2	7.18	5.68	6.9
N1	22.3	9.91	6.44	23.91	12.98	9.96
N3	23.1	9.99	6.98	24.87	13.76	10.43
N5	23.97	10.12	7.23	24.98	13.91	10.53

TABLE 7: Fastness properties of coloured wool fabrics coloured using conventional heating.

Fabric sample	Washing		Perspiration				Rubbing		Light
	Alt	St.	Acidic		Alkaline		Dry	Wet	
			Alt	St.	Alt	St.			
Basic dye									
UW	3	3-4	3	3	3	3	3	3	5
W1	3-4	4	4-5	4-5	4-5	4-5	5	5	5-6
W3	4	4	4-5	4-5	4	5	4-5	4-5	5-6
W5	4	4	4-5	4-5	4	5	4-5	4-5	6
Acid dye									
UW	3	3	3	3	3	3	3	3	5
W1	4	4	4	4	3-4	3-4	3-4	4	5
W3	4	4-5	4-5	5	5	5	4-5	4-5	5
W5	4	3-4	3-4	3-4	4	3-4	4	4	5
Direct dye									
UW	2-3	3	3	3	3	3	3	3	5-6
W1	3	3-4	4	4	4	4	3-4	4	5-6
W3	3	3-4	4	4	4	4	4	3-4	5-6
W5	3-4	3-4	4	4	4	4	4	3-4	6

TABLE 8: Fastness properties of coloured wool fabrics coloured using Microwave irradiation.

Fabric sample	Washing		Perspiration				Rubbing		Light
	Alt	St.	Acidic		Alkaline		Dry	Wet	
			Alt	St.	Alt	St.			
Basic dye									
UW	5	4-5	4-5	5	5	5	4-5	4-5	6-7
W1	4-5	4-5	4-5	4-5	4-5	4-5	5	5	6-7
W3	5	4-5	4-5	5	5	5	4-5	4-5	6-7
W5	5	4-5	4-5	5	5	5	4-5	4-5	7
Acid dye									
UW	4-5	4-5	4-5	5	5	5	4-5	4-5	5-6
W1	5	5	5	5	5	5	5	5-6	5
W3	5	4-5	4-5	5	5	5	4-5	4-5	6-7
W5	5	5	5	5	5	5	5	6-7	6-7
Direct dye									
UW	5	5	5	5	5	5	5	5	5-6
W1	5	4-5	4-5	5	5	5	4-5	4-5	6-7
W3	5	5	5	5	5	5	5	5	6-7
W5	5	4-5	4-5	5	5	5	4-5	4-5	6-7

TABLE 9: Fastness properties of coloured polyamide-6 fabrics coloured using conventional heating

Fabric sample	Washing		Perspiration				Rubbing		Light
			Acidic		Alkaline				
	Alt	St.	Alt	St.	Alt	St.	Dry	Wet	
Basic dye									
UN	3	3	3	3	3	3	4	4	5
N1	3	3-4	4-5	4-5	4-5	4-5	5	5	6-7
N3	3-4	4	4-5	5	5	5	4-5	4-5	6-7
N5	3-4	4	4-5	5	5	5	4-5	4-5	6-7
Acid dye									
UN	3	3	3	3	3	3	3-4	3	5
N1	3-4	3-4	3-4	3-4	3-4	4	4	3-4	5
N3	3-4	3-4	3-4	3-4	3-4	4	4	4	6-7
N5	3-4	3-4	3-4	3-4	3-4	3-4	3-4	4	6-7
Direct dye									
UN	3	3	3	3	3-4	3-4	4	4	6
N1	4	4	4	4	3-4	3-4	4	4	5-6
N3	4	4	4	4	3-4	3-4	4	4	5-6
N5	4	4	4	4	3-4	4	4	4	6-7

TABLE 10: Fastness properties of coloured polyamide 6 fabrics coloured using Microwave irradiation.

Fabric sample	Washing		Perspiration				Rubbing		Light
			Acidic		Alkaline				
	Alt	St.	Alt	St.	Alt	St.	Dry	Wet	
Basic dye									
UN	3-4	4-5	4-5	4-5	4-5	4-5	4-5	4-5	5
N1	4-5	4-5	4-5	4-5	4-5	4-5	5	5	6-7
N3	5	4-5	4-5	5	5	5	4-5	4-5	6-7
N5	5	4-5	4-5	5	5	5	4-5	4-5	6
Acid dye									
UN	4	4	4-5	5	5	5	4-5	4-5	5-6
N1	5	5	5	5	5	5	5	5-6	5
N3	5	4-5	4-5	5	5	5	4-5	4-5	6-7
N5	5	5	5	5	5	5	5	6-7	5
Direct dye									
UN	5	5	5	5	5	5	5	5	6-7
N1	5	4-5	4-5	5	5	5	4-5	4-5	6-7
N3	5	5	5	5	5	5	5	5	5-6
N5	5	5	4-5	5	5	5	5	5	6-7

Alt: Alteration the colour, St: Staining of polyamide fabrics

bacteria. While, the percentage of polyamide-6 sample were 71%, 61% for (G+) and (G-) bacteria, respectively.

Infrared spectra

The investigation into the chemical interaction of the untreated and SiO_2 NPs incorporated polyamide 6 and wool fabrics were examined by FTIR. As shown in figure 5 and 6 (a, b) the characteristic peaks of untreated wool sample (fig. 5 (a)) due to NH broad absorption at 3275.5 cm^{-1} with correlation intensities 40.0032, and C=O (waving) was detected at 1631.48 cm−1 with correlation intensities 43.2165 as well as at 1517.7 cm^{-1} with correlation intensities of 48.4212 while in the treated wool fabric with SiO_2 NPs (fig.5 (b)) 5% was a shifted occurred NH (stretching abroad peak) at 3272.61 cm^{-1} with correlation intensities of 42.0315and C=O (stretching peak) at 1631.48 cm^{-1} with correlation intensities of 45.5169 and at 1516.74 cm−1 with correlation intensities of 50.1094, this shift indicate that NH, C=O of the wool molecules interact with the surface of SiO_2 NPs. Also, the characteristic bands almost at 1085, 800 and 460 cm^{-1} are correspond to the stretching, bending and out of plane of Si O bonds, respectively. The position and the shape of the main Si O vibrational band at 1085 cm^{-1} shows a stoichiometric silicon dioxide structure.

As shown in figure 6 (a, b) the characteristic peaks of untreated polyamide 6 fibres (fig 7 (a)) due to NH at 3289.96 cm^{-1} with correlation intensities 22.305 (sharp peak), and C=O was detected at 1631.48 cm^{-1} with correlation intensities of 22.9974 (Stretching), expanded C=O 1536.02 cm^{-1} with correlation intensities 29.884, While in treated one the characteristic peak of polyamide 6 fibres (fig. 6 (b)) NH was shifted and it appeared at 3290.93 cm^{-1} with correlation intensities 45.7561, and C=O was shifted at 2190.74 cm^{-1} with correlation intensities 94.3112 and C=O (stretching) at 1633.41 cm^{-1} with correlation intensities 42.6471 and CO (sharp peak) at 1534.1 cm^{-1} with correlation intensities 41.6461 this mean that the C=O of the polyamide molecules interact with the surface of SiO_2 NPs.

TABLE 11: Antibacterial activity of SiO_2 NPs of untreated and treated wool and polyamide 6

Fabrics type	Reduction%			
	Wool fibre		Polyamide 6 Fibre	
	Staphylococcus Aureus (G+) bacteria	Klebsiella Pneumoniae (G^-) bacteria	Staphylococcus Aureus (G+) bacteria	Klebsiella Pneumoniae (G^-) bacteria
Untreated	24	23	20	21
Treated	81	76	61	53

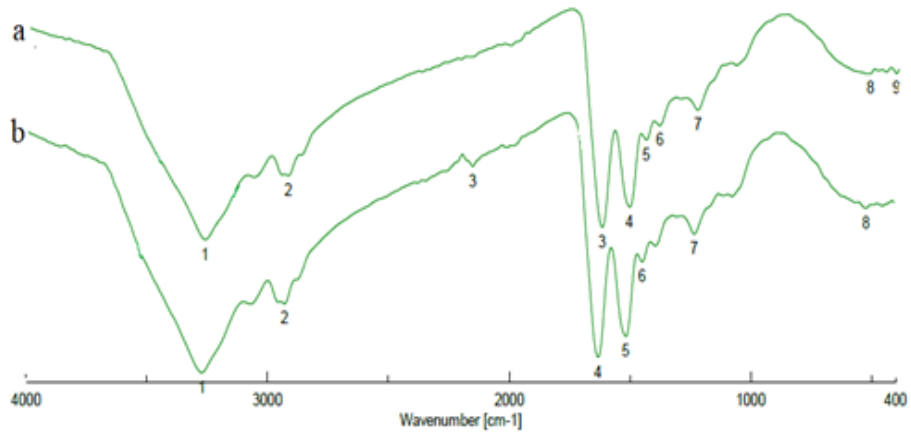


Fig. 5: FTIR of untreated and treated wool fabrics

(a) Untreated wool fabrics

(b) Treated wool fabrics

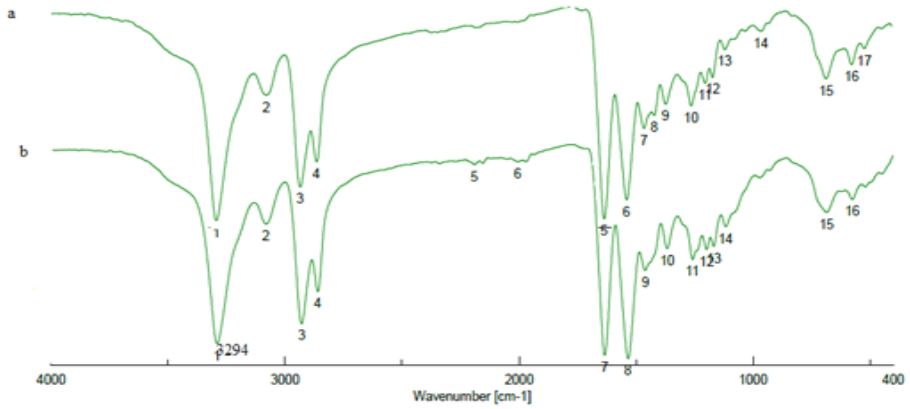


Fig. 6: FTIR of untreated and treated polyamide 6 fabrics
(a) Untreated polyamide fabrics
(b) Treated polyamide fabrics

Conclusion

A benign method for SiO_2 NPs incorporating wool as well as polyamide 6 fabrics was established for the improvement of wool and polyamide 6 fabrics dyeability under the combined effects of microwave irradiation.

The SEM and EDX results are the evidence of the presence of SiO_2 NPs in the W5 & N5 samples. The investigation into the mechanical properties (weight, thickness, moisture regain as well as UPF protection) of the control and SiO_2 NPs incorporated wool and polyamide 6 fabrics were confirmed the presence of nanoparticles (SiO_2 NPs) on the both treated fabrics.

The incorporation of SiO_2 NPs on the wool and polyamide 6 fabrics surfaces leads to a great enhancement on UPF. On the opposite side of moisture regain, as the SiO_2 NPs concentration increased the moisture regain little increased, this may be due to the loss of physically bound water.

We believe that the increase in the binding rigidities values of the treated fabric dose not greatly affect or hinder the uses of the fabrics.

Moreover, as the SiO_2 NPs concentration increases there are a slightly increase in tensile strength for wool fabric as well as burst for polyamide 6 fabric.

The K/S values of the SiO_2 NPs incorporated wool and polyamide 6 fabrics are significantly higher than the untreated fabrics, K/S value of the treated fabric increases with increasing SiO_2 NPs concentration, indicating a higher amount of SiO_2 NPs incorporated into the both fabrics. The order K/S values: basic Red 18 > Acid Red 1 > Direct Orange.

Furthermore, the K/S value of dyed samples by using microwave irradiation as a heating source are significantly higher if compared with the traditional heating.

The treatment with the SiO_2 NPs incorporated both fabrics showed fastness results ranged from well to very well when using conventional heating and from very well to excellent when using microwave irradiation which is referred to the chemically stable of SiO_2 NPs on the fabrics**.**

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استخدام الطاقة المستدامة كمصدر تدفئة لتحسين قابلية الصباغة والخصائص الأخرى لأقمشة الصوف والبولي أميد ٦ باستخدام نانو سيليكا

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تتناول هذه الدراسة استخدام جسيمات ثاني أكسيد السيليكون النانوية (SiO2 NPs) فى معالجة الالياف من الصوف و / أو البولي اميد و تتم معالجة الأقمشة بتركيزات مختلفة من SiO2 NPs باستخدام تقنية الغمر و العصر و التجفيف. تم دراسة مورفولوجيا السطح والعناصر الكيميائية السطحية للأقمشة المعالجة وكذلك غير المعالجة من خلال الفحص المجهري للماسح الضوئي الإلكتروني عالي الدقة (SEM) ومنظار الأشعة السينية المشتته (EDX) لدراسة العناصر على الاقمشة المعالجة، وفى نفس الوقت تتم دراسة التأثيرات الجوهرية للأقمشة المعالجة تجاه الأصباغ الحمضية ، القاعدية والمباشرة باستخدام تقنية حديثة(الميكروويف) لتوفير الطاقة والمياه والوقت ، ثم تتم مقارنتها مع تقنية الصباغة التقليدية.

ويتم تقديم نتائج هذا البحث من خلال معاملات (K / S) شدة اللون بالإضافة إلى ذلك ، يتم تقييم آثار اختبارات ثبات العينات المصبوغة المعالجة وغيرالمعالجة. بمادةSiO2 NPs مثل الثبات للغسيل و الثبات للتعرق و الثبات للاحتكاك و الثبات للضوء و درست الخصائص متعددة الوظائف للعينة المعالجة بما في ذلك مقاومة الأشعة فوق البنفسجية والنشاط المضاد للميكروبات. تشير النتائج التي تم الحصول عليها إلى أن تحسين معايير عملية الصباغة وكذلك المعالجة المسبقة المحسنة للصوف وكذلك أقمشة بولي أميد مع SiO2 NPs له تأثير كبير على خصائص الثبات. وتم تمييز الخصائص الكيميائية لأقمشة الصوف والبولي أميد غير المعالجة والمعالجة باستخدام FTIR.