SURFACE MODIFICATION OF COTTON AND POLYESTER FABRICS USING ALGINATE and COPPER (II) SULPHATE INTERACTIONS: CHARACTERISATION of THERMAL COMFORT PROPERTIES

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Abstract: In this experimental study, 100% cotton and 100% polyester woven fabrics, which are commonly used in hospital environment, were treated with sodium alginate and copper sulphate by using ultrasonic energy. The fabrics were immersed in sodium alginate solution (2.5% w/v) for 24 hours and rinsed with distilled water. The rinsed fabrics were submerged in 1%, 3%, 5%, 10% and 15% w/v copper solution and subsequently the fabric specimens were subjected to 10 minutes of ultrasonic energy treatment. The untreated and the treated fabrics' thermo physiological properties including; thermal conductivity, thermal resistance, thermal absorptivity, water vapor permeability, and heat loss were tested and analyzed by using Alambeta and Permetest instruments.

1. Introduction

Fulfilling physical and thermal comfort and functionality in hospital beddings, curtains and apparel are critical for healthcare workers and patients. The maintenance of thermal comfort and necessary protective performance of medical apparel are important due to hard and diverse physical activities in hospital environment. A common threat with antibiotic resistant bacteria is that they are spread very easily through patient-staff and patient-patient contact. These prevalent bacteria are often found on general surfaces such as the floor, radiators, and beds and are also on fabrics such as hospital gowns, gloves, bed linen and curtains. Copper has been identified as being effective against a broad spectrum of microorganisms such as *Clostridium difficile*, *Escherichia coli O157:H7*, Influenza *A* (H1N1), *Listeria monocytogenes*, and methicillin-resistant *Staphylococcus aureus*.

Sodium alginate can form a hydrophilic gel when in the presence of divalent cations such as copper (Cu2+) via a unique ion exchange mechanism whereby the sodium ions attached to the carboxyl groups on the uronic acid monomers are exchanged by the copper ions, which subsequently cross-links the alginate chains together, forming a crystalline structure [1]. Several studies have shown that the ultrasonic energy has many advantages over alternative treatment methods such as superior cleaning, a reduction in the textile processing time, and reduced energy and chemicals [2-4].

2. Materials and Methods

2.1. Materials

100% plain cotton and PES fabrics were purchased from the UK market. The fabric dimensional properties were tested and the results are given in Table 1. Sodium alginate, MANUCOL ® DH, was obtained from Ashland Ltd. (formerly ISP) (SA, medium viscosity 40-90 mPas (1%), M: G ratio 61/39). Copper (II) sulphate, pentahydrate was obtained from Fisher Bioreagents Ltd.

TABLE 1: *Dimensional properties of fabrics*

	Area density (gm^{-2})	Thickness (mm)	Warp no. (per cm)	Weft no. (per cm)
Cotton	126	0.29	35	30
PES	127	0.23	55	28

2.2. Methods

- Treatment

A novel technique of incorporating copper into 100% cotton and 100% polyester (PES) woven fabrics using sodium alginate, copper sulphate and ultrasonic energy has been effectively established. In order to investigate the effect of the copper on the cotton and PES fabrics, five different concentrations (1%, 3%, 5%, 10% and 15%) of copper sulphate solution were prepared and the fabric specimens were soaked for two hours and then the fabrics were subjected to 10 minutes of ultrasonic energy.

- Thermophysiological Comfort

The thermophysiological properties of the untreated and treated fabrics were determined by using the Alambeta and Permetest instruments (Sensora Instruments, Czech Republic). The Alambeta instrument provides values for thermal conductivity, thermal resistance (insulation), thermal absorptivity (warmth-to-touch), fabric thickness and thermal diffusion. The test instrument was used to analyze the transient and steady state thermophysical properties of the fabrics. The specimens of 20cm ×20cm were prepared and placed in between two plates. With the two plates the heat flow through the fabric due to the different temperature of the bottom measuring plate (at ambient temperature) and the top measuring plate which is heated to 40ºC. The thermal absorptivity of the textile structure is a measure of the amount of heat conducted away from structure's surface per unit time [5-7]. The test was performed on the dry and wet states of the fabrics which were wetted with 0.2ml of distilled water in the centre of the fabrics and allowed 4 minutes before retesting, in order to allow for the thermal recovery of the fabric. All tests were carried out on both faces of each specimen and the mean values calculated.

Water vapor permeability and the resistance to evaporative heat loss of the fabrics were tested by using the Permetest Instrument (Sensora Instruments, Czech Republic). This instrument is based on the skin model, which simulates dry and wet human skin surface in terms of its moisture, water vapor and evaporative heat permeation [8]. The instrument uses the same principle as specified in ISO 11092 developed by Hohenstein Institute, whereby a heated porous membrane is used to simulate the sweating skin. The heat required for the water to evaporate from the membrane, with and without a fabric covering, is measured [5].

3. Results and Discussion

Thermophysiological comfort results of the untreated and treated fabrics are given in Table 2 and Table 3. The wet state after allowed 4 minutes to recovery was investigated individually due to the importance of fabric application areas and to determine wet performance of the fabrics.

TABLE 2: *Thermal Resistance (r) and Absorptivity of Fabrics*

	Thermal Resistance ($W^{-1}K\ m^2 \times 10^{-3}$)		Thermal absorptivity ($Ws^{1/2}\ m^{-2}\ K^{-1}$)	
Cotton fabrics	**Dry**	**Wet**	**Dry**	**Wet**
0% cotton	58.1	42.7	71.1	115.5
1% cotton	91.3	55.3	68.5	103.3
3% cotton	100.0	59.9	62.1	100.9
5% cotton	123.9	93.4	54.1	93.5
10% cotton	146.8	115.1	50.5	90.1
15% cotton	163.1	123.3	40.1	88.4
PES fabrics				
0% PES	49.3	40.2	51.0	103.7
1% PES	80.3	57.1	45.5	95.9
3% PES	90.4	62.2	41.2	83.6
5% PES	97.3	70.1	37.6	74.6
10% PES	108.9	78.1	35.6	70.1
15% PES	123.2	93.4	27.3	60.4

TABLE 3: *Thermal conductivity and Permatest Results*

	Thermal conductivity ($W/mK \times 10^{-3}$)		Permatest	
Cotton fabrics	**Dry**	**Wet**	**Water vapour permeability (%)**	**Resistance to evaporative heat loss (m^2PaW^{-1})**
0% cotton	32.8	45.1	65.4	3.2
1% cotton	35.4	51.2	61.1	3.7
3% cotton	36.1	56.7	57.2	4.0
5% cotton	36.7	58.6	53.7	4.3
10% cotton	37.9	61.2	49.5	4.9
15% cotton	38.2	63.5	43.2	5.3
PES fabrics				
0% PES	30.9	53.1	62.1	3.7
1% PES	31.2	60.9	60.0	4.1
3% PES	32.1	63.2	58.7	4.9
5% PES	33.1	67.5	56.1	5.6
10% PES	34.7	69.4	54.3	6.2
15% PES	35.4	70.1	49.1	6.9

3.1. Thermal Resistance Of Nonwoven Fabrics In Dry And Wet State

The thermal resistance of any structures depends on the fabric thickness and thermal conductivity value. The fabrics used to make the apparel should have a relatively low thermal resistance. A higher thermal resistance will cause the wearer to become uncomfortable and extremely warm. The resistance is expressed by the following relationship.

$R\ (m^2kW^{-1}) = h(m)/\lambda$ in $W^{-1}K\ m^2 \times 10^{-3}$ Eq. (1)

where:

h = fabric thickness

λ = thermal conductivity

Table 2 shows the thermal resistance of the fabrics in the dry and wet state. The thermal resistance of cotton fabrics ranged from 58.1 to 163.1$W^{-1}K\ m^2 \times 10^{-3}$ for the dry state and from 42.7 to 123.3$W^{-1}K\ m^2 \times 10^{-3}$ for the wet state. In the wet state, the fabrics had drastically decreased thermal resistance. The differences between the untreated and treated fabrics are significant. The effect of copper treatment on the thermal resistance of the fabrics varied; however, generally there is a considerable increase for both cotton and PES fabrics. The cotton fiber fabrics had higher thermal resistance as compared to PES fabrics in both dry and wet states. It can be concluded from these results that copper treatment affect the thermal resistance properties of natural and synthetic fiber based fabrics significantly. It is also noted that the untreated and treated cotton fabrics had the highest thermal resistance in each fabric treatment combinations. The treated fabrics could give warmer feeling when in contact with the skin due to the increase in thermal resistance properties of the fabrics. This could be beneficial for hospital textiles such as curtains, bed linens etc.

The percentage recoveries of the fabrics after allowed 4 minutes before retesting were also determined. It ranged from 55% to 65%. It is well-known that any fabrics which have a 75% recovery are assumed to dry quickly. The higher ratios (10-15%) of copper treatment had higher percentage recovery value after 4 minutes allowed for the recovery; however, their recovery values were found to be similar to the untreated fabrics.

3.2. Thermal Absorptivity Of Woven Fabrics In Dry And Wet State

'Warm-cool' feeling (thermal absorptivity) of fabric is one of prior characteristics for textile fabrics and this feature is first sensation that is felt when anyone touches the fabric, this is a kind of heat transfer between the skin and the fabric surface. Pure fabric 'warm-cool' characteristic can be modified during the textile finishing processes. Lower thermal absorptivity causes a warm feeling and a diametrically higher thermal absorptivity value tends to give a cooler feeling. The thermal absorptivity can be calculated by the following equation.

$b = \sqrt{\lambda \times \rho \times c}$ in $Ws^{1/2}\ m^{-2}\ K^{-1}$ Eq. (2)

where:

λ = thermal conductivity;

ρ = fabric density;

c = specific heat of the fabric.

The cotton fabrics had significantly higher thermal absorptivity than the PES fabrics (Table 2). A noteworthy difference in thermal absorptivity of the fabrics was detected when the fabrics were wetted and retested after 4 minutes. The treated fabrics had lower thermal absorption than their untreated forms. The thermal absorptivity of cotton and PES fabrics decreased gradually due to the copper treatment. 15% copper treated PES fabric had the lowest thermal absorptivity. It is found that the copper treatment and washing of fabrics had a critical affect on the amount of thermal absorptivity of the tested fabrics.

3.3. Thermal conductivity of woven fabrics in dry and wet state

The thermal conductivity basically gives the amount of heat, which passes from 1 m^2 area of tested structure through the distance 1 m within 1 s and create the temperature difference 1 K. The thermal conductivity can be calculated by using the following expression, [9, 10]

$\lambda = Q/ F\tau \times \Delta T/\sigma$ in $Wm^{-1} K^{-1}$ Eq. (3)

where:
Q = amount of conducted heat,
F = area through which the heat is conducted,
τ = time of heat conducting
ΔT = drop of temperature,
σ = fabric thickness

The thermal conductivity results are presented in Table 3. The cotton fabrics had significantly higher thermal conductivity in their dry and wet states as compared to the PES fabrics. The thermal conductivity of the fabrics ranged from 30.9 to 38.2W/mK$\times 10^{-3}$ in the dry state and 45.1 to 70.1 W/mK$\times 10^{-3}$ in the wet state. The wetting and retesting after 4 minutes increased the fabric's thermal conductivity substantially due to excess amount of water content on the fabric surface.

The thermal conductivity of the fabrics was influenced in varied ways when treated with copper solutions and in the most cases; the copper treatment increased the thermal conductivity of the fabrics. The untreated cotton fabric had a slightly higher thermal conductivity in comparison with the untreated PES fabric. There are three fundamental ways by which heat energy can be transferred through the porous materials such as nonwoven fabrics conduction, convection, and radiation. Depending on the fiber's specific thermal conductivities, the size and configuration of the space between the fibers in the fabrics, heat transfer mechanisms - conductive, radiative, and convective – will provide very different contributions to the overall heat transfer throughout the specimens. Very complex interactions and contributions of various heat transfer mechanisms in the overall thermal properties of textile fabrics make the direct instrumental measurement of the thermal conductivity [11].

3.4. Water vapor permeability and resistance to evaporative heat loss (Permetest)

The Water Vapour Permeability (WVP) depends on the water vapor resistance which indicates the amount of resistance against the transport of water through the fabric structure. The amount of fluid present in a structure (which has critical importance in the degree of comfort and absorbency for wound dressing) must to be a minimum. The relative WVP is expressed using the following formula.

WVR = $Q_s\,(Wm^{-2}) / Q_0\,(Wm^{-2}) \times 100$ in % Eq. (4)
where;
Q_s = the heat flow with the fabric specimen
Q_0 = the heat flow without the fabric specimen

The WVP and resistance to evaporative heat loss results are given in Table 2. According to the test results there is difference between cotton and PES fabrics. The PES fabrics had lower WVP as compared to the cotton fabrics. The treatment reduces the WVP of the fabrics significantly. The effect of the treatment on the cotton fabrics was found to be higher than the PES fabrics. It could be due to relatively higher absorbency of the cotton fibers in comparison with PES fibers. The resistance to evaporative heat loss results is shown in Table 3, in most of the cases, the PES fabrics had higher value than cotton fabrics. It has been observed that the tested parameters of the fabrics were increased significantly after the treatment.

4. Conclusions

The results clearly demonstrated that the cotton and polyester fabrics were successfully treated with the copper sulphate solutions and the treated fabrics showed significant changes compared to their untreated forms. The fabric's thermal conductivities and thermal resistances were increased considerably after the treatment. It was also observed that the conductivity of the fabrics increased gradually. Furthermore, the treated fabrics had lower thermal absorptivity values as compared to untreated fabrics. The treated fabrics showed noticeably lower water vapour permeability compared to the untreated fabrics. According to the Permetest results, the differences between the untreated and the treated fabrics are significant. The treated fabrics had reduced water vapour permeability for both cotton and PES fabrics. Heat loss increased when the fabrics treated with the copper solution and the PES fabrics had greater heat loss values than the cotton fabrics.

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