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Comfort and Thermo Physiological Characteristics of Multilayered Fabrics for Medical Textiles

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ABSTRACT

Multilayered fabrics consist of different layers of the fabrics which have the ability to complement and maximize the essential comfort properties for a bed linen. Presence of more number of layers can reduce pressure, temperature, shear and friction developed on body and also enhance the moisture absorbency and moisture vapor transport property. Few hospitals are providing uncomfortable tough mattress, covered by water proof coated fabric cover, over which simple single layered cotton bedspread is being used, which makes the patient highly uncomfortable due the strain on the contact areas and excessive heat generated. Excess compression in the contact area damages the blood vessels, leading to bedsores of different degrees with unbearable pain. In this research work an effort has been made to produce a pressure reliving mattress and bed sheet, a pressure relieving support surface was developed with super soft polyurethane foam, with horizontal and vertical drill holes connected to an air circulation device to give enough air circulation and pressure distribution to more area. Single layered and multi layered bed sheets have developed using fibers like lyocel, cotton, polypropylene and micro polyester fibers in different fabric structures. The comfort properties such as air permeability, water absorbency, wicking, water vapor permeability and thermal conductivity of multilayered fabrics have tested and their test results are discussed. The comfort properties of multilayered bed mattress with selected combination of fabrics have been studied with and without air circulation system for improving the pressure and temperature of the patient have been reported.

Keywords: Lyocel, pressure ulcer, multilayered bed linen, pressure distribution, comfort properties.

1. INTRODUCTION

Medical textiles stand in sixth position among technical textiles. India's market for medical textiles grows 10-12%, making it one of the fastest growing sectors in the country. However, it is currently only worth about US$ 500 million, insignificant compared with the global market of US$ 8.2 billion. The per capita spending on healthcare has gone up in India and is hovering around four per cent of the GDP and good sign of medical textile industry. There is a wide scope for a large scale research and development in the field of medical textiles to make the shift from low value to high value products such as functional bed Linens, wound dressings, scaffolds for tissue engineering, sanitary products, medical linens and gowns. The hospital bed sheets are functional textiles which are expected to fulfill the comfort properties such as air, thermal and moisture management. The thermal property like thermal conductivity, air transport property like air permeability and moisture properties such as wettability, wick ability, and water spreading. The commercially available bed sheets are produced from plain woven cotton, polyester fibres and their blends. The moisture absorbency and heat transportation of these plain woven fabrics is not so good for patient sleeping in long time, hence the body fluids and body heat are not absorbed and transmitted quickly and thus it makes a moist laden atmosphere which is heaven for growth of microorganisms like bacteria, fungus and virus. Hence the high frictional and the poor absorbent plain woven cotton bed sheets are the main problem for frictional festers and pressure ulcer to patients.

Various research works have been carried out to analyze the functional properties of multilayered textile fabrics. The heat and water transport through these fabrics were analyzed their properties like heat conductivity, vapor diffusivity, air permeability simulated a mathematical model to determine heat and water transfer through multilayered fabrics [1, 2]. When liquid water contacted a fabric, such as in the case of sweating, the surface wettability of fabric played a dominant role in determining the water vapor transport rate through layered fabrics. The wicking characteristics, which determines how quickly and how widely liquid water spreads laterally on the surface or within the matrix of the fabric, determines the overall water vapor transport rate through the layered fabrics [3-5]. An experimental apparatus to permit simultaneous measurement of temperature change and moisture flux through multilayered fabrics during the transient period after one set of fabrics has been exposed to humidity and temperature gradients for study the moisture transport in textiles for the first time and analyzed water transport properties in a layered composite [6-8]. The heat and moisture transfer through clothing assemblies consisting of porous fibrous battings sandwiched by inner and outer layers of thin covering fabric and found that the water content accumulates with time and water content is higher at the outer regions than at the inner regions of battings [9]. The moisture transport that vapor diffusion is the major mechanism of moisture transport between two layers of fabrics at low moisture levels for all fabrics. Wicking did not begin until the moisture content was high, more than 30% above regain for the woven samples [10, 11]. In an attempt has been taken to overcome the problems faced by the bedridden patients and people confined to multilayered bed linens using different varieties of fabric engineered with the necessary comfort characteristics like thermal conductivity, air permeability and moisture management properties.

2. MATERIALS AND METHODS

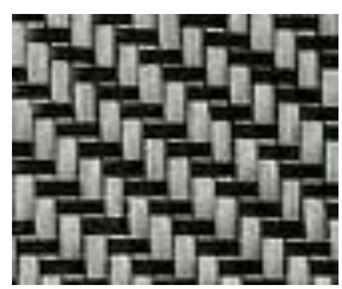
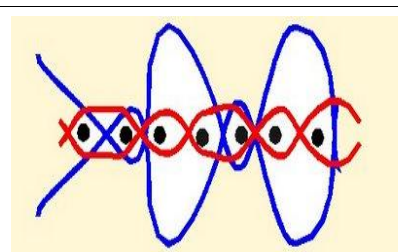
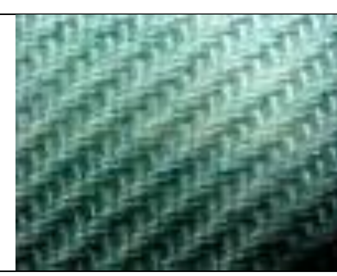
In this research work, the fabrication of bed sheets with multilayered textile fabrics was designed with fibers like lyocel, micro polyester, polypropylene and cotton, selected to suit different climatic conditions and fabrics produced with the weave structures like 2/2 twill, terry with 3-pile, knitted fleece, single jersey and plaited knitted structures which are expected to provide a soft and flexible support to skin surface. Lyocel fiber is selected for the multilayered textile fabrics with different fabric structures, because of its good breath ability, moisture absorption, dry and cool micro climate on the skin, smooth fibre surface, low wet cling effect and no electrostatic charging. Ultimately it might offer relief to people who suffer from skin diseases. The micro polyester is preferred because of its improved moisture management property like wicking and moisture vapor transmission. Different combinations of fabric layers were prepared based on their ability to complement and maximize the essential comfort properties for a bed linen. Considering the moisture management property as the key factor various woven and knitted fabric combinations were analyzed and the various combinations of fabric layers were selected to enhance the comfort properties of the bed sheets. The yarn and fabric parameters and various weave structures are given in Table 1 and 2 respectively.

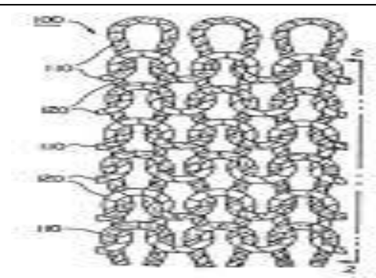
TABLE 1. YARN AND FABRIC PARAMETERS – MULTILAYERED FABRICS

Sample code	Fabric type	Yarn count (Ne)	Fabric structure	Ends /cm	Picks /cm	Fabric weight (g/m^2)	Fabric cover factor	Fabric thickness (mm)
A	100% Lyocel	30/2	Terry 3-Pile	24	18	240±5	24.28	0.31±0.12
B	100% Cotton	30/2	Terry 3-pile	24	18	248±5	23.98	0.42±0.12
C	100% Lyocel	30/2	2/2 Twill	30	22	150±8	21.58	0.135±0.10
D	100% Micro- polyester	32/2	2/2 Twill	30	22	140±8	21.46	0.14±0.10
E	100% Cotton	30	Single jersey	$20^{\#}$	25^{*}	150±8	$16.42^{\#\#}$	0.15±0.10
F	Cotton/Polypropylene plaited fabric	30	Single jersey	$18^{\#}$	17^{*}	220±8	$16.73^{\#\#}$	0.2±0.10
G	Cotton/polyester blend	30	Fleece	$20^{\#}$	20^{*}	400±8	$15.40^{\#\#}$	0.4±0.15

Note: # - wales per inch; *- course per inch; ## - tightness factor

TABLE 2. MULTILAYERED FABRIC PARAMETERS – WEAVES AND STRUCTURES

Materials	Fabric structure	Fabric appearance
2/2 Twill weave		
Terry with 3 pile		

Single jersey knit fabric		
Knitted fleece		
Plaited knit		

3. TESTING PROCEDURE

3.1 Physical properties of fabrics

The fabrics made out of woven structures were measured their fabric sett, warp and weft yarn linear density, fabric weight per unit area and fabric thickness. Fabric sett was measured using the counting glass according to ASTM D3775-03 standard. Yarn linear density and fabric weight per unit area determined according to ASTM D1059 standard. The thickness of a textile material is measured as per the ASTM D1777-96(2002) Standard test method for thickness of textile materials. The thickness of the fabric is measured by Essdiel Thickness tester at a pressure of 20 gf/cm^2 with an accuracy of 0.01 mm. An average of 20 readings was taken for each sample in case of each test. Standard atmospheric conditions of 65^0±2^{0}C and 21^{0}C±2^{0}C have been maintained for all experiments. The fabric parameters have been mentioned in Table 1.

3.2 Air permeability

Air permeability of the multilayered fabrics were measured using Air permeometer at an air pressure of 100 Pa using ASTM D737 test standard. An average of 20 readings for each sample was measured.

3.3 Thermal conductivity

Thermal conductivity (K) is intensive property of the material that indicates its ability to conduct heat. It is defined as the quantity of heat, Q, transmitted through a thickness L, in a direction normal to a surface of area A; due to temperature difference ΔT, under steady state conditions and when heat transfer is dependent only on the temperature gradient.

Thermal Conductivity = heat flow rate x distance / (area x temperature difference)

$$K = QxL/(Ax\Delta T) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

3.3.1 Determination of Thermal Conductivity

The Figure 1 represents the simple form of Lee's Disc which has used for determining the thermal conductivity of Jute/Cotton blended knitted fabric. The knitted fabric sample (D) is placed in between a brass base (B) and a brass disc (C), the whole arrangement is suspended by means of strings attached to hooks in brass disc (C). The T_1 and T_2 thermometers are inserted into the holes in B and C to record the temperature.

A steam is admitted into the chamber (A). The heat conducted through the sample (D) is imparted to the brass disc (C) which raises the temperature gradually and finally attains a steady temperature $T_2{}^0$C. When steady state is reached the heat conducted by the disc (C) by conduction through the fabric sample is just lost by radiation from the surface of the disc. Temperatures of brass disc (C) and (B) are noted at intervals of 5 minutes. When the temperature indicated by T_1 and T_2 remains steady it means the whole arrangement has reached the steady state. Now the temperature T_1 and T_2 are noted.

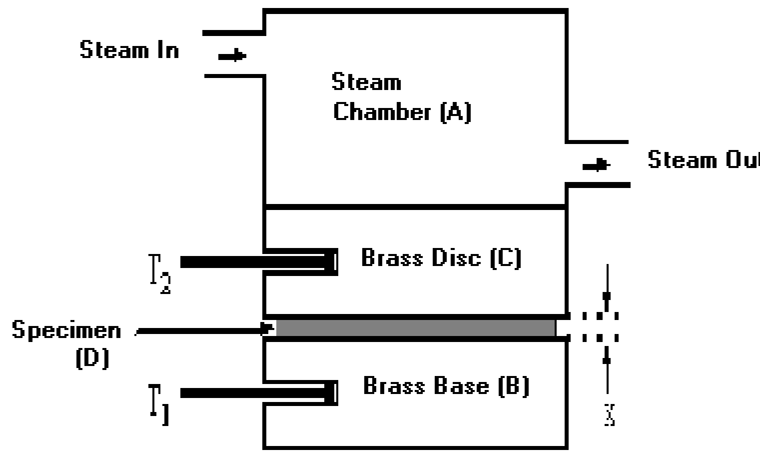


FIGURE 1. LEE'S DISC

To find the rate at which heat is radiated by the brass disc (C), it is brought directly into contact with the steam chamber after removing the sample (D) and its temperature is allowed to rise about 10^0C above the steady temperature $T_2{}^0$C. The brass disc (C) is removed and then suspended from a stand with a stop clock the time is recorded for every one degree fall of temperature as it cools from $(T_2+5)^0$C to $(T_2-5)^0$C (ie. 82.5 to 72.5^0C) when the steady temperature is (say 77.5^0C). If 't' is the time (in sec) taken by the disc to cool from $(T_2+1)^0$C to $(T_2-1)^0$C, then the rate of fall of temperature of the brass disc at the mean temperature T^0C is equal to 2/t deg/sec.

Similar calculations are made with the other readings and average value of the fall of temperature R at $T_2{}^0$C is found. The thermal conductivity of Jute/ Cotton blended knitted fabric is determined by using following formula:

Heat conducted by the Specimen = $\left\{ \frac{KA(T_1 - T_2)}{d} \right\}$ ………….. (2)

Heat lost by the disc = $MSR(2h + r)/(2h + 2r)$ ……………..… (3)

At the steady state

$$KA(T1 - T2)/d = MSR(2h + r)/(2h + 2r) \ldots\ldots\ldots (4)$$

$$K = \left[MSRd(2h+r) \right] \Big/ \left[A(T_1 - T_2)(2h+2r) \right] \ldots\ldots(5)$$

Where

K = Thermal conductivity of sample (x 10-3 $WM^{-1}K^{-1}$)
M = Mass of brass disc (C) in kgs
S = Specific heat of the material of the disc (370 JKg^{-1} K^{-1})
R = Rate of fall of temperature (dT/dt)
h = Thickness of brass disc in mm
r = Radius of the brass disc in mm
d = Thickness of the specimen in mm
A = Area of cross section of the specimen in mm^2

3.4 In- plane wicking test

In-plane wicking or transverse wicking is the transmission of water through the thickness of a fabric that is perpendicular to the plane of the fabric. It is perhaps of more importance than longitudinal wicking because the mechanism of removal of liquid perspiration from the skin involves its movement through the fabric thickness. Transverse wicking is more difficult to measure than longitudinal wicking as the distances involved are very small and hence the time taken to traverse the thickness of the fabric is short. One test is the plate test which consists of a horizontal sintered glass plate kept moist by a water supply whose height can be adjusted so as to keep the water level precisely at the upper surface of the plate. A fabric placed on top of this glass plate as shown in Figure 2 can then draw water from the glass plate at a rate which depends on its wicking power. It is important that the water level is adjusted to touch the underside of the fabric but not to flood it. In plane wicking behavior of the fabric has been determined by measuring the initial wicking rate (g/min). The fabric sample 10 cm x 10 cm is placed on a horizontal porous base plate, which is placed over a reservoir filled with water. The fabric sample is covered by a cover plate so as to ensure intimate contact with the liquid in the reservoir. Water level in the reservoir and the fabric level is kept same.

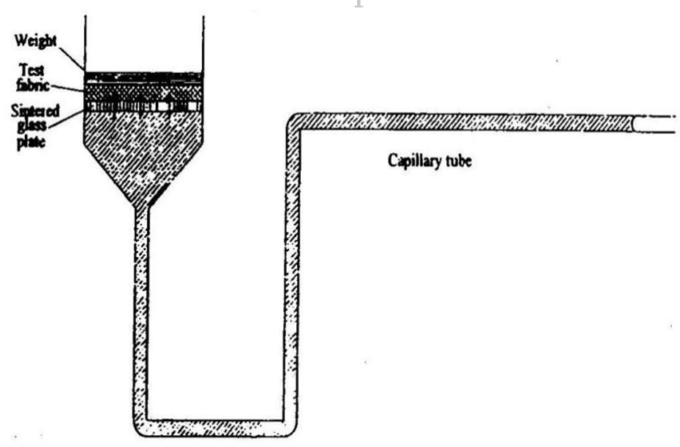


FIGURE 2. ILLUSTRATION OF IN-PLANE WICKING TESTER

3.5 Water absorbency by drop test

Ability of the fabric to absorb moisture is measured by the time taken to absorb a drop of water on the fabric surface and the spreading diameter as per standard test method.

3.6 Compressibility

To evaluate the compression set, we used the test method ISO 1856. Specimens are compressed to 50% of their original thickness for 22 hours at 70°C. Compression set (%) is then specified as 100x $(d_0 - d_1)/d_0$ where d_0 is the original thickness and d_1 is the thickness after the test compression.

4. RESULTS AND DISCUSSIONS

The air permeability, thermal conductivity, water absorbency, water spreading rate, water vapor permeability and wicking characteristics of multilayered fabrics have been tested and reported.

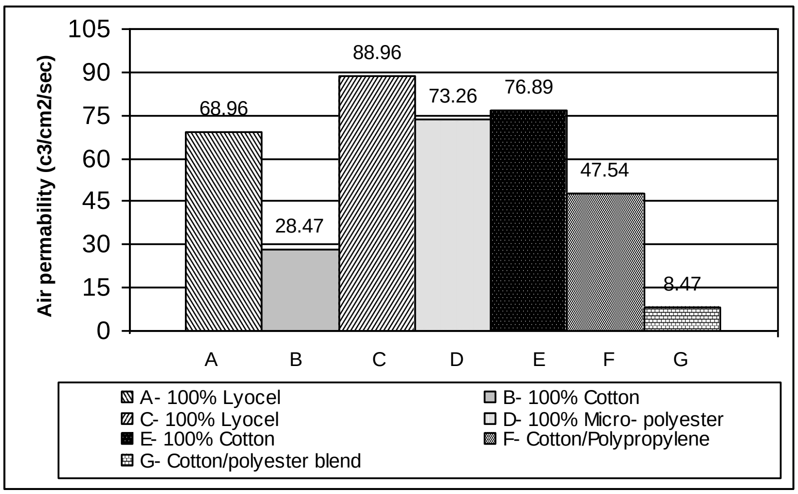


FIGURE 3. AIR PERMEABILITY BEHAVIOR OF MULTILAYERED FABRICS

4.1 Air Permeability

The air permeability behavior of multilayered textile fabrics is shown in Figure 3. The air permeability of the fabrics depends on the fiber type, type yarn, ends per inch, picks per inch, fabric thickness and fabric cover factor. From Figure 3, it is observed that the lyocel made multilayered fabric both pile and twill structure fabrics are having higher air permeability behavior when compared to cotton and micro-polyester fabrics of similar characteristics. In case of knitted fabrics made out of cotton is having higher air permeability when compared to cotton/polypropylene plaited structure of similar structures, it may be due to compactness of the polypropylene presence of plaited structure and volumetric nature. Fleece structure of cotton/polyester blended knitted fabric has the minimum air permeability which may be attributed to the compact structure of fabric and having higher polyester content and hence lesser number of pores of lower cross sectional area available for air passage. Since the cotton terry and fleece fabrics are closely woven with more cover factor, air permeability is reduced and the above two combinations could be used for cold climatic conditions.

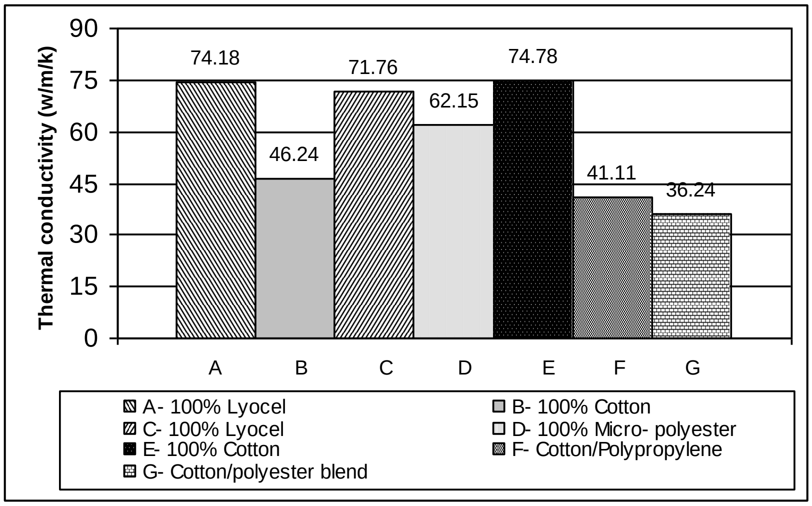


FIGURE 4. THERMAL CONDUCTIVITY BEHAVIOR OF MULTILAYERED FABRICS

4.2 Thermal conductivity

Thermal properties of textile materials especially thermal conductivity have always been the major concern when the comfort properties of clothing are concerned. The thermal conductivity is a measure of amount of heat transferred through fabric and it takes place through air pore, interlaced regions of warp and weft, and through unsupported warp and weft yarns of the fabric. It is noticed that Lyocel fabrics both twill and pile structures has very good thermal conductivity when compared to similar construction of fabrics made out of cotton and micro-polyester fabrics which is shown in Figure 4. It may be due to the lyocel fiber of their behavior of its soft and smooth surface. This shows that these two combinations can conduct away the heat from the body easily and keeps the patient cool. The polypropylene/cotton and fleece terry combinations are showed lower thermal conductivity. This may be attributed to the greater thickness of fabric having higher polyester content and cover of the fabric. Fabric thickness is the most important factor governing the thermal insulation. Other factors affecting the thermal insulation are fiber type, bulk density, and fiber arrangement. This character seems to be applicable to bed sore preventive fabrics. The other two combinations with cotton/polypropylene- and fleece knitted fabrics may be recommended for winter because of its higher thermal values.

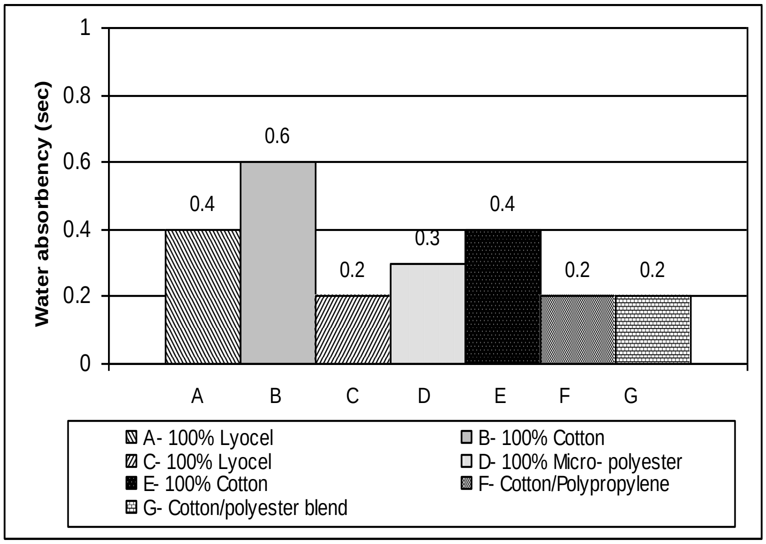


FIGURE 5. WATER ABSORBENCY BEHAVIOR OF MULTILAYERED FABRICS

4.3 Water Absorbency

From Figure 5, the lyocel twill and lyocel pile fabrics have noticed excellent absorbing tendency owing to the higher moisture content of these fibers. There is a strong polar attraction between lyocel and water. Its higher water retention than the liquid holding capacity may be due to the strong hydrophilic attraction between water and fibers and water retention in the fibrillar spaces of the fibers. All the four combinations except knitted fleece exhibits very good water absorbency resulting in immediate transfer of moisture to inner layers and gives a dry feel. This property is essential to keep the patient dry and avoids problem created due to wet skin.

4.4 Water spreading behavior

The water spreading behavior shows the extent to which a water drop spreads on the fabric; it is an indicator of its drying rate. From Figure 6, lyocel fabrics both pile and twill structures (sample A and C) have noticed immediately spreads the drop to maximum extent due to the better water absorbency of lyocel fibers and proves its water management ability. The cotton and cotton/polypropylene blended knitted fabrics have noticed better water spreading (sample E and F), it is mainly due to knit structure and hydrophilic nature of cellulose fiber. Lyocel pile, lyocel twill woven and lyocel pile, micro-polyester combinations are also very good in water management.

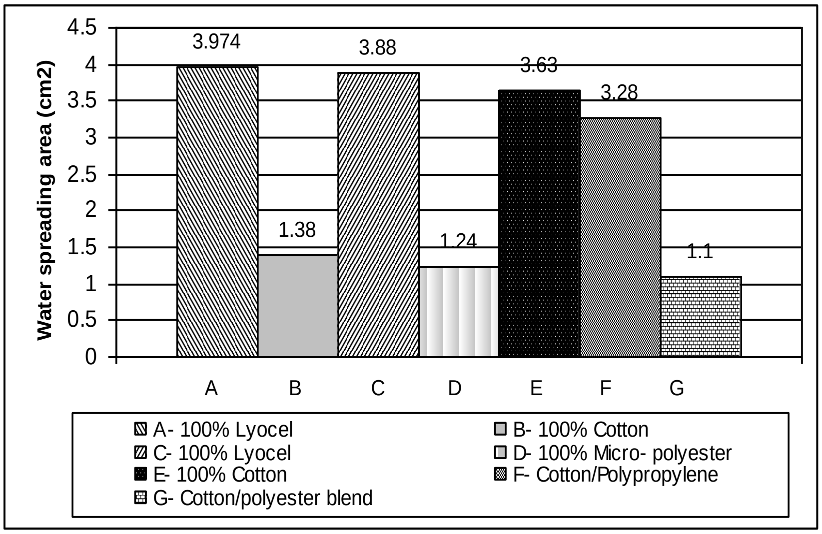


FIGURE 6. WATER SPREADING BEHAVIOR OF MULTILAYERED FABRICS

4.5 Water vapor permeability

Moisture vapor transfer is the ability of the fabric to transfer the perspiration in the form of moisture vapor through it. It is a measured in terms of amount of water vapor passing through a square meter of fabric per day. A fabric with low moisture vapor transfer is unable to transfer sufficient moisture, leading to sweat accumulation and hence discomfort.

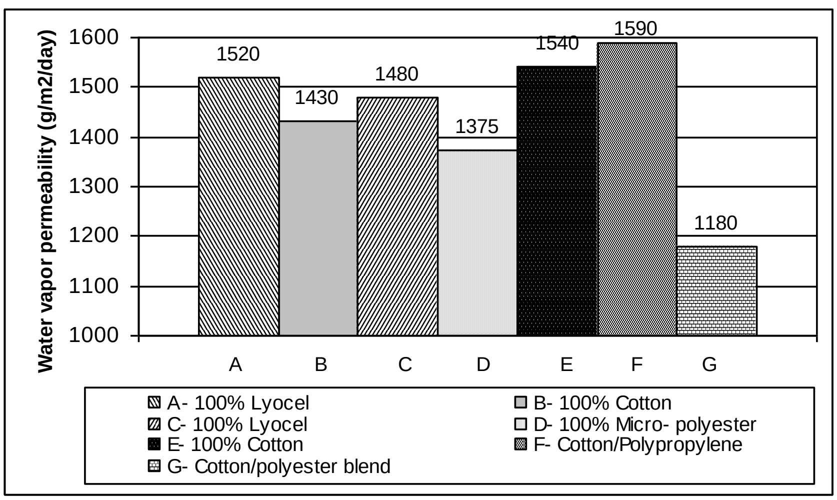


FIGURE 7. WATER VAPOR PERMEABILITY OF MULTILAYERED FABRICS

The water vapor permeability of multilayered fabrics is shown in Figure 7. The highest water vapor permeability is noticed in case of cotton/polypropylene plaited knitted fabrics and cotton knitted fabrics, it may be due to the knit structure permeates better air and thermal permeability nature when compared to other fabrics of woven structures. Secondly the lyocel made pile and twill fabrics have noticed higher water vapor permeability when compared to cotton and micro-polyester fabrics of similar structures. It may be due to hydrophilic and better air permeability nature of fabric and lyocel fibers. Again the fleece fabric shows lesser water vapor permeability owing to the reason that moisture vapor transfer of the fabric decreases with the increase in fiber content and fabric thickness of the fabric.

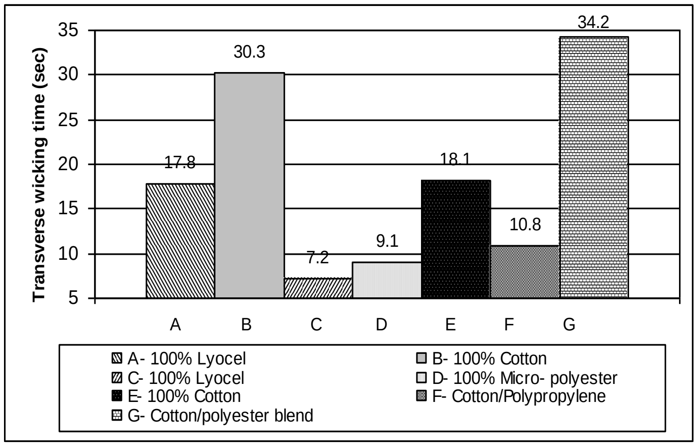


FIGURE 8. TRANSVERSE WICKING RATE OF MULTILAYERED FABRICS

4.6 Wickability - Transverse Wicking

Transverse wicking indicates the ability of the fabric to wick away the sweat developed on the skin of the bo
micro-polyester are having higher traverse wicking rate when compared to other fabrics, it may be due to lower fabric thickness and smooth surface of the fibers. It is noticed that fleece knitted cotton/polyester knitted fabrics and cotton pile structure fabrics are lower transverse wicking. The cotton/polypropylene plaited knitted fabrics are also having better transverse wicking; it may be due to polypropylene fiber presents in the fabrics which have lower moisture regain and water holding capacity.

4.7 DESIGN OF BED WITH MULTILAYERED FABRICS

An analysis of all the test results ensures that the Lyocel woven and Lyocel

terry combination proves to be an excellent combination for bed sore prevention in all aspects like air permeability, thermal conductivity, water vapor and moisture management followed by the micro polyester, polypropylene. From the test results, the best combination of fabrics for bed sheet and mattress in bed sore prevention is designed with following specification which is shown in Figure 9,

- Lyocell woven twill top layer
- Lyocell pile middle (two layers) : Middle layer
- Polyurethane foam (with air circulation system) : Bottom layer
- Recron fibers fill (quilting with knitted fabric) with air circulation system acts as a suitable pillow.

FIGURE 9. ILLUSTRATION OF MULTILAYERED BED WITH AIR CIRCULATION MEASURING KID

4.7.1 Pressure

Pressure exerted by the mattress on the body parts is measured to learn about the pressure on the blood vessels. The patient is made to lie-down over the mattress. Weight of various body parts are measured using electronic weighing machine. Areas of various body parts in contact with the body are calculated. The pressure experienced by each body part is then calculated which is given in Table 3.

TABLE 3. BODY PRESSURE AND AREA CONTACT FOR BED SHORE BED DESIGN

S.No	Body part	Mass (Kg)	Area (cm^2)	Pressure (g/cm^2)
1	Head	4.5	75	600
2	Shoulder	15.1	879	171.78
3	Stomach	20.7	1189	174.09
4	Leg	10.9	434	165.29
5	Foot	7.2	34	941.17

When the pressure on any body part of the body increases beyond 33 mm mercury level, blood circulation is arrested which leads to bed sore development. To avoid excessive pressure area of contact of the body with the bed has to be increased. This objective is achieved by developing a super soft polyurethane bed or recron filled bed with the required thickness with the criteria that the bed should not compress more than half of its original thickness. The more area of contact by the soft bed is also complemented by using knitted fabric in the top layer. The knitted fabric ensures good elongation, confirmation to body contour and reduced shear on the body.

4.7.2 Temperature

Temperature of the body parts while in contact with bed is measured and compared with the temperature of the body while lying on the newly designed air circulation mattress and multilayered bed linen is measured. The normal body temperature is noted initially. After one hour temperature is measured on the body and also beneath the first layer of fabric with and without air circulation system for all the combinations of fabrics which is shown in Figure 10.

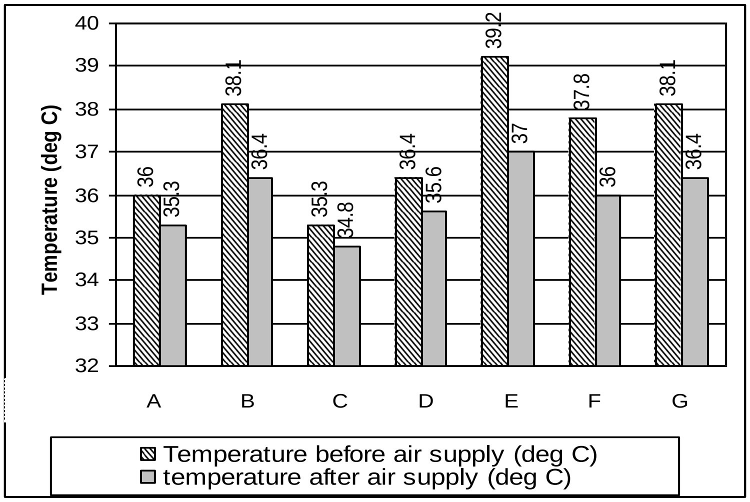


FIGURE 10. TEMPERATURE OF BED WITH AND WITHOUT AIR SUPPLY

When a patient lies for a long duration on the bed, unbearable heat is generated. This excessive heat creates restlessness to patients. The raise in temperature is measured on the patient's body while lying on normal hospital bed and on the new bed developed with different combination of fabric. Temperature is also measured with and without air circulation system. The result shows that there is a considerable reduction in the raise in temperature when compared to normal hospital bed .With air circulation system, the reduction in temperature confirms the efficiency of the mattress in preventing bed sores.

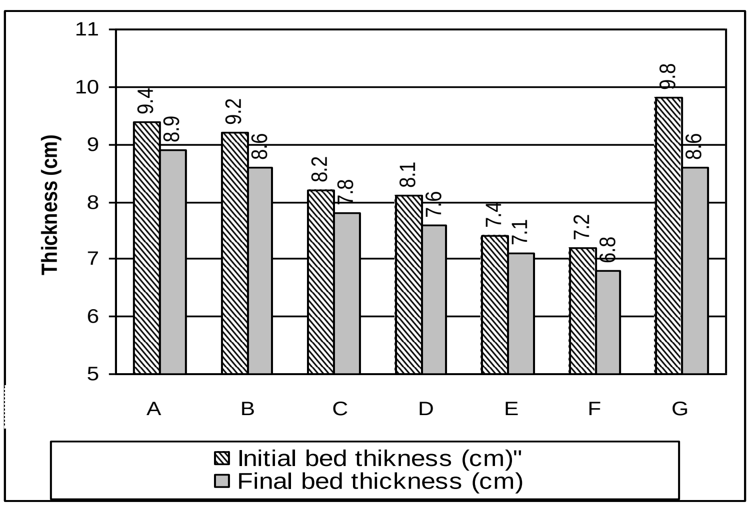


FIGURE 11. COMPRESSIBILITY OF MULTILAYERED BED

4.7.3 Compressibility

The compression test indicates the thickness of multilayered fabrics after applying load for a particular duration. Lyocell pile, Lyocell woven and Lyocell pile, micro denier polyester combination seems to compress less and regain its original thickness when unloaded. This is a favorable property for bed sore preventing fabrics which is shown in Figure 11.

5. CONCLUSIONS AND FURTHER PROSPECTIVE SCOPE

A multilayered mattress is designed for bed sore prevention with different combination of fabric layers and a bed with air circulation system and tested for the comfort properties. An analysis of all the test results ensures that the Lyocell fabrics both pile and twill structure proves to be an excellent combination for bed sore prevention in all aspects like air permeability, thermal conductivity, Moisture vapor management. Lyocel pile, cotton/polyester knitted fleece and cotton/polypropylene plaited knitted fabrics can be used for cold climatic conditions. The thermal conductivity for Lyocell fabrics of pile and twill combination have noticed higher followed by micro polyester and fleece fabrics. So this character seems to be very much applicable to bed sore fabrics which are expected to keep the patient cool. Lyocell pile fabrics have very good water absorbency which immediately absorbs and transfers the moisture to inner layer and gives a dry feel. The compression test indicates the thickness of fabric after applying load for a particular duration. Lyocell pile ad twill fabrics, micro denier polyester combination seems to compress less and regain its original thickness when unloaded. With air circulation system, the reduction in temperature confirms the efficiency of the mattress in preventing bed sores. From this research work, it provides pave for development of bed sore mattress and healthcare for patients and further research is required to study the various regenerated cellulosic and protein fibers with various weave and design of mattress to analyze the comfort properties of bed sore diseases. The same concept of multi layered fabric with super soft polyurethane foam mattress attached with air circulation system may be extended to design a wheel chair cushion, wheelchair cover, arm crutch pad, heel pads, Elbow pads, and medical shoes for healthcare textiles.

REFERENCES

[1] Fohr J P, Couton D & Treguier G, (2002). Dynamic heat and water transfer through layered fabrics, Textile Research Journal, 72(1), 1-12.

[2] Yasuda T & Miyama M, (1992). Dynamic water vapor and heat transfer through layered fabrics, Part II: Effect of the chemical nature of the fibers, Textile Research Journal, 62(4), 227-235.

[3] Wang J H & Yasuda, (1991). Dynamic water vapor transport through layered fabrics, Part I: Effect of surface modification", Textile Research Journal, 61(1), 10-20.

[4] Markus Weder et al, (2004). Neutron radiography measurements of moisture distribution in multilayer clothing systems" Textile Research Journal, 74(8), 695-700.

[5] Jintu Fan & Xiao-yin cheng, (2005). Heat and moisture transfer with sorption and phase change through clothing assemblies, Part I: Experimental Investigation, Textile Research Journal, 75(2), 99-105.

[6] Martha Molly Adler & William K.Walsh, (1984). Mechanism of Transient moisture Transport between fabrics, Textile Research Journal, 76(1), 334-432.

[7] Choi M & Ashdown S, (2000). Effect of Changes in Knit Structure and Density on the Mechanical and Hand Properties of Weft Knitted Fabrics for Outerwear, Text Res J, 70(12), 1033-1045.

[8] Mohammad M, Banks-Lee P & Ghadimi P, (2003). Determining Effective Thermal Conductivity of Multilayered Nonwoven fabrics, Textile Research Journal, 73(9), 802-808.

[9] Jirsak O, Gok T, Ozipek B & Pan N, (2000). Thermo-insulating Properties of Perpendicular-laid

versus cross-laid Lofty Nonwoven fabrics, Textile Research Journal, 70, 121-128.
[10] Debarati Bhattacharjee & Vijay K Kothari, (2007). A Neural Network System for Prediction of Thermal Resistance of Textile Fabrics, Textile Research Journal, 77(1), 4-12.
[11] Kawakawa S & Rengasamy R S, (2002). Thermal Conductivity of unidirectional fibers composites made from yarns and computation o f thermal conductivity of yarns, Indian J Fibre Text Res, 27, 217-223.