THE FUNCTIONAL PROPERTIES OF TENCEL® - A CURRENT UPDATE

Heinrich Firgo[a], K. Christian Schuster[a*], Friedrich Suchomel[a], Johann Männer[a], Tom Burrow[a], Mohammad Abu-Rous[b]

[a] Textile Innovation, Lenzing AG, Austria
[b] Christian Doppler-Laboratory / Chemistry Cellulosic Fibers and Textiles, Institute of Textile Chemistry and Textile Physics of Leopold-Franzens-University Innsbruck, Austria
[*] Corresponding Author: c.schuster@lenzing.com, tel.:+43 -7672 - 701 - 3081

For many years the textile world was very simple when it came to the function of textiles: hydrophilic natural fibers like cotton and wool and the man made cellulosic fibers stood for absorbency and breathability and the synthetic fibers stood for strength and easy care.

With increasing use of the term "functional textile", the situation has become more complex. The synthetic fiber industry has been developing new products and marketing approaches claiming enhanced "physiological function in textiles" for sportswear and other fields. Consumers have accepted these arguments and there is a general belief that synthetic fibers are the product of choice for active sportswear, even where the hydrophilic fibers may be superior.

In order to redress the situation, Lenzing AG as a leading producer of cellulosic fibers [1][2] decided that a deeper insight into the "inherent physiological properties and functions" of hydrophilic fibers was needed. A research program was started to look at the inherent properties of fibers using new methods and approaches. The objective was to produce the evidence needed to make our customers aware of the excellent "inherent functionality" of Lenzing's cellulosic fibers and that in many cases there is no need to use highly sophisticated functional synthetic fibers and finishes to achieve a "functional textile".

There are two ways of developing the physiological functions of a textile product. Properties can be modified or enhanced by work on the fabric development level and/or fibers can be used which offer physiological functions on the fiber level. The best products will result from a combination of the two approaches. However this paper does not consider specific textile product development possibilities; it presents statements of the "inherent physiological fiber properties" of Lenzing's hydrophilic fibers. For each physiological function that is described, evidence is presented.

To help understand the origins of the "inherent physiological functions" of textile fibers it can be postulated that:

1. When hygroscopic or hydrophilic fibers come into contact with water, they absorb it **into** the fiber structure.
2. Cellulosic fiber type A will not handle/absorb water in the same way as cellulose fiber type B. There are significant differences between different types of cellulosic fibers.
3. Cellulosic fiber plus water gives inherent physiological functions. It is only the combination of cellulose with water that gives interesting physiological properties.
4. TENCEL® plus water gives enhanced physiological properties
5. Hydrophobic synthetic fibers do not absorb water **into** the fiber structure, they can only adsorb water **onto** the fiber surface.
6. Therefore the combination of synthetic fibers with water normally will not result in added physiological properties (or only to a very low extent).

To demonstrate the difference between cellulosic fibers and synthetic fibers, samples of fiber were placed in the specimen chamber of an environmental scanning electron microscope. The atmosphere surrounding the fibers was saturated with water.
Figure 1 shows the result [3]. The fiber on the left is polyester; the fiber on the right is a TENCEL® fiber.

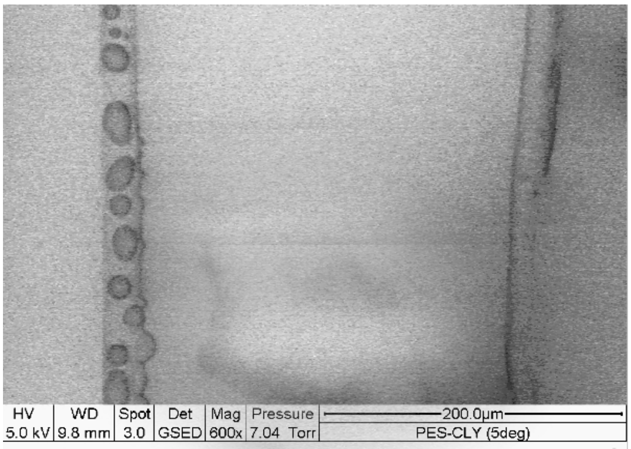


Figure 1: Polyester (left) and TENCEL® fibers (right) in water vapor atmosphere in environmental SEM.

Water droplets have condensed on the surface of the polyester fiber. The TENCEL® fiber does not show any water on the surface. This is the major difference between synthetic fibers and cellulosic fibers. Synthetic fibers such as polyester are non-absorbing, non-hygroscopic and therefore not breathable. They will only adsorb water on the fiber surface. Cellulosic fibers like TENCEL® are hygroscopic, water absorbing and breathable. Water is absorbed into the fiber structure.

The ability to absorb water into the fiber structure is a common feature of all cellulosic fibers and is the basis of some very important physiological properties. All cellulosic fibers show the following eight physiological properties to a certain extent:

- High absorbency
- Warm and dry (as an insulation layer)
- High heat capacity
- Cool and dry to the touch
- Can actively reduce temperature
- Neutral electric properties
- Strongly retards bacterial growth
- Gentle to the skin

TENCEL® has a very high absorption capability, a unique nano-fibril structure and a very smooth surface. As a result, all these physiological functions are much more pronounced for TENCEL® than for other cellulosic fibers. The inherent physiological properties depend on the amount of water which is absorbed and how it is distributed within the swollen fiber structure.

Absorbency of cellulosic fibers

Transmission electron microscopy can be used to show the location of water in a fiber. For imaging, water-containing pores are filled and stained with a contrasting substance. The water-containing pores show up black, but the cellulose without stain shows up white.
Figure 2 shows the cross-sections of four water swollen cellulosic fibers [4]. Cotton absorbs much less water than TENCEL®, Modal or Viscose. The crystalline skin of Modal contains less water than the core. The water distribution of TENCEL® is very uniform over the whole fiber cross section. Modal and Viscose have a rather coarse pore system with a wide range of pore size distribution from nanometer to micrometer size dimensions The voids in TENCEL® (Lyocell) are very small and quite uniform, in the nanometer range. Latest findings on Lyocell (TENCEL®) fiber structure are reported in [4]-[6].

At a higher magnification using transmission electron microscopy, it can be seen that the pore structure of TENCEL® is a true nano-structure. This is unique amongst the man made cellulosic fibers. TENCEL® consists of countless, very hydrophilic, crystalline nano-fibrils, which are arranged in a very regular manner. The fibrils themselves do not absorb water; water absorption only takes place in the capillaries between the fibrils.

A single TENCEL® fiber, therefore, will behave like an ideally wetting bundle of nano-fibrils with pores in nanometer range in between [4][5][6], something which does not exist in the synthetic fiber world. This is the reason for the excellent water management and the very good comfort in wear of textiles containing TENCEL®.

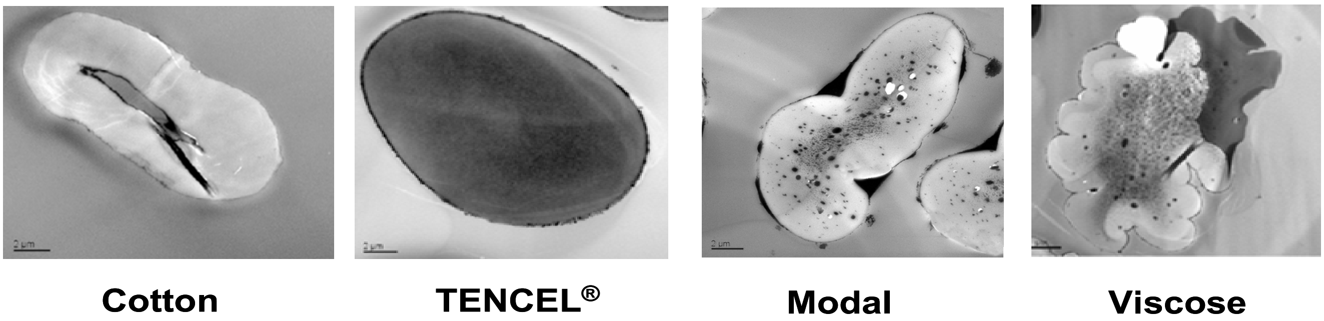


Figure 2: Position of absorbed water in cellulosic fibers. Transmission electron micrographs. Water appears dark (electron dense), cellulose bright [4]

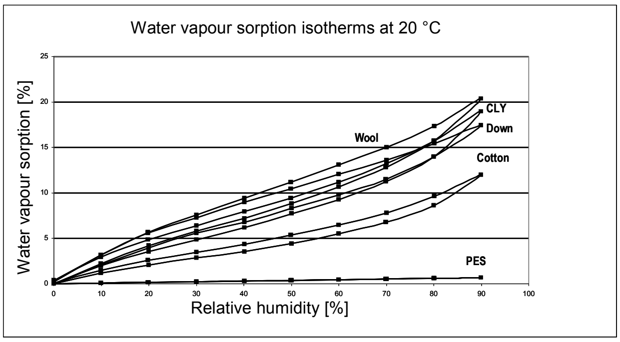


Figure 3. Water vapor absorption isotherms of various textile fibers

Figure 3 is a graph of the "water vapor absorption isotherms" of some fibers [7]. It shows how much water vapor will be absorbed into a fiber from air of a given relative humidity at a given temperature (20°C in this case). Polyester fiber absorbs only negligible amounts of water; cotton absorbs much more. TENCEL® absorbs up to 20% water at 90% relative humidity, which is approximately the same water vapor absorption capacity as wool or down.

The absorption capacity and rate of liquid water absorbency is another important feature of textile fibers. Good water vapor absorbency does not necessarily mean also a high rate of liquid water absorption; the wicking properties of a fabric greatly influence the absorption rate.

One way to measure the absorbency of a fabric for liquid water is the "gravimetric absorbency testing system", the "GATS" test [12]. In this test the sample is exposed to liquid water from below without any hydrostatic pressure. Therefore the sample will only take up water as it "demands" it. The test allows measurement of the total water absorption and the absorption rate.

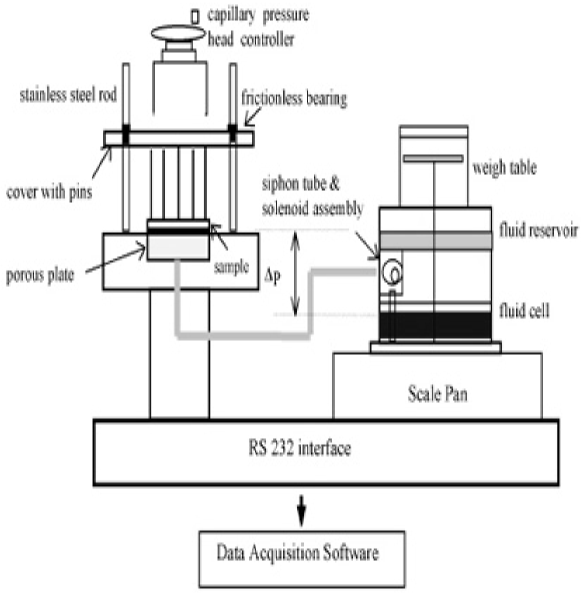


Figure 4. Schematic drawing of the GATS (gravimetric absorbency testing) device [11]

Results with polyester and TENCEL® fabrics of comparable weight which had been washed once before testing have been reported previously. The TENCEL® jersey clearly outperformed the hydrophobic polyester fabric in absorption rate and the amount absorbed [8].

Figure 5 is another example of a GATS test, which was performed on commercial high performance fabrics developed by IBQ in Spain

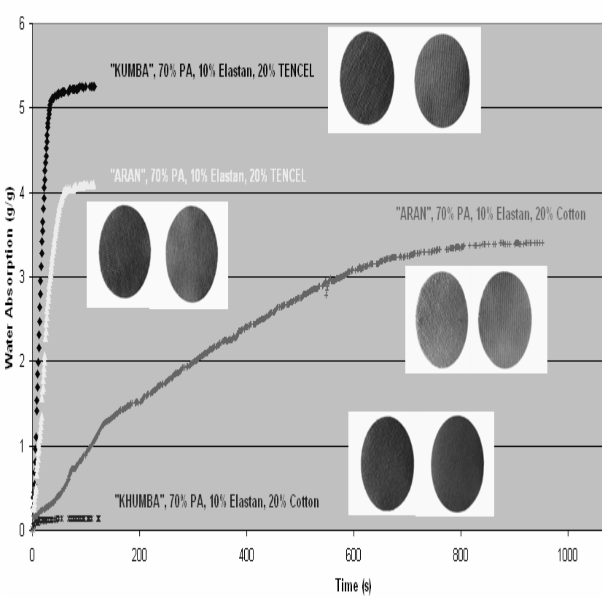


Figure 5. GATS test results on fabrics for sports wear applications

The material is used for mountaineering pants. In two different two-layered constructions ("ARAN" and "KHUMBA"), normally made from 70% Polyamide/ 10% Elastane/ 20% cotton, the cotton was replaced by TENCEL®. Both TENCEL® containing fabrics perform very well in terms of quantity and rate of absorption whereas the cotton variant of "ARAN" absorbs less water more slowly.

The cotton variant of "KHUMBA" did not absorb any water in this test. As the samples were not machine washed before the test, the very bad performance of the cotton - "KHUMBA"- could be due to hydrophobic softeners.

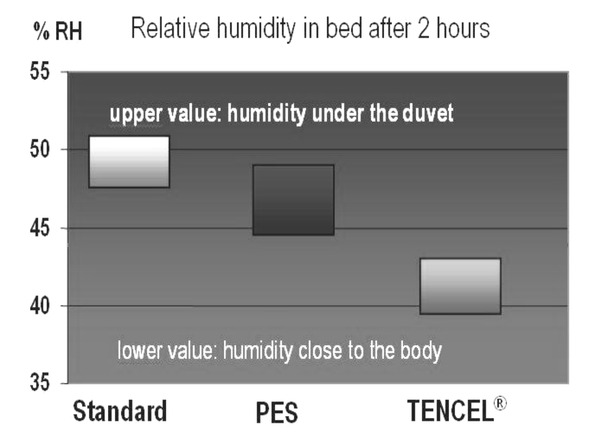
Insulation Properties – Warm and Dry

TENCEL® FILL (a fiber specially designed for use as the filling in duvets) is used to make duvets with very good thermal insulation combined with high water vapor transport, and high absorption of water [7], leading to a high overall comfort compared to polyester fillings [7] and even compared to down fillings [8].

To confirm the laboratory tests for bedding material, a study with test persons was also arranged. Details are reported by Helbig, this volume [13]. Briefly, a group of strongly sweating persons rested in beds with differing bedding materials. Three types of beds were used:

1) a "standard bed" with a mattress having a polyester fleece and a cotton cover. The bed linen was cotton, the duvet and pillow were polyester filled and had a cotton shell.
2) a "polyester bed" with all materials made from polyester and
3) a "TENCEL® bed" with all materials produced from TENCEL®.

The humidity and the temperature were measured in the middle of the duvet filling, under the duvet and close to the body. In Figure 6, the graph shows the humidity under the duvet and close to the body. The TENCEL® bed gave the lowest air humidity both under the duvet (the upper value of the bar) and close to the body (the lower value of the bar).



	Standard	PES	TENCEL®
Mattress Fabric Filling	 Cotton PES	 PES PES	 CLY blend CLY blend
Bed linen	Cotton	PES	µ CLY
Duvet/Pillow FillingCover	PES Cotton	PES PES	CLY Fill µ CLY

Figure 6. Humidity in bed, and composition of test beds [13]

The insulation properties of TENCEL® fibers in waddings of outdoor jackets were tested under wear conditions. A volunteer cycled on an ergometer in a cooled climate room at -20°C. The jacket she used contained an insulation fleece of TENCEL® / Polyester on the left side and polyester on the right side. The outside surface temperature on the back was measured by an infrared camera. The sides showed a temperature difference of around 1 degree C.

Figure 7 shows the situation after 15 minutes cycling.

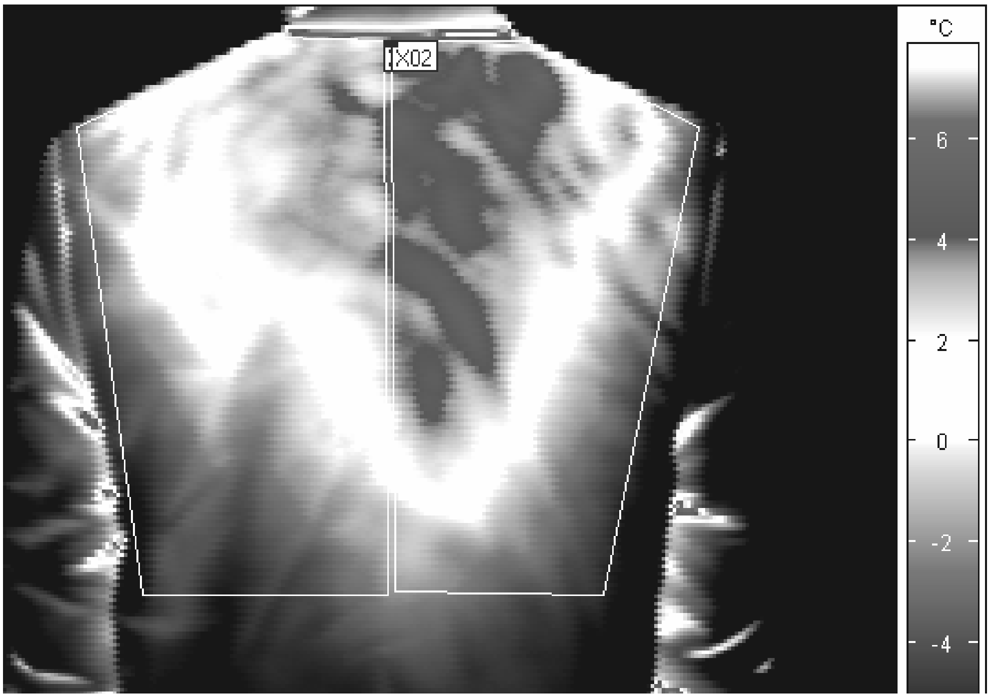


Figure 7. Infrared image of the surface temperature of an outdoor jacket in wear trial at -20°C ambient temperature. Left, TENCEL® /polyester wadding, 0.08 °C average in the marked box, right, polyester wadding, 1.23 °C average in box

Table 1 shows the textile data of the wadding fleeces and the textile physiological measurements taken by the sweating guarded hot plate instrument [10]. It can be seen by the infrared image and by the R_{ct} -value that with basically the same textile properties, the fleece containing TENCEL® fibers shows better insulation. A temperature difference of more than 1 degree on the outside of the jacket will lead to a marked difference in heat loss.

Table 1. Textile physical and physiological data of the waddings used. R_{ct}, , thermal resistance; i_{mt} , water vapor permeability index

Wadding	Fiber data		Area weight [g/m^2]	Fleece thickness [cm]	R_{ct}	i_{mt}
	[dtex]	[mm]				
100 % PES	3.3	55	120	1.5	0.287	0.73
70% Tencel® 30% PES	1.7 3.3	51 55	120	1.7	0.430	0.68

Heat Capacity and Thermoregulation

Water has a high heat capacity. Therefore, fibers which contain water will also have a high heat capacity. This can be used to help the human body's temperature regulation. On the water vapor absorption isotherm we have seen that TENCEL® FILL always contains water [7].

Figure 8 shows small samples of fiber fill with a defined water content sealed into plastic bags. The samples were placed in an oven at 50°C until they had equilibrated. They were then taken out of the oven at the same time and the cooling rate was monitored with an infrared camera.

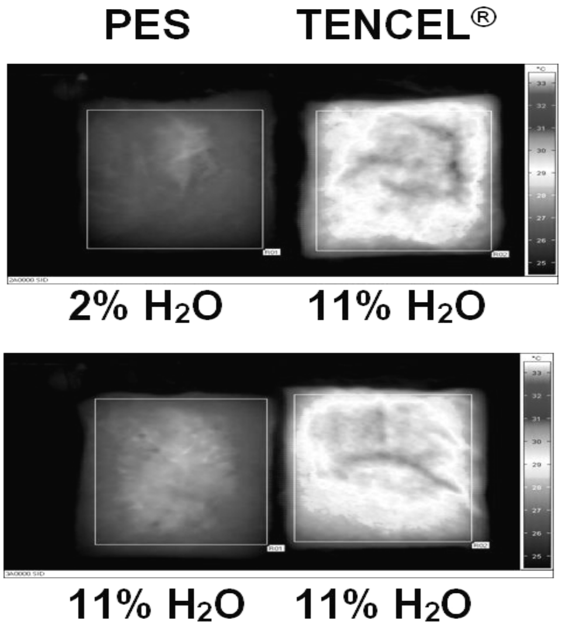


Figure 8: Cooling of duvets. Duvets were heated to 50°C, then left at ambient to cool. The difference is shown by an infrared camera.

The first trial (top) used very realistic conditions with TENCEL® having a moisture content of 11% and polyester 2%. The brighter colors of the TENCEL® sample show that it is retaining heat much more effectively than the polyester sample.

In the second trial both fiber fills had a water content of 11%, but still TENCEL® shows a higher heat capacity and slower cooling rate. The water absorbed within the fiber structure of TENCEL® has a higher heat capacity than the liquid water which is only adsorbed on the surface of the polyester fibers.

TENCEL® FILL in duvets, therefore, acts like a hot water bottle and has a high heat capacity. It can help to smooth out the temperature fluctuations in bed and supports more restful sleep.

Cool and Dry to the Touch

The “Thermal Absorptivity” of a fabric is a measure of the amount of heat conducted away from the surface of the fabric per unit time. A fabric which does not conduct heat away from its surface will feel warm; one that does conduct heat away will feel cold.

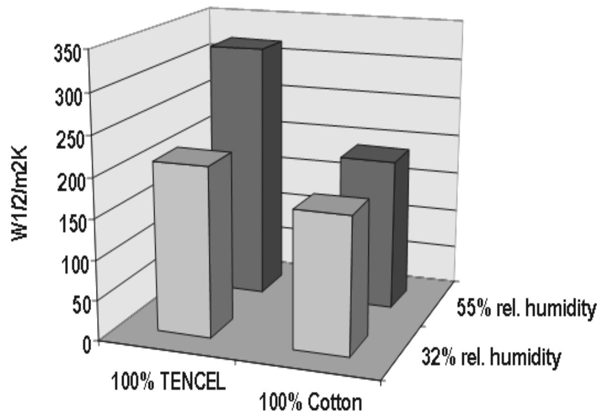


Figure 9: Thermal absorptivity of bed linen

The “Thermal Absorptivity” can be measured using the “Alambeta Test” (Prof. Lubos Hes in Liberec, CZ; [14]).

Figure 9 shows test results on bed linen made from 100% TENCEL® and from 100% cotton. It shows that TENCEL® feels cooler to the touch and that the “cool feeling” increases with increasing air humidity because the moisture content of the fibers increases. With TENCEL® this behavior is much more pronounced than with cotton as the increase in water content with increasing air humidity is much steeper for TENCEL® than for cotton.

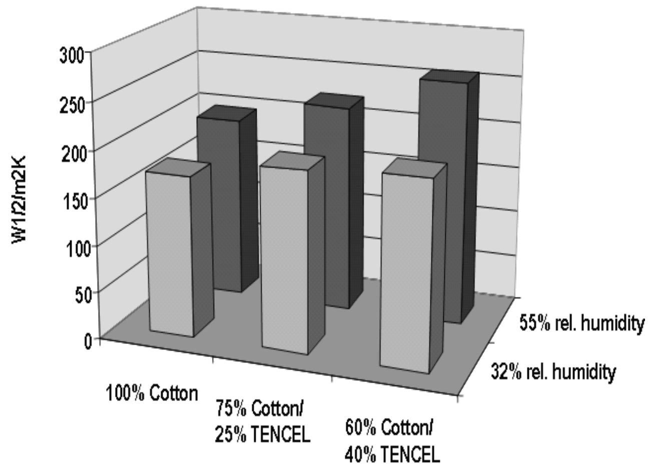


Figure. 10: Thermal absorptivity of shirt fabrics , TENCEL® / cotton blends

Even in minority blends TENCEL® will enhance the “cool feeling” of textiles. Blends of 25% to 40% TENCEL® with cotton in a shirting fabric will give a cooler feeling compared to 100% cotton - especially at higher air humidity (Figure 10). This represents a self-regulating system: In warm and humid ambient conditions, the cool feeling is increased.

Active Cooling

At very high physical activity levels or in very hot and humid climates the temperature control of the human body mainly relies on the production and evaporation of sweat. As the sweat evaporates it carries energy away from the body in the form of the latent heat of vaporization. To do this the sweat must either evaporate from the skin and pass through the covering fabric as vapor or it must be transferred from the skin to the fabric and subsequently evaporate. If the sweat cannot be transported through the fabric, the cooling effect will be too low and the physical performance will drop accordingly.

The ideal "active cooling" textile, therefore, has to have good water transport properties, however it should allow water evaporation next to the skin in order to achieve maximum cooling of the human body. (Many of today's high performance 2 layer sports shirts evaporate the moisture from the surface of the fabric, instead of from next to the skin!)

To investigate the differences of the active cooling properties of TENCEL® and polyester fibers, ergometer tests were performed on subjects wearing T-shirts consisting of 2 halves. The left half was polyester, the right half TENCEL® - both single jersey with the same construction. The test subjects performed a strenuous exercise with the power output increasing in stages to 250 Watts, which guaranteed full sweat production. There were two relaxation stages in between.

The surface temperature of the two halves of the T-shirts was monitored with an infrared camera. In Figure 11, the surface temperature on the right side of the T-shirt – the TENCEL® fabric – is higher.

This demonstrates the better heat dissipation through the TENCEL® fabric during high sweat production. The temperature difference of 0.5 to 1°C seems to be small, however in physiological terms it is significant.

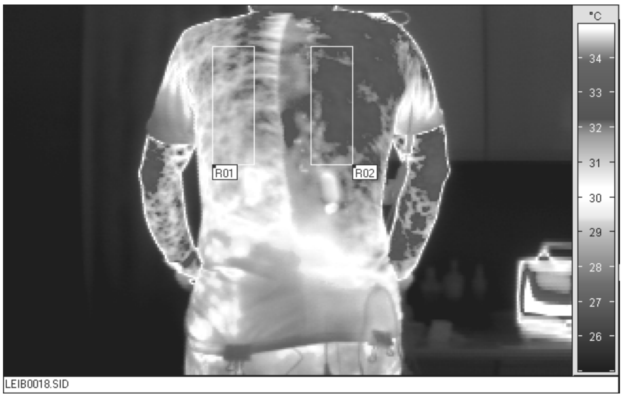


Figure 11: T-shirt in two halves after exercise. Left, polyester. Right, TENCEL® The temperature measured on average over the boxes are 31.5°C (left) and 32.3 °C (right)

Neutral Electrical Properties

Friction induces electrostatic charging of textiles. The extent of electrostatic charging depends on the electrical resistance of the textile surface. A physical measure for the tendency to build up electric charge is the surface resistance of textiles. A surface resistance of higher than 10^{10} Ohm will cause electrostatic charging when friction is applied to a fabric. A high level of electric charge on textiles can cause a very unpleasant experience when the static charge is suddenly discharged and can even cause sparks. Measurements have been made of the electrical surface resistance of TENCEL® and Polyester fabric. Even at a very low air humidity of 25%, the TENCEL® fabric has a surface resistance which is 3 orders of magnitude lower than for the polyester fabric. At higher air humidity (65% RH), the surface resistance of the TENCEL® fibers is 6 orders of magnitude lower [8].

As direct measure for the charge build-up in textiles in contact with the human body, a volunteer stood on an isolated rubber matt and pulled various textiles from his naked shoulders. The electrostatic charging of the body was measured. Polyester and polypropylene cause very high charging in this test (>2500 V); TENCEL® and cotton gave a neutral result; polyamide was much better than the other synthetic fibers but still worse than the cellulosic fibers. An electrostatic charge of more than 1800 Volts can be felt [8].

Not much is known about the impact of this electrostatic charging on the well being of human individuals, but there are hints of negative effects on muscle coordination [15][16].

Strongly Retards Bacterial Growth

If a dry TENCEL® fabric absorbs 60% water, all the water will be absorbed into the fiber, which will cause the fiber to swell. No film of liquid water will cover the surface of the fibers. However if a polyester fabric absorbs 60% water, none of the water will be absorbed by the fibers; all of the water will sit on the surface of the fibers as a water film and/or droplets on and between the fibers of the fabric.
Bacteria and fungi require liquid water for optimum growth. Thus it would be expected that micro-organisms would be more likely to grow rapidly on moist polyester than on moist TENCEL®.
This is the most probable reason for a lower bacterial growth on textiles made from cellulosic fibers as compared to textiles made from synthetic fibers, as was shown by *in vitro* (laboratory) tests [8] under conditions of a challenge test with growth medium (Figure 12).

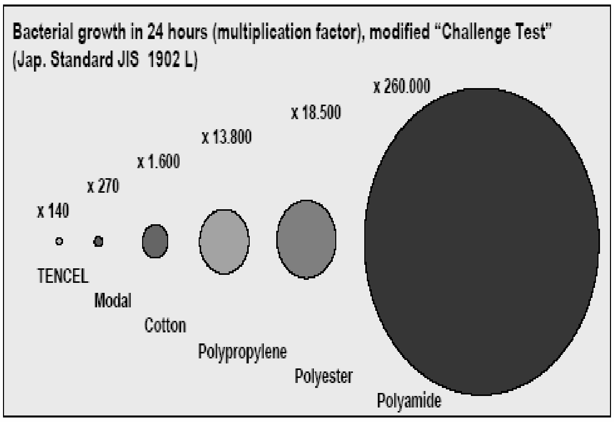


Figure 12: Bacterial growth as multiplication factor in the Challenge Test. Circle areas are proportional to the multiplication factors.

All cellulosic fibers perform well in this test. The bacterial growth on synthetic fibers can be higher by some orders of magnitude. However, within the family of cellulosic fibers TENCEL® shows 10 times lower bacterial growth than cotton. This is probably due to the very good water absorption of TENCEL® in combination with its smooth surface.

In vivo trials (wear trials) with divided T-Shirts confirmed the trend: Under an identical wear situation, on one side of the divided T-Shirt of sports wear fabrics made from synthetic fibers, more bacteria could grow than on the other side made of TENCEL® fabric [6].
For the methods applied to assess interactions of microorganisms and textiles see [17].

Gentle to the Skin

Fibers with poor water absorption capacity result in textiles which cling to the skin when they are wet. Wet skin is much more sensible to irritation than dry skin. The coarseness, the stiffness and the surface character of the fibers will also have an impact on the skin's sensory perception. Both cotton and wool have rather good water absorbency, however they have a rather rough fiber surface.

TENCEL® combines good water absorbency with a smooth fiber surface which makes it a fiber which is very gentle to the skin.

All these positive inherent properties of TENCEL® - good breathability and moisture absorption, dry and cool micro-climate on the skin, smooth fiber surface, low wet cling effect and no electrostatic charging – mean that textiles made from TENCEL® might offer relief to people who suffer from skin diseases.

A clinical test was organized at the University Hospital in Heidelberg (Germany) which was led by the dermatologist Prof. Diepgen [18]. 60 patients suffering from atopic dermatitis or psoriasis tested commercially available TENCEL® products including bedding, T-shirts, polo-shirts and nightwear. People suffering from these conditions have had to optimize their clothing to identify materials that will cause them the least discomfort.

In summary, approximately 80% of the patients suffering from atopic dermatitis or psoriasis preferred TENCEL® products over their normally used textiles.

A second study was performed by Dr. I. König using a specially designed sleeping overall with scratch protection, tested by children aged 2 to

13. Children and parents were very positive about the properties, reported less itching and scratching, leading to a better night's sleep and a more relaxed overall situation [19].

The outcome of these studies is a very convincing argument for the sensorial properties of TENCEL® textiles [20].The main comfort properties noted by the patients were: thermoregulatory properties, cool, smooth and dry feeling, and the overall excellent skin compatibility.

Conclusion

The combination of absorbent fibers and the water that they absorb is the basis of the positive physiological functions of cellulosic fibers. High absorbency, the unique nano-structure and the smooth surface of TENCEL® result in enhanced physiological functions that make it stand out amongst the family of cellulosic fibers.

Acknowledgement

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