Hydrophilic natural fibers like cotton and wool and the man made cellulosic fibers are recognized as having excellent absorbency and breathability. Most synthetic fibers are hydrophobic and non absorbent but can deliver strength and easy care properties.

Sportswear fabrics need to provide a comfortable environment for the wearer and consequently need to be able to handle moisture vapor and sweat produced by the body, they need to help in controlling temperature and they need to feel good. Modern sportswear is most usually made from synthetic fibers. The objective of this work was to explore whether the natural hydrophilic properties of TENCEL® — a man made, solvent spun cellulosic fiber — could be used to enhance the moisture handling and other properties of sportswear fabrics while at the same time improving the aesthetics.

Moisture Management

“Moisture management” in relation to a fabric refers to its ability to transport, store and dispose of liquid water released from the body. “Breathability” refers to the ease with which gases including water vapor can pass through the fabric.

Liquid water released by the body is known as sensible perspiration. To be removed from the body it must be wicked through the fabric structure and then evaporate from the outside of the fabric. When it evaporates heat is removed which helps to control the temperature of the body.

Water vapor or insensible perspiration can pass through openings between fibers and yarns in a breathable fabric. When water vapor is produced by the body, heat is removed giving a direct cooling effect.

During exercise, both insensible and perspiration and sensible perspiration are produced, but the latter increases in response to rising body temperature producing liquid at the surface of the skin. Fabrics used for active sportswear must have the ability to transport moisture away from the skin to the fabric surface for evaporation. The most effective fabrics will spread moisture over a wide area to maximize the surface area available for evaporation and hence cooling.

Cellulosic fibers in sportswear

100 % cellulose fiber garments are widely used for general sports clothing and street wear, but the only fabrics actively promoted for high performance sportswear are made from synthetic fibers. Consumers and sportswear manufacturers have the view that cellulosic fibers are unsuitable for use in sportswear for high activity where sweat production needs to be dealt with.

The reasons for this view of cellulosic fabrics are real and need to be addressed if the use of cellulosic fabrics in sportswear is to be increased. Cellulosic fabrics absorb water into the fiber structure and become heavy. This leads to stretching of the fabric, sticking to the skin and when activity ceases the fabric may feel cold against the skin. Higher levels of moisture absorbed in the fabric mean longer drying times.

However, cellulosic fabrics are generally perceived to be more comfortable than synthetic fabrics when worn for normal day-to-day activities. They are preferred for a wide range of apparel fabrics where visual aesthetics, handle and comfort are important. In these areas synthetic fibers
are only used in blend with cellulosic fibers or where price and/or easy care performance are considered more important.

In order to deliver these positive properties of cellulosic fibers and to eliminate the negative aspects of performance, a new approach is needed. A successful cellulosic containing fabric will need to have a much lower absorbent capacity than a 100 % cellulosic but must also deliver the good visual aesthetics, handle and touch that cellulosic fibers are known for. The fabric would also have excellent moisture handling capability and be easy care. The hypothesis which is tested in this work is based on this thinking.

**Basic considerations**

The most common strategy used to give high performance in synthetic fiber based active sportswear is to use a two layer fabric with a hydrophobic skin contact layer and a hydrophilic outer layer (Fig. 1). Sweat is pulled through the fabric by the hydrophilic fiber on the outside and then spreads through the fabric outer surface to maximize the area available for evaporation. This leaves the skin contact layer feeling dry because the moisture has been transported to the outside. Because the fabric has a low moisture content — as moisture is not absorbed directly by the fibers — it will dry rapidly.

For example:
- standard polyester
- coarser fiber polyester for reduced surface area

**Figure 1.** Two-layer fabric strategy

Polyester is the most common fiber for active sportswear although nylon is sometimes used. 100 % polyester two-layer fabrics perform well in general, but do have some disadvantages. The hydrophilic surface finishes used for the fiber on the outside can be removed as the garment is washed and worn. Hydrophilic polyester fibers are specialty products and carry a premium price. For 100 % polyester fabrics the only aesthetic options possible are a synthetic appearance, handle and touch which does not appeal to all users.

**Hypothesis**

TENCEL® is naturally and permanently hydrophilic. It has a high water absorption capacity which means that if it were used as 100 % of the outer layer of a sportswear fabric it would suffer from the disadvantages described above. However, if it were blended with polyester, the absorbent capacity could be controlled to an acceptable level by the blend ratio and the TENCEL® would deliver the hydrophilicity needed for transport of moisture through the fabric and for spreading across the outer surface.

*Figure 2. 20 % of the fibres in a yarn*

To work effectively, the TENCEL® would need to be present in sufficient quantity to give a continuous network of fibers in the fabric to provide an uninterrupted path for the moisture to follow. To achieve this goal a blended yarn containing at least 20 % TENCEL® should be adequate to give good wicking and liquid spreading.

**Basic investigations: test fabrics and test methods**

The first trials to test the hypothesis were made with simple single jersey fabrics containing a range of blend ratios of TENCEL® and polyester staple fiber. The fibers were intimately blended during yarn production.
The following tests relevant for physiology were done on the fabrics

- Water absorbency/wetting (GATS test)
- Spreading of water
- Drying velocity
- Water vapor permeability resistance, Ret value (guarded sweating hot plate)
- Thermal resistance, Ret value (guarded sweating hot plate)
- Water vapor permeability index, imt value
- Wet cling index

**Basic investigations: water absorbency and wetting – Fig. 3**

The GATS test measures the amount of water absorbed by a sample when water is delivered at zero pressure to a point at the centre of a disc of fabric. For the fabric to absorb, it must positively pull the water into its structure.

The 50% TENCEL®/50% PES fabric has the highest water absorption capacity and absorbs at a similar rate to the 100% TENCEL® fabric. The 30% TENCEL®/70% PES absorbs at a lower rate but matches the total absorbency of the 100% TENCEL®. Normal hydrophobic polyester (100PES) does not wet at all.

**Basic investigations: spreading of moisture – Fig 4**

500 mg of water containing a dye is applied with a syringe to the center of a 15 cm disc of fabric. The area over which the water spreads is measured.

Spreading of moisture is best for 30% TENCEL®/70% PES fabric. On the 100% PES fabric moisture does not spread at all.
Basic investigations: Drying velocity – Fig 5

The sample from the moisture spreading test above is placed on a balance in a conditioned atmosphere and continuously weighed as it dries.

The 30 % TENCEL® / 70 % PES fabric dries about 25 % faster than the other blends. The 100 % PES dries very slowly because the applied water did not spread. The surface available for evaporation is small.

Figure 5. Basic investigations – drying rate

Basic investigations: breathability and thermal behavior – Fig 6

The sweating guarded hotplate method is used to measure the evaporative resistance (Ret) and thermal resistance (Rct) of a fabric by carefully monitoring heat and vapor transmission in a closely controlled environmental chamber. From these measurements, the water vapor permeability index can be calculated as in eq. 1.

\[ \text{imt} = 0.6 \times \frac{Rct}{Rct} \]  

(1)

The imt – value is a measure of the balance between water vapor permeability and thermal conduction of a fabric and should normally be as high as possible. The 30 % TENCEL® / 70 % PES blend still gives an intermediate imt – value.

Basic investigations: Wet cling behavior – Figure 7

The wet cling index is a measure for the tendency of a fabric to cling to the wet skin. It is determined by measuring the force required to pull a wet fabric over a standard wet surface. According to the Hohenstein Institute, Germany, an acceptable performance is generally lower than \( \text{ik} = 15 \).

With increasing TENCEL® content of the fabric, the wet cling index becomes smaller. TENCEL® therefore improves the wet cling performance of PES fabrics.

Figure 7. Basic investigation – Wet cling

Overall results of basic investigation

The PES rich single jersey made from 70% PES / 30% TENCEL® yarn showed the best overall performance giving:

- good absorbency
- best moisture spreading
- fastest drying rate
- intermediate water vapor permeability index
- good wet cling behavior
These are the properties that are needed for the outer layer of a two-layer active sportswear fabric.

Two-layer fabric trials

Based on the results of the basic investigation, a range of fabrics was produced which included fabrics using a 30 % TENCEL® / 70 % PES intimate blended yarn on the outside face and a 100 % PES filament yarn on the inside as the skin contact layer. The physiological properties have been compared to single jersey constructions. As a benchmark polyester running shirts with “Nike DriFit” and “Reebok PlayDry” technologies have been used.

Examples

- Double layer 1 (“DL SJ”)  
  - Outside Single Jersey 70 % PES / 30 % TENCEL®  
  - Inside Single Jersey 100 PES filament
- Double layer 2 (“DL PIQ”)  
  - Outside Pique 70 % PES / 30% TENCEL®  
  - Inside Single Jersey 100 % PES filament
- Single Jersey 1 (“SJ 80/20”)  
  - 80 % PES / 20 % TENCEL®, 5 % Doralastan plated
- Single Jersey 2 (“SJ 70/30”)  
  - 70% PES/ 20% TENCEL, 9% Doralastan plated
- Single Jersey 3 (“SJ 30/70”)  
  - 100% TENCEL® yarn alternating with 100% PES filament yarn, 5% Doralastan
- Nike DriFit (“Nike”)  
- Reebok PlayDry (Reebok’)

Two-layer fabric trials – moisture absorbency (GATS) – Figure 8

The two layer fabrics have best water absorption properties of those tested. The fabrics that contained Elastane gave lower Gats - test absorbency due to tighter fabric construction.

Two-layer fabric trials – moisture spreading – Figure 9

Moisture spreading performance of the TENCEL® two-layer fabrics is between the Nike and Reebok fabrics. The 70 % PES / 30 % TENCEL® intimate blend single jersey shows better spreading than the TENCEL® rich 30PES/70TENCEL® system blend single jersey because the TENCEL® fibers absorb the moisture as well as spreading it.

Two-layer fabric trials – Drying rate – Fig 10

The drying rate of the TENCEL® two-layer fabrics is comparable to the Nike and Reebok benchmark shirts. The Elastane containing single jersey fabrics dry slower than the two-layer fabrics. The TENCEL® rich single jersey dries the slowest.

Two-layer fabric trials – “Water vapour permeability index – Fig 11

The water vapor permeability index for all of the TENCEL® containing fabrics is much better than for the Nike and Reebok benchmark fabrics. The double layer piquet construction shows extremely good breathability.

Two-layer fabric trials – Wet cling – Fig 12

The wet cling properties are OK for all of the fabrics (ik < 15). The TENCEL® containing two-layer fabrics show excellent wet cling behavior.
Figure 8. Two-layer fabric trials – GATS

Figure 9. Two-layer fabric trials – Moisture spreading

Figure 10. Two-layer fabric trials – Drying rate
Conclusions

TENCEL® can be used effectively for the development of high performance sportswear provided that the fabric is carefully designed to maximize the contribution the TENCEL® makes to the performance of the fabric.

TENCEL® can serve as a permanent hydrophilic component as an alternative to hydrophilic topical treatments of polyester or expensive hydrophilic PES fibers.

Compared to high quality 100% polyester sportswear, two-layer fabrics made using TENCEL® in the outer layer give:

- better moisture absorption and buffering
- equal moisture spreading
- same drying rate
- equal wet cling behavior
- a much better balance of water vapor permeability and thermal comfort
- a less synthetic look and touch

TENCEL® can be used in minority blends with polyester as the outer layer of a two-layer construction to give high performance sportswear for athletic activities where sweat production is high. The fabrics produced have a non-synthetic look and touch.