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100% Cotton Moisture Management

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ABSTRACT

Moisture management often refers to the transport of both moisture vapor and liquid away from the body. Moisture vapor can pass through openings between fibers or yarns. In the case of cotton or other hydrophilic fibers, the fiber can serve as a buffer by absorbing moisture vapor and adding to the comfort properties of a fabric. This study is an example of ongoing research and development at Cotton Incorporated related to moisture management. Results indicate that it is possible to create a whole spectrum of performance properties on 100% cotton for different activities in a wide range of environments.

KEYWORDS: cotton, moisture, moisture vapor transmission, MVT, recreational performance apparel, RVT

Moisture management often refers to the transport of both moisture vapor and liquid away from the body. Moisture vapor can pass through openings between fibers or yarns. In the case of cotton or other hydrophilic fibers, the fiber can serve as a buffer by absorbing moisture vapor and adding to the comfort properties of a fabric. Liquid water (or perspiration) must be wicked into a fabric structure, and then evaporate from the outside of the fabric.

There is much hype in the market about fast-drying fabrics. In general, all flat or non-raised surface fabrics when saturated will dry at the same rate, independent of fiber type. Fabrics used in athletic and recreational end uses should have the ability to transport moisture to the fabric surface for evaporation. There are very few, if any, 100% cotton garments that are advertised as recreational performance apparel for athletic activities. Consequently, research and development is ongoing at Cotton Incorporated to develop such garments to allow cotton to participate in this market.

For cotton fabrics and, therefore, garments to offer the performance desired for athletic endeavors, innovation and enhancement of the cotton fabric must take place.

Innovation is today's catch phrase. The consumer wants something different, and the industry must respond. Innovation is also known by many other names such as high-tech, intelligent textiles, nano-technology, and functional finishes.

Cotton fiber has perceived limitations with regards to what is called recreational performance apparel (RPA). Basically, cotton is not perceived as “high-tech” even though it is one of the most chemically reactive and versatile fibers. Perceived technical issues on cotton, as may be seen in some of the advertisements for synthetics, can be summarized as follows:

- Too heavy when wet
- Sags when wet due to the extra weight
- Takes too long to dry
- Sticks to the skin, restricting movement
- After the activity ends, the wearer often feels cold

These issues with cotton, as an active wear, candidates are perceived by the trade press, by the synthetic competition, and sometimes by the wearer. In some respects, garments made from synthetic fibers have similar disadvantages when wet, such as in sticking to the skin and restricting movement. All these issues with 100% cotton relate to absorbent capacity of the basic cotton fabrics; most are often knit goods.

The most important factor in determining how much water (or perspiration) can be absorbed by a fabric is the fabric thickness. The drying time is dependent mainly on how much water is absorbed by a fabric and, therefore, by the thickness of a fabric. A saturated terry towel will take a long time to dry, not because it is cotton, but because it is a thick fabric. Very thin cotton gauze, on the other hand, has been shown to dry faster than a high-tech polyester fabric when equal amounts of water are applied to both fabrics. Consequently, the drying time and energy required to evaporate water from a wet garment depends on the amount of water absorbed and not on the fiber type.

Various factors are known to influence the comfort of wearing apparel. Cotton is one of the most comfortable apparel fabrics because of a combination of properties. For most end uses, natural cotton provides excellent thermophysiological and sensorial comfort. Thermophysiological comfort is complex and relates to the thermodynamics, heat and moisture transfer of the human body and clothing. Sensorial comfort is a function of the feel of a fabric or garment against the skin and may include various sensations or descriptors such as clammy, prickly, stiff, dry, etc. Ergonomic comfort is a function of the fit of a garment and may be influenced by factors such as a tendency to stick to the skin.

Figure 1 shows the energy balance of the human body when exposed to the environment (sunshine or lack of sunshine). As the body produces heat during exercise, which would otherwise cause the core temperature to rise above 37^{o}C, the body tries to regulate the temperature via perspiration and evaporative cooling. Clothing can serve as a buffer in the moisture transfer process. For evaporative cooling to occur, the moisture must transport through the fabric. In some places, the fabric touches the skin, and in other places, it does not. For any garment to be comfortable during exercise where liquid sweat is produced, it must wick. Wicking simply means the capillary movement of moisture within a fabric structure. Cotton fabrics wick naturally. A certain amount of liquid moisture or sweat will build up in any fabric that wicks. Thicker fabrics, including traditional cotton fabrics, will absorb more liquid, and this will be roughly proportional to their thickness. In some parts of the garment where there are openings, moisture vapor and heat can by-pass the fabric by going out the sleeve, neck, or pants leg.

To maximize comfort in recreational apparel applications, the fabric must allow vapor and liquid to pass to the surface of the fabric for evaporation. Too much absorbency (as with thicker fabrics) has a negative aspect in

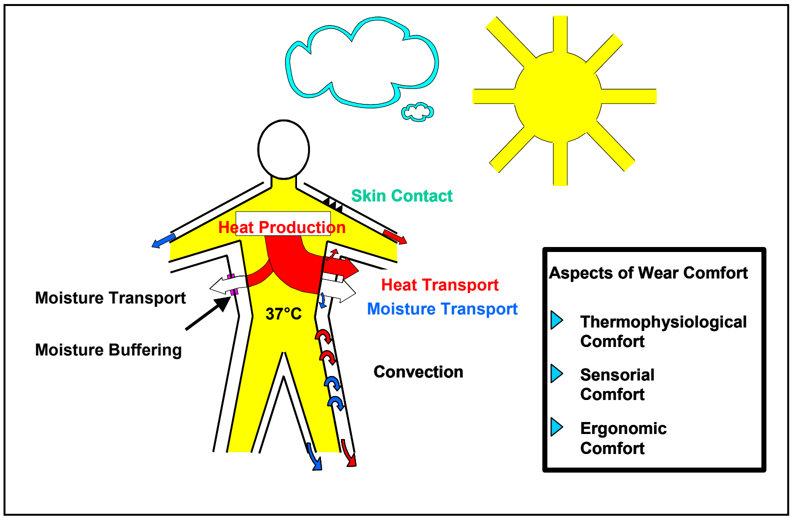


Figure 1. Energy Balance of the Human Body

that the fabric becomes heavy, takes too long to dry, and in cooler weather after the activity ends, the wearer often feels cold.

Moisture management can be defined in this discussion as:

> "The controlled movement of water vapor and liquid water (perspiration) from the surface of the skin to the atmosphere through a fabric."

A wide variety of chemistries and technologies can be used to modify the moisture management properties of cotton fabrics. Some of the chemistries, such as fluoropolymers, can be applied to cotton without altering the basic comfort-related properties, such as moisture vapor transport, air permeability, and moisture regain. These chemistries include:

- Fluoropolymers
- Silicones
- Waxes
- Coating
- Laminations
- Innovative technologies

Fluoropolymers can provide useful modifications to natural (untreated) cotton for certain end uses. Some of these products are durable to multiple home launderings. Some will greatly reduce the absorbent capacity, which will reduce the drying time of a fabric. However, techniques to maintain wicking must be used if the apparel is designed for activities where high levels of perspiration are a factor.

Fluoropolymers can offer a wide range of properties, such as:

- Water resistance
- Abrasion resistance
- Softness
- High durability
- Permanence through regeneration
- Compatibility with other chemicals such as polyurethanes

Figure 2 shows LAD fluoropolymers, which offer durability. LAD refers to the property of regeneration through laundering and air drying. Most fluoropolymers require that treated fabrics be ironed or dried at elevated temperatures after laundering to return the

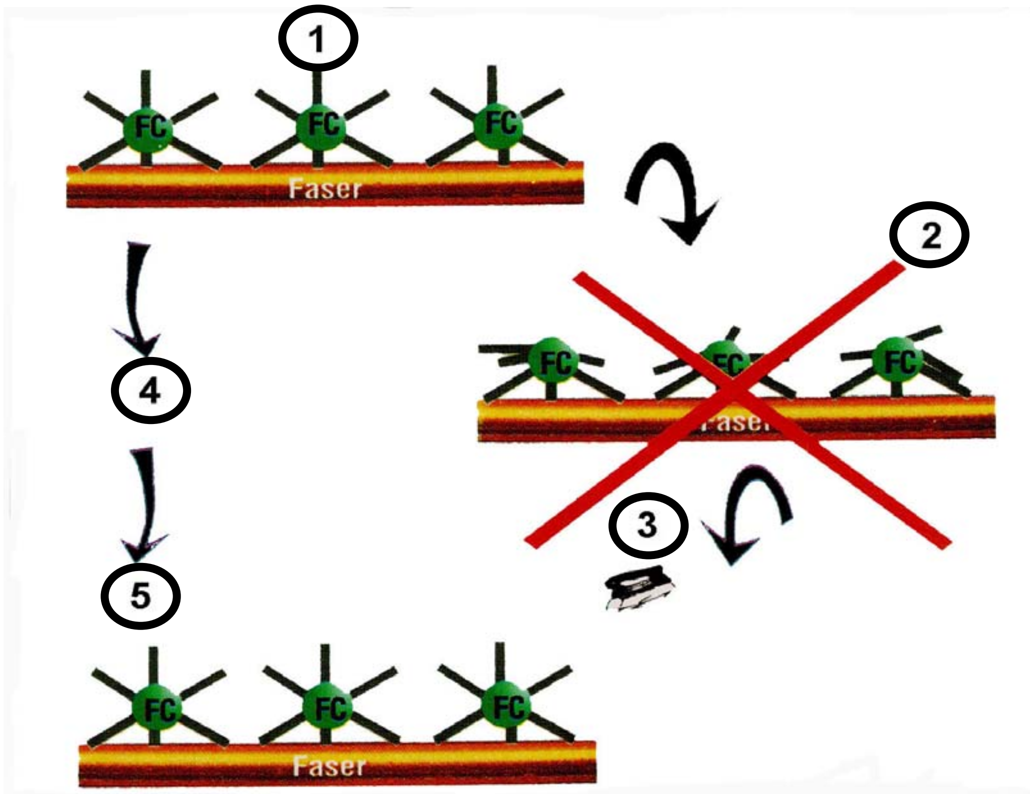


Figure 2. LAD Fluoropolymers Effect[1]

1. Oriented FC residues = good repellency.
2. Disorientation = poor repellency.
3. Ironing.
4. LAD effect.
5. Reorientation = repellency reactivation.

full benefits of the treatment to the fabric. New chemistries do not require ironing for performance after laundering, because they can renew with air-drying.

MOISTURE VAPOR TRANSMISSION RATE

Moisture vapor transmission rate (MVT) is the speed or rate at which moisture vapor moves through a fabric. It is typically determined by measuring the amount of moisture vapor in grams that pass through $1m^2$ of fabric in 24 hours with a specific driving force (e.g. humidity). MVT is primarily a function of fabric thickness and porosity. At rest, a body will give off a quarter of a cup (2 ounces, about 60 ml) of water vapor per hour at ambient conditions. Moderate exertion (walking, etc.) will increase the amount to one pint (16 ounces, about 450 ml) per hour. The ASTM moisture vapor test (open cup test) is one of a number of test methods for moisture vapor transmission rate. In this test, fabric is placed tightly over cups of water where the water, the air above the water, and the room environment are at the same temperature and pressure. The humidity of the room must be controlled. The rate of water vapor that passes through the fabric is determined by

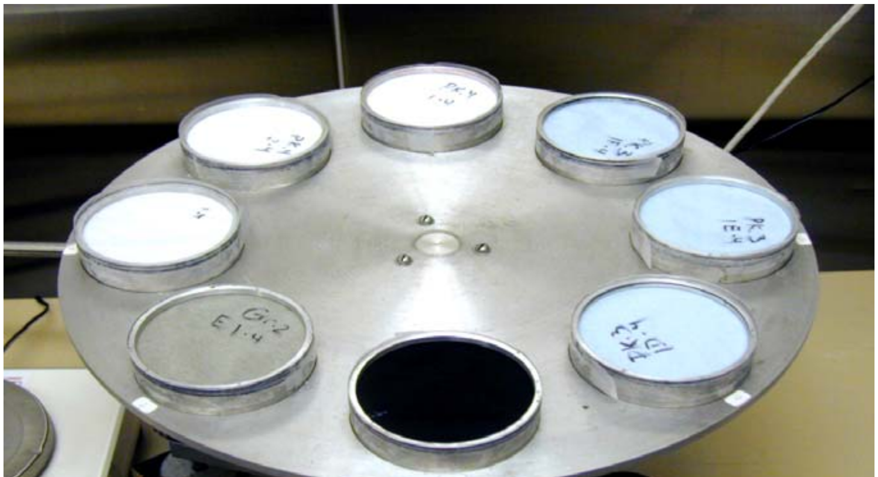


Figure 3. Moisture Vapor Test – Open Cup Method

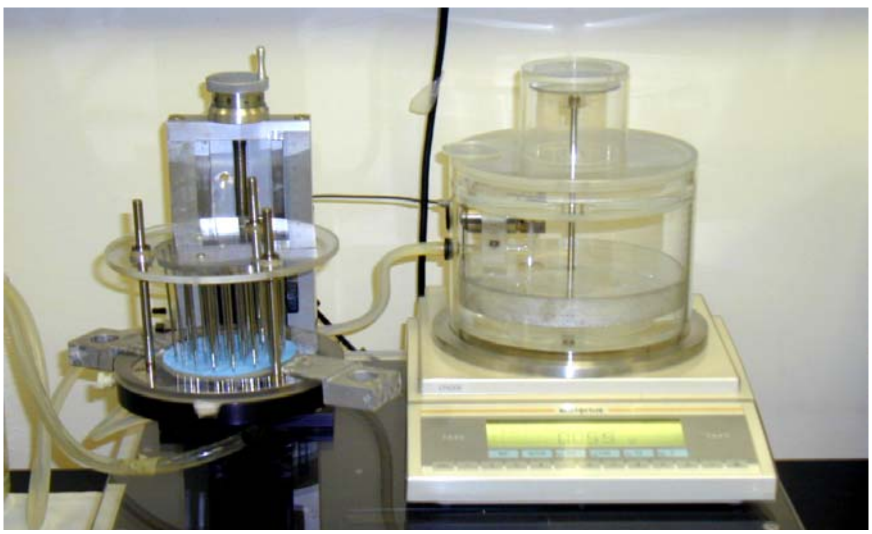


Figure 4. GATS (Gravimetric Absorbency Test System)

weighing the cups. Figure 3 shows the open cup apparatus.

The GATS (gravimetric absorbency test system) test apparatus is shown in Figure 4. A fabric sample is placed on a porous plate. Water (or other liquid) is fed to the sample, and the sample is free to absorb without pressure or restriction. The absorbency rate and absorbent capacity are measured. Drying rates may be measured as well, but this is not a standard part of the test method. In one series of tests run at Cotton Incorporated, a 100% polyester microfiber fabric - Nike DRI-FIT T-shirt - was compared to five different cotton-blended T-shirt fabrics and five 100% cotton T-shirt fabrics. The blends included cotton/polyester, cotton/nylon, and cotton/polypropylene.

The results of testing on the GATS showed that the high-tech polyester was different from the cotton and blended fabrics in two ways. The Nike DRI-FIT did wick quickly and had a much lower absorbent capacity than the cotton or blended fabrics. Because the synthetic fabric absorbed less water (due to the thin construction and hydrophobic nature), the drying time was much less. However, the drying rate was essentially the same for all fabrics. Cotton Incorporated is currently collecting data to demonstrate that thin cotton fabrics can be constructed to have greatly reduced drying time. For flat fabrics, drying time is a function of how much water a fabric absorbs, which in turn depends mainly on the thickness of the fabric.

Table 1 shows the weight, thickness, absorbent capacity, drying time, and drying rate (water evaporated per unit time) for a Nike DRI-FIT fabric, the average values for a series of five blends of cotton and polyester, and the average values for a series of 100% cotton fabrics. There are significant differences in the fabric weights, thicknesses, and absorbent capacities; however, there is not a difference in the drying rates, which were all 0.026 – 0.028 grams per minute.

Table 1. Comparison of Typical T-shirt Fabrics for Active Wear

Test	Nike DRI-FIT	Blends (avg)	100% Cotton (avg)
Fabric Weight (oz/yd^2)	4.13	6.92	6.19
Fabric Thickness (mm)	0.66	1.60	1.34
Absorbent Capacity (grams H_2O on fabric)	2.77	6.09	4.71
Drying Time (in minutes)	99	236	180
Drying Rate (g/min.)	0.028	0.026	0.026

MODIFYING COTTON FOR PERFORMANCE

Cotton naturally has excellent comfort properties in the dry state. In order to match the performance of the high-tech synthetics in terms of moisture management for applications like recreational performance fabrics, the absorbent capacity of cotton must be reduced. This can be achieved by making thinner cotton fabrics and/or by finishing techniques. Beneficial properties must be maintained and include:

- Comfort
- Breathability
- Moisture vapor transport
- Softness
- A cool, pleasing hand

Problems in the wet state must be minimized by:

- Reducing the absorbent capacity
- Maintaining the natural wicking

Reducing Absorbent Capacity and Maintaining Wicking

Cotton fabric's absorbent capacity can be reduced by making the fabric thinner by using finer yarns and by making more open constructions. Absorbent capacity reduction can also be achieved by chemical treatments. Resins, such as the common wrinkle resist type chemistries, can reduce the absorbent capacity of cotton on the order of 15-20% or more. Resins reduce the amount of water held inside the fiber.

Discontinuous water-repellent treatments can be applied on the side of the fabric that will be worn next to the skin. These applications create “wicking windows” that are areas of no treatment contained within or adjacent to areas of treatment. For example, leaving 50% of the surface area on the inside of the garment as natural absorbent cotton will allow the moisture to be wicked to the outside of the garment. The untreated outside of the garment allows for wicking to the outside of the garment and provides evaporative cooling effects. Discontinuous, durable water-repellent applications can be achieved by treating fibers, yarns, fabrics, or garments.

For applications where moderate to heavy perspiration is likely to occur, the entire fabric could be water-repellent treated. However, if it is, it will not absorb the liquid moisture. Without the garment absorbing or wicking, evaporative cooling is greatly reduced, and the garment is perceived as very hot. Also, fully treated fabric will not wick moisture away from the skin. This method is obviously undesirable.

Alternative methods to achieve recreational performance apparel (RPA) on cotton can include:

- Fiber treatments – intimate blends of treated and untreated fibers in the same yarn.
- Yarn treatments – mechanical blends of treated and untreated yarns.
- Fabric treatments – printing.
- Multi-layered fabrics – treated and untreated yarns.
- Crosslinking – resins.
- Garment treatments – printing.

The general concept of moisture management for 100% cotton RPA is shown in Figure 5. Liquid moisture will be wicked away from the skin via the untreated, absorbent areas to the outside of the fabric where it can evaporate. The absorbent capacity of the cotton is much reduced; therefore, the drying time of the fabric is significantly reduced. This effect can be achieved by any of the alternative methods listed above.

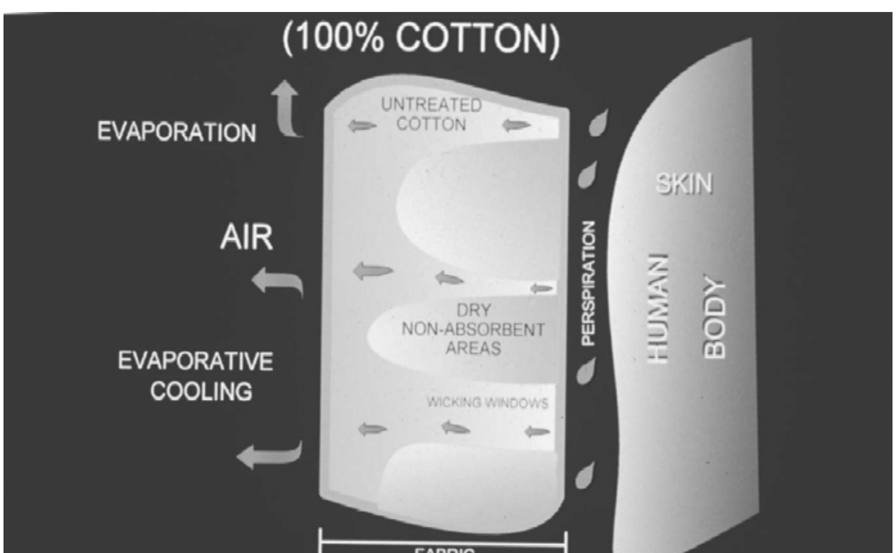


Figure 5. Concept: 100% Cotton RPA

Print applications of durable water repellents (on the side to be worn next to the skin) are one technique. Another is yarn treatments where treated and untreated yarns are plaited to achieve the effect. The overall concept will have the following results:

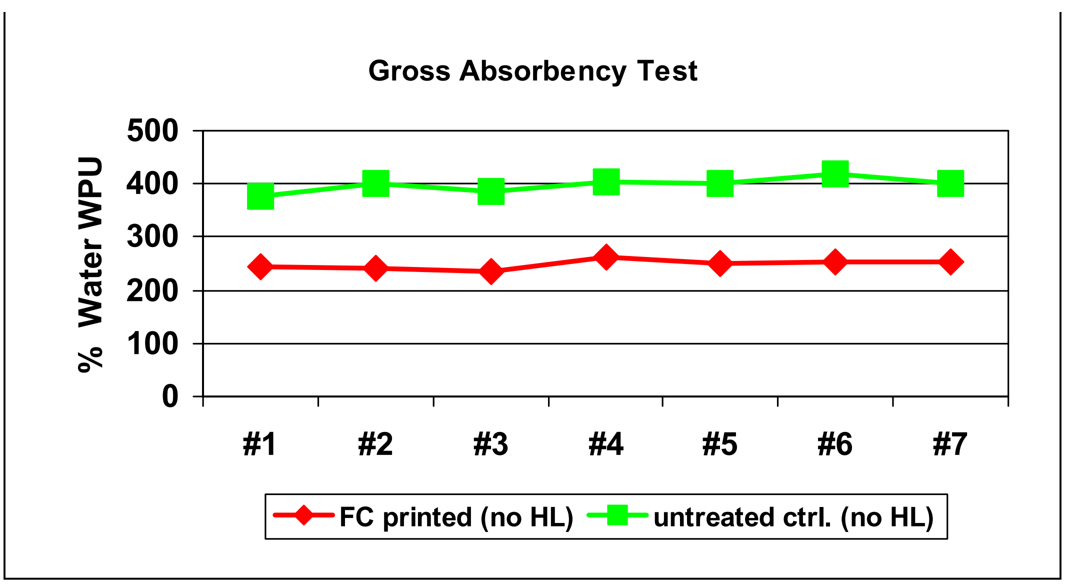
- 40-90% of the cotton fabric next to the skin is treated and remains dry.
- 10-60% of the cotton fabric next to the skin is untreated, absorbent, and wicks moisture away into the outside of the fabric for evaporation and cooling.
- The outside of the fabric is untreated and absorbent.
- The chemistry and process technology required is simple and widely available.

- The chemistry is durable to home laundering.

In one test series, 100% cotton fabric was printed with durable fluorocarbons (FC). Table 2 shows the results for seven replicate samples, which were rather consistent. In this case, the FC was printed in a striped pattern on one side of the fabric with about 50% coverage, and as planned, the FC did not penetrate the full thickness of the fabric. The absorbent capacity (in this case wet pickup) was substantially reduced by almost 50%.

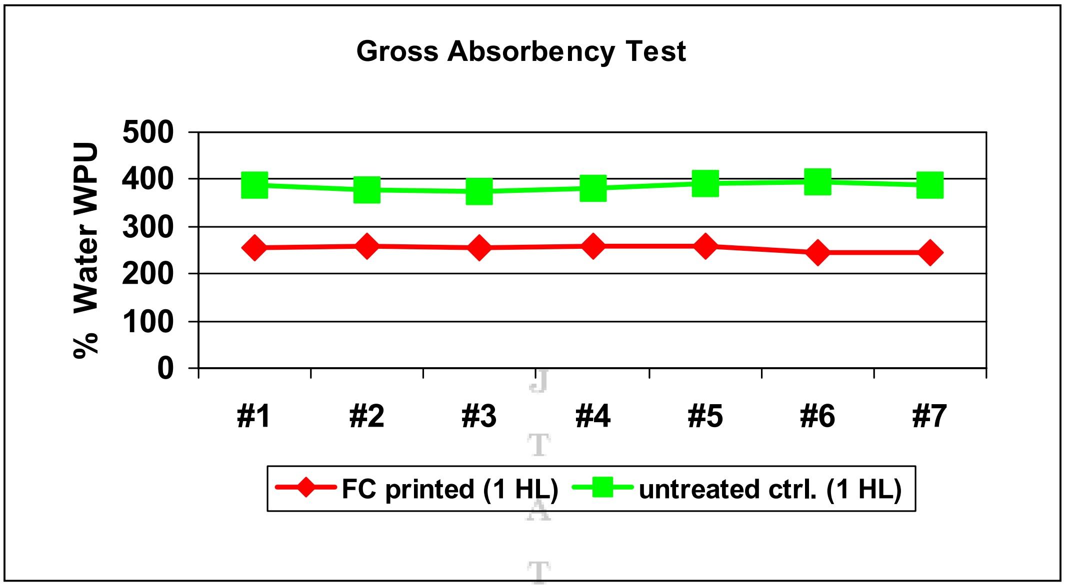
The test method used for Tables 2 (no laundering) and 3 (one laundering) was the Cotton Incorporated Gross Absorbency Test. This test measures the absorbent capacity of fabric samples by placing them on a "uniformly saturated fabric" with a readily available water supply. In this test, the "uniformly saturated fabric" is in a horizontal position and is maintained in the saturated state by being in direct contact with a fine-pore sponge, which is mostly immersed in a tray of water. The exact details of this test can be obtained by contacting the Cotton Incorporated Textile Chemistry Research Department.

Table 2: Comparisons of % Wet Pickup for FC Printed vs. Unprinted 100% Cotton (no laundering)



This same test was performed after one home laundering. The FC that was chosen can be crosslinked to cotton and becomes very durable to laundering. The manufacturer's data indicates that the chemistry is durable to more than 50 home launderings. Table 3 gives the comparison for the seven replicates of treated and untreated samples after one home laundering.

Table 3: Comparison of % Wet Pickup for FC Printed vs. Unprinted 100% Cotton (After One Home Laundering)



<u>Drying Rates</u>

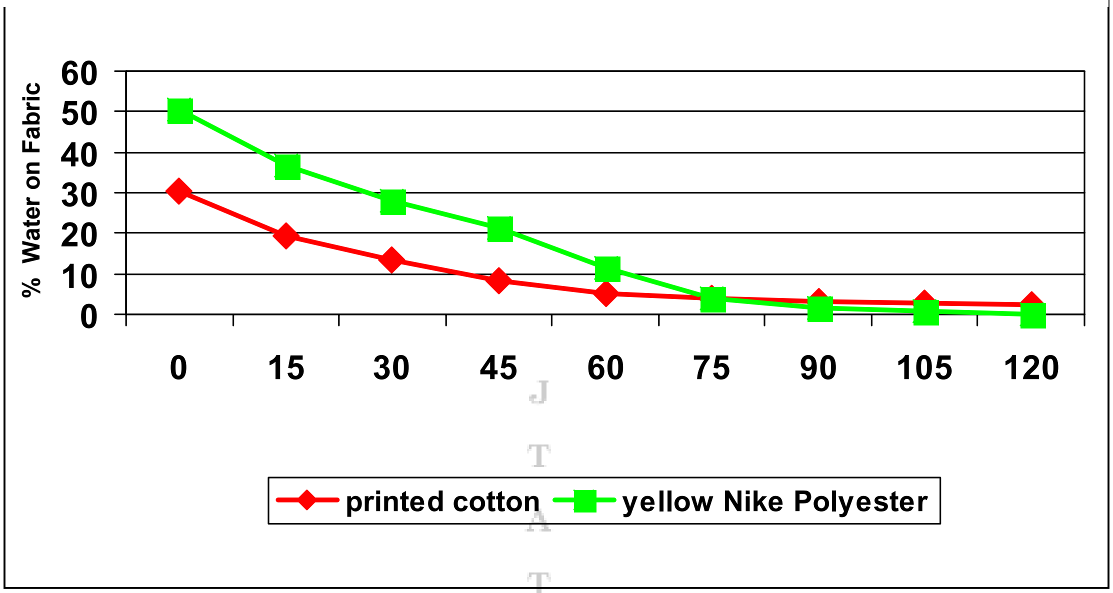
Drying rates were determined for a Nike DRI-FIT polyester fabric and a 100% cotton fabric printed with a FC. The rate of drying for each is shown in Table 4.

The fabrics were saturated with water and extracted in a laboratory garment washing/dyeing machine (rotary drum). The data shows that the percent water on the polyester fabric was just over 50% (50.6%), and the cotton fabric yielded just over 30% (30.5%). Both fabrics were allowed to air dry in a conditioned laboratory (74^{o}F and 53% RH). Both the cotton and the polyester fabric's dry or basis weights were based on ambient weights rather than bone-dry weights. The fabric samples were cut and weighed after conditioning for about four hours in the conditioned environment. The fabrics were then wet-out with just water in the rotary drum machine and extracted for two minutes. The samples were then placed in plastic bags and immediately brought to the conditioned lab and reweighed; whereas, the initial percent water on fabric was calculated, using the ambient fabric weight as the basis.

The cotton fabric can feel dry to the touch when it contains a significant amount of moisture because of its hydrophilic nature. Cotton's normal regain is 6-8%. However, the polyester fabric can feel damp or clammy when it contains only a few percent moisture because of its very low moisture regain of about 0.5 percent. In this example, the cotton can be expected to feel dry after 60 minutes; whereas, the polyester may still feel damp or clammy after 90 minutes.

Because of cotton's higher natural regain, a cotton fabric can feel dry when it contains as much as 15% moisture. However, just a few percent moisture on a polyester fabric can make it feel clammy and uncomfortable.

Table 4: Drying Rate of 100% Cotton FC Printed Fabric versus Polyester Fabric (74°F (23°C) and 53% Relative Humidity)



CONCLUSIONS

With some of the techniques that are being developed, it will be possible to create a whole spectrum of performance properties on 100% cotton for different activities in a wide range of environments. From this study, the following can be derived:

- 100% cotton fabrics can be produced with reduced absorbent capacity.
- Reducing absorbent capacity while maintaining wicking is critical.
- Various methods can be used to manufacture recreational performance apparel from 100% cotton.
- A wide range of performance characteristics can be achieved using existing chemistries and available mill equipment.

It is possible to create a whole range of performance characteristics for different activities or environments in 100% cotton. A creative marketing program based on this concept can provide an incentive at retail with emphasis on innovation.

References

[1]Stefan Thumm, "LAD Fluorocarbon Technology for High-Tech Sportswear," International Textile Bulletin, January 2000, p. 60

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