Waterproof Breathable Active Sports Wear Fabrics

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India is increasing total wealth and per capita income per head. The rapid spread of satellite television is globalising the vision of the healthy lifestyle and spreading knowledge of sports and leisure wears from country to country. Due to this consumers are becoming more and more conscious for the comfort of the garments that they are wearing. As a result new fibres and fabrics are emerging out for satisfying the stringent needs.
The paper reviews various works done in development of waterproof, breathable sportswear textiles. The moisture transport properties and various factors affecting it are also discussed for sportswear fabrics using different fibres. The various branded fibres and fabrics have been described along with their constitutional elements and special characteristics.

Introduction

Waterproof breathable fabrics are designed for use in garments that provide protection from the environmental factors like wind, rain and loss of body heat. Waterproof fabric completely prevents the penetration and absorption of liquid water. The term breathable implies that the fabric is actively ventilated. Breathable fabrics passively allow water vapour to diffuse through them yet prevents the penetration of liquid water. High functional fabrics support active sportswear with importance placed on high functions as well as comfort. Finally, materials with heating and/or cooling property have newly attracted the interest of the market. All these materials do not pursue a single function, but different functional properties combined on a higher level.

Fabrics that can convey water vapor from body perspiration out through the material while remaining impervious to external liquids such as rainwater are widely used in sportswear and similar applications. Water-resistant and moisture-permeable materials may be divided into three main categories - high-density fabrics, resin-coated materials and film-laminated materials - which are selected by manufacturers according to the finished garment requirements in casual, athletics, ski or outdoor apparel.

Densely woven water breathable fabrics

The densely woven waterproof breathable fabrics consist of cotton or synthetic microfilament yarns with compacted weave structure. One of the famous waterproof breathable fabrics known as VENTILE was manufactured by using long staple cotton with minimum of spaces between the fibres[1]. Usually combed yarns are weaved parallel to each other with no pores for water to penetrate. Usually oxford weave is used. When fabric surface is wetted by water the cotton fibres swell transversely reducing the size of pores in the fabric and requiring very high pressure to cause penetration. Therefore waterproof is provided without the application of any water-repellent finishing treatment. Densely woven fabrics can also be produced from micro-denier synthetic filament yarns. The individual filaments in these yarns are of less than 10 micron in diameter, so that fabrics with very small pores can be engineered.

Laminated waterproof breathable fabrics

Laminated waterproof breathable fabrics made by application of membranes into textile product. These are thin membrane made from polymeric materials. They offer high resistance to water penetration but allow water vapour at the same time. The maximum thickness of the membrane is 10 micron. They are of two types:

1) Micro porous membranes
2) Hydrophilic membranes.

The micro porous membranes have tiny holes on their surface smaller than a rain drops but larger than water vapour molecule. Some of the membranes are made from Polytetrafluoroethylene PTFE polymer , Polyvinylidene fluoride PVDF, etc[2,3].

The hydrophilic membranes are thin films of chemically modified polyester or polyurethane. These polymers are modified by the incorporation of poly. The poly (ethylene oxide)[4] constitutes the hydrophilic part of the membrane by forming amorphous region in the main polymer system. This amorphous region acts as intermolecular pores allowing water vapour molecules to pass through but preventing the penetration of liquid water due to the solid nature of the membrane.

Coated waterproof breathable fabrics

Coated fabrics with waterproof breathable fabrics consist of polymeric material applied to one surface of fabric[4,5]. Polyurethane is used as the coating material. The coatings are of two types:

1) Micro porous membranes
2) Hydrophilic membranes.

In microporous membrane the coating contains very fine interconnected channels much smaller than finest raindrop but larger than water vapour molecules. Hydrophilic coatings is same as hydrophilic membrane but the difference between the microporous and hydrophilic material is the former water vapour passes through the permanent air-permeable structure whereas the later transmits vapour through mechanism involving adsorption-diffusion and de-sorption.

The desirable attributes of functional sportswear and leisurewear are as follows[6]:

- Optimum heat and moisture regulation
- Good air and water vapour permeability
- Rapid moisture absorption and conveyance capacity
- Absence of dampness
- Rapid drying to prevent catching cold
- Low water absorption of the layer of clothing just positioned to the skin
- Dimensionally stable even when wet
- Durable
- Easy care
- Lightweight
- Soft and pleasant touch

It is not possible to achieve all of these properties in a simple structure of any single fiber or their blend[7]. The two layer structure has layer close to skin of the wicking type comprised of synthetic fibers e.g. micro-denier polyester and the outer layer

usually cotton or rayon that absorbs and evaporates. Micro denier polyester is ideal for wicking perspiration away from the skin. The use of superfine or microfibre yarn enables production of dense fabrics leading to capillary action that gives the best wicking properties[8,9].

No single fibre or blend of different fibres can give ideal sportswear. The right type of fibre should be in the right place. Blending of fibres does not give the same effect as that of multi-layer fabric. The wicking behaviour of the fabric is mainly depending on its base fibres moisture properties.

MOISTURE TRANSPORT MECHANISM[10]

The mechanism by which moisture is transported in textiles is similar to the wicking of a liquid in capillaries. Capillary action is determined by two fundamental properties of the capillary:

- Its diameter; and
- Surface energy of its inside face.

The smaller the diameter or the greater the surface energy, the greater the tendency of a liquid to move up the capillary. In textile structures, the spaces between the fibres effectively form capillaries. Hence, the narrower the spaces between these fibres, the greater the ability of the textile to wick moisture. Fabric constructions, which effectively form narrow capillaries, pick up moisture easily. Such constructions include fabrics made from micro fibres, which are packed closely together. However, capillary action ceases when all parts of a garment are equally wet.

The surface energy in a textile structure is determined largely by the chemical structure of the exposed surface of the fibre, as follows. .

- Hydrophilic fibres have a high surface energy. Consequently, they pick up moisture more readily than hydrophobic fibres-
- Hydrophobic fibres, by contrast, have low surface energy and repel moisture.

Special finishing processes can be used to increase the difference in surface energy between the face of a fabric and the back of the fabric to enhance its ability to wick.

FACTORS AFFECTING MOISTURE TRANSPORT[10, 11]

There are several factors, which affect moisture transport in a fabric. The most important are:

- Fibre type;
- Cloth construction or weave;
- Weight or thickness of the material; and
- Presence of chemical treatments.

Synthetic fibres can have either hydrophilic (wetting) surfaces or hydrophobic (non-wetting) surfaces. They also have a range of bulk absorbencies, usually reported by suppliers and testing organisations as the percentage moisture regain[1] by weight. Synthetic fabrics are generally considered to be the best choice for garments worn as a base layer. This is because they are able to provide a good combination of moisture management, softness and insulation.

While most fabrics, both natural and synthetic, have the ability to wick moisture away from the skin, not all of these are fast-drying and air permeable-two factors, which have a direct influence on cooling and perceived comfort. High-tech synthetic fabrics are lightweight, are capable of transporting moisture efficiently, and dry relatively quickly.

It is generally agreed that fabrics with moisture wicking properties can regulate body temperature, improve muscle performance and delay exhaustion. While natural fibres such as cotton may be suitable for clothing worn for low levels of activity, synthetic fabrics made of nylon or polyester are better suited for high levels of activity. They absorb much less water than cotton, but can still wick moisture rapidly through the fabric.

The main parameters for comfort and functionality are:

- Water and wind proof, breathability and comfort.
- Moisture/Sweat management
- Warmth/temperature control
- Easy-care performance
- Smart and functional design.

Polyester

Polyester has outstanding dimensional stability and offer excellent resistance to dirt, alkalis, decay, mold and most common organic solvents. Being durable, yet lightweight, polyester has elasticity and a comfortable smooth feel or “soft hand”. These are all important qualities to consumers for a wide variety outerwear and recreational applications. Excellent heat resistance or thermal stability is also an attribute of polyester. It is the fibre used most commonly in base fabrics for active wear because of its low moisture absorption, easy care properties and low cost. Polyester is essentially hydrophobic and does not absorb moisture. However, most polyester used in base layer clothing is chemically treated so that they are able to wick moisture. This can be done by:

- Coating the polyester with a hydrophilic finish; or
- Changing its surface chemistry to improve its wetting by moisture.

Changing the surface chemistry of the polyester involves introducing free hydroxyl groups into molecules on the surface of the filament. The result is a de structuring of water, causing wetting. The combination of opposing properties-a hydrophobic core and a hydrophilic surface-creates a fabric in which the fibres encourage moisture to migrate through the fabric along the outer surface of the filament while the hydrophobic core does not absorb moisture.

The main disadvantage of chemical or molecular modification is that it is more costly for the fabric manufacturer. However, the effect on the fabric is "permanent". To be classified as permanent, it has to have the capability to withstand at least 50 home washings. Most coatings, by contrast, have an average lifespan of five home washings.

Toray[12] develops airfine Fieldsensor which is made from a polyester filament yarn which has the grooves help the fabric absorb sweat quickly and disperse it along the

surface. Company claims that the moisture absorbing and dispersing property of the new material is twice a great as its former Fieldsensor fabric.

Polyester coolmax[10] has been claimed to increase wearer comfort through rapid removal of perspiration by capillary. Also it has good wicking properties and non-absorbency. Coolmax and thermostat polyester fibers used in two fold garments claimed to wick moisture away from the skin (the former) and to maintain warmth (the later).

Polypropylene

Polypropylene cannot wick liquid moisture. However, moisture vapour can still be forced through polypropylene fabric by body heat. Polypropylene has the advantage of providing insulation when wet But it can melt at medium heat in home dryers.

Also, polypropylene is more oleophilic (oil absorbing) than polyester Consequently, it has a greater tendency to attract and hold oily bod) odours even more. Polypropylene is claimed to be a proved performer in moisture management due to its hydrophobic nature and has very good thermal characteristics, keeping the wearer warm in cold weather and cold in warm weather[13].

Nylon

Nylon fibre characteristic include lightweight, high strength and softness with good durability. Nylon also quickly when wet. Nylon is good fabric choice when combined with PU coatings. Nylon has a much higher moisture regain than polyester and therefore has better wicking behaviour. It is most often used in tightly woven outerwear, which can trap heat because of low air permeability. It is also used in more breathable knitted fabrics, where it can perform well. However, it is much more expensive than polyester and is therefore only used in premium applications such as swimwear and cycling wear. Also, because of its higher moisture regain, it dries more slowly than equivalent fabrics made from polyester.

Teijin DuPont Nylon has developed a waterproof fabric, polus-Ex that is permeable to moisture. The material is made by laminating a multiporous film to a nylon fabric and a moisture permeability of 8000 g/m^2/24 hours, as well as 20 m head of water.

Silk

Because of its hollow structure, silk breathes well. It is soft strong and has natural wicking properties. However, it dries slowly and requires care in cleaning.

Wool[14]

Not all grades of wool are appropriate for a base layer. First, since it's next to skin, it shouldn't itch. The "itch" so commonly noticed in wool garment results from the fiber ends tickling. Consequently, short fibers will cause more itch than long fibers because there will be more fiber ends touching your skin. Second, the fiber should be very fine. This allows for a fabric of high fiber density to be made, which increases strength and abrasion resistance in addition to increasing the air movement between and adjacent to pockets of dead air space in the fabric (thus, increasing warmth). Finally, fine fibers absorb less water weight per cross-sectional area, so they are more resilient than coarse fibers. The efficiency of wicking is also greater with a fine-

fibered fabric because more fibers (and correspondingly, more cross-sectional surface area) can be packed into a given space than an equal volume of coarse fibers.

Wool has good, natural wicking properties and will provide insulation even when wet. However, it is slow to dry. However the use of fine chlorinated merino wool is employed in Sportwool as a base layer.

Wearing a Merino wool undergarment will result in the garment staying dryer for longer during periods of exertion. Wool fibers have micropores in them (a characteristic not unique to Merino wool) that readily allow for the absorption of water vapor-up to 1/3 the fiber weight. Consequently, it takes longer for a wool garment to reach the high relative humidity required for condensation to occur (synthetic fibers typically absorb less than 5% of their own weight in moisture vapor before feeling wet)[13].

A wool fabric (manufactured into long-sleeved T- shirt form) has been shown to absorb significantly more sweat than a polyester fabric (of comparable structure) during a period of exercise followed by rest. The amount of moisture desorbed from the wool fabric was significantly higher than that from the polyester fabric, and the skin temperature decreased faster and recovered more slowly after contact with the wool fabric compared with polyester fabric.

Cotton

Cotton garments provide a good combination of softness and comfort. However, cotton is not recommended for use in base layer clothing because of its tendency to absorb and retain moisture. When wet, cotton garments cling to the skin. causing discomfort. Wearing jeans on the ski slopes, for instance, will not only weigh down the skier but will also cause chilling if the jeans become wet.
The slow-to-dry and cold-when-wet characteristics of cotton make this material unsuitable in conditions in which there are high levels of moisture-either perspiration or precipitation-and where the ambient temperature is low.

During SASMIRA's trials for wicking of cotton treated with hydrophobic finishes showed good wicking properties[33].

Viscose Rayon

The viscose rayon is not preferred next to skin as it holds water (13 % moisture regain) in sportswear. The outer layer of knitted hydrophilic portion of the twin layer sportswear can be of viscose rayon, which absorbs 2-3 times more moisture than cotton. The wicking behaviour improves by incorporation of some hydrophobic finishes.

DEVELOPMENTS IN ACTIVE SPORTSWEAR

The 1980s was a period of highly fruitful innovation in sportswear garments. Some reasonably simple microfibres and coated fabrics were developed; variants of which have met the needs of many sports garments. The innovation of new materials and garments was so successful that in many sports the fundamental performance requirements have been identified and largely satisfied. Nowadays, from very simple microfibres to much more complex fabrics are effectively used in active sportswear.

The latest textile materials are much more function specific for fulfilling specific needs in different sports activities [15,16,17].

Sweat absorption and fast drying property

Moisture handling properties of textiles during intense physical activities have been regarded as major factor in the comfort performance. Actually the comfort perceptions of clothing are influenced by the wetness or dryness of the fabric and thermal feelings resulting from the interactions of fabric moisture and heat transfer related properties. For the garment that is worn next to skin should have[18,19]:

a) good sweat absorption and sweat releasing property to the atmosphere, and
b) fast drying property for getting more tactile comfort.

It has been found that frictional force required for fabric to move against sweating skin (resulting from physical activities, high temperature and humidity of surroundings) is much higher than that for movement against dry skin. Which means, the wet fabric, due to its clinging tendency, will give an additional stress to the wearer.

In removing the liquid sweat from the skin, some textile manufacturers claim that moisture absorbency of the fibre is important and hence cotton or viscose is a necessary compone-nt for the sportswear, which is next to skin. While others say that fibres in these garments should not absorb moisture, so that moisture or perspiration is wicked away from the skin to outer layers of clothing from whence it can evaporate into atmosphere. However, a lot will depend on the degree of activity contemplated. In fact, so far as cotton is concerned, the synthetics should be preferred in clothing of active sports as they do not retain moisture and this has the advantage of keeping garments lighter than the cotton when it is wet. Also synthetic fibres have some added advantage of quick dry and good shape retention property. Most of the modern textile materials use the basic idea of capillary action for sweat absorption and fast drying.

SPECIAL FIBRES USED

Hygra[20] : Unitika Limited has launched Hygra, (fig. 1) which is a sheathcore type filament yarn composed of fibre made from waterabsorbing polymer and nylon. The water-absorbing polymer has a special network structure that absorbs 35 times its own weight of water and offers quick releasing properties that the conventional water-absorbing polymer cannot do. On the other hand, nylon in the core gives tensile strength and dimensional stability. Hygra also has superior antistatic properties even under low wet conditions. The main apparel applications include sportswear like

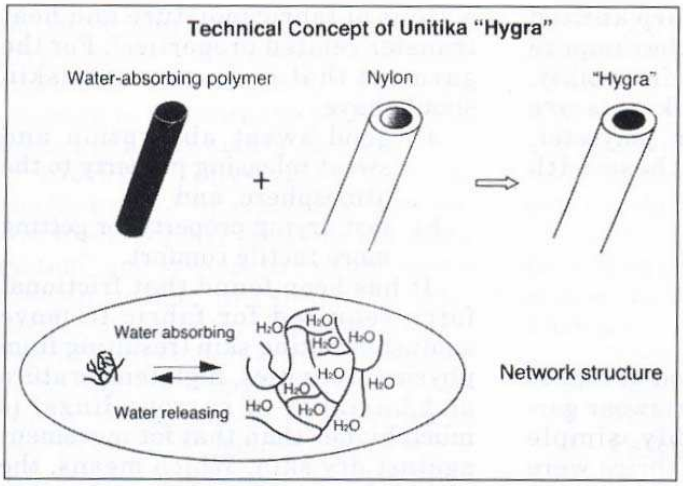


Fig 1 : Hygra sheath-core type fibres

athletic wear, skiwear, golf wear etc.

Lumiac[21] : Lumiace is also a product from Unitika. It is a collection of polyester filaments having different fineness (0.5 - 2.0 denier per filament) and irregular cross sections. Hygra - Lumiace combination in knitted fabric is very popular in top Japanese athletes.

Dryarn[22] : Dryarn is the new fibre from Aquafil. It is a completely recyclable polypropylene microfibre. Fabric from Dryarn is very lightweight and comfortable and used in different sports. In addition it has a soft handle and a high thermo-regulatory capacity and also dries quickly. Bacteria cannot settle on smooth surface of the fibre which avoids unpleasant odour associated with decomposition of bacteria.

Killat N[23] : Killat N from Kanebo Ltd is a nylon hollow filament. The hollow portion is about 33 per cent of the cross section of each filament due to which it gives good water absorbency and warmth retentive property. The manufacturing technology of Killat N is very interesting. The yarn is spun as bicomponent filament yarn with soluble polyester copolymer as the core portion and nylon as the skin portion. Then by giving alkali weight loss treatment the soluble polyester copolymer of the bicomponent filament will dissolve and a large hollow portion (exceeding 30 per cent of the cross section) will be created. Which is shown is figure. 2.

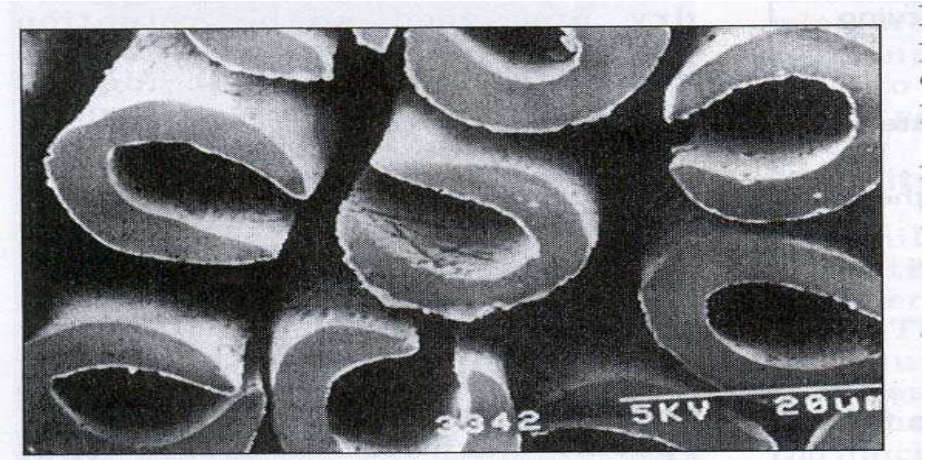


Fig 2 : Killat N hollow nylon fibre

Triactor [24]: Toyoba Co Ltd has developed Triactor, which is a perspiration absorbing/quick drying polyester filament as shown in fig.3. Polyester is hydrophobic and does not absorb moisture but by changing the filaments to Y shaped cross section Toyobo has realised quick perspiration absorbency by capillary action. The hydrophobic nature and large filament surface of polyester filaments realise quick drying and refreshing properties at the same time.

There are many other fibres, which have good sweat absorption and fast drying property. Most of them are either nylon or polyester.

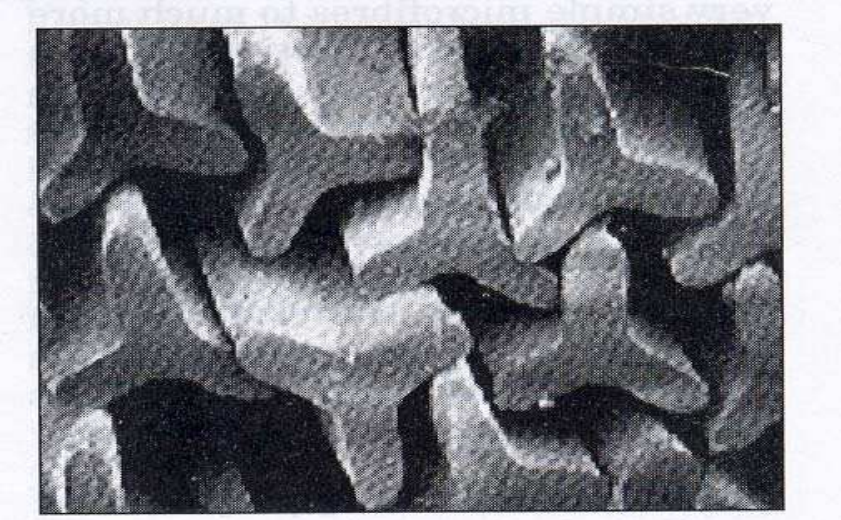


Fig 3 : Structural model of Triactor

Lycra[25]*:* Lycra, a truly synthetic fibre oflong chain polymer composed of at least 85% segmented polyurethane, finds wide range of end uses such as swimwear, active sportswear, floor gymnastics because of its comfort and fit2O. Adding Lycra to a fabric gives it stretch and recovery, particularly in gymnastics and swimwear where body skin flexing and stretching are inevitable. Lycra T-9026 requires still effort for the same extensibility.

Roica and Leofeel[26] : Roica is a polyether type spandex made by dry spinning method and Leofeel is a soft nylon-66 yarn developed by Asahi Chemical. The combination of Roica and Leofeel in mixed knitted tricot fabric gives a soft touch and excellent stretch. It is mainly used in swimwear.

Various other fibres like Elite from Nylstar Co, Linel Ac from Fillattice Co, Elastil and Sens from Miroglio etc also have good stretchability and are effectively used in swimwear.

Branded synthetic fibres for sportswear[11]

Brand	Fibre	Property Claimed
Sillook Royal S	Polyester	Three petal cross-section, silk-like fabric, including traditional 'rustle'
Malor	not given	Continuous filament, textured, random crimp along filament
UTS	not given	Smooth touch, textured fibre, 2 μm microfiber
Reebarg P	not given	Rustling sound
Sillok Chatelaine	not given	Dry touch of fabric; microgrooved cross-section allowing water absorption
Cheddy	not given	Dry touch of fabric; microcaters on surface of fiber, which when rubbed together give silky-dry handle
CEOx	not given	Water-absorbency based on capillary tubes of up to 10 μm between single filament yarns in a multifilament arrangement, ultra fine and ultra thick fibres interspersed
Rirancha	not given	Slab-shaped yarns
Sillook Airly	not given	Crinkling, dry touch, air-hole, highly modified cross-section (hollow?)
Sillook Sildew	not given	
Belima-X	Polyester /polyamide core	Consisting of polyester and polyamide 6, splittable

MULTI-LAYERING OF FIBERS

Blends in form of layering of fibres are capable of offering the best properties of each. Bicomponent knits such as polyester/wool or polypropylene/wool blends provide wicking and insulation properties in a single layer[10,27,28].

Push-pull fabrics are bicomponent materials composed of a non-absorbent hydrophobic material on the inside-worn next to the skin-and an absorbent hydrophilic material on the outside. Usually, the hydrophobic material is polyester, and the absorbent hydrophilic material nylon.

Sportswool[29], a trade mark of The Woolmark Company, is an example of a fabric which has been engineered to manage moisture. Developed by scientists in 1994, it is a hybrid material composed of a fine Merino wool sub-layer for Insulation and a polyester exterior which draws moisture away from the wool layer to the surface.

The wool fibre next to the skin attracts perspiration vapour molecules, before they have the chance to condense into liquid, and disperses them into the atmosphere. The fabric has attracted the attention of top Australian athletes and the Manchester United soccer team. Its major drawback, however, is that it takes longer to dry because of its wool content.

Dri-release[10] is a wicking performance yarn developed by US-based Optimer, a company founded by a group of former DuPont scientists. This patented product is an intimate blend of 85-90% hydrophobic low moisture-absorbing staple fibre-such as polyester-and 10-15% hydrophilic wicking staple such as cotton.

Dri-release is incorporated in athletic wear, socks and underwear. It is used by a number of major brand names in apparel-including Adidas, Fila and The North Face.

The main Dri-release product is made from 85% copolymer polyester and 15% long staple cotton. Dri-release combines the wicking and soft touch properties of cotton with the non-absorbing nature of polyester.

When combined in small quantities with polyester, chemicals can be added during the manufacturing process to inhibit the formation of body odour-for which polyester is notorious-in the final fabric.

The incorporation of cotton during spinning results in an intimate blend, which locks the wicking phase into the structure. Consequently, its effects are permanent.

Over time, the soft ends of the cotton become more exposed on the fabric surface. This improves the wiping action and gives the fabric a softer touch.

The incorporation of cotton in Dri-release contrasts with the approach used in the case of other treated polymers, where fabrics are made wettable by applying topical polymeric finishes. However, fabrics treated in this way can lose their ability to wick moisture after only
five washings.

Tests by Optimer and its customers show that its 85/15 copolyester/cotton blend wicks and releases moisture better than a fabric made from 100% polyester fibre whose entire surface has been converted to hydrophilic hydroxyls.

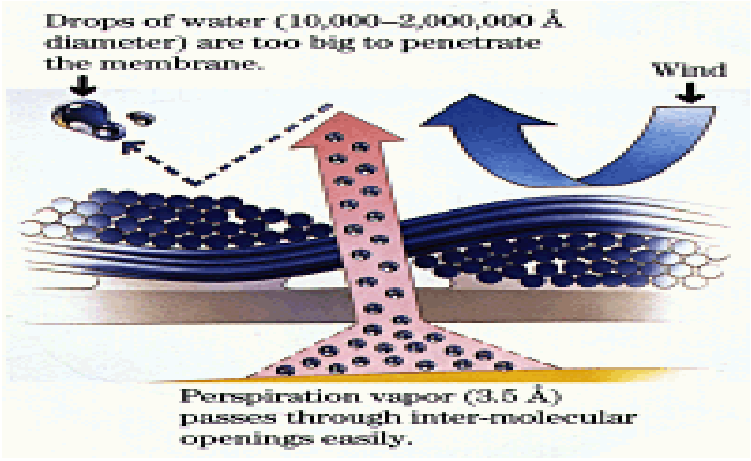
In tests, Dri-release was shown to dry four times faster than cotton and as fast as, or faster than, other performance polyesters-particularly after several washes.

Dri-release also incorporates a Freshguard finish. This neutralises odours retained in the fabric for the life of the garment.

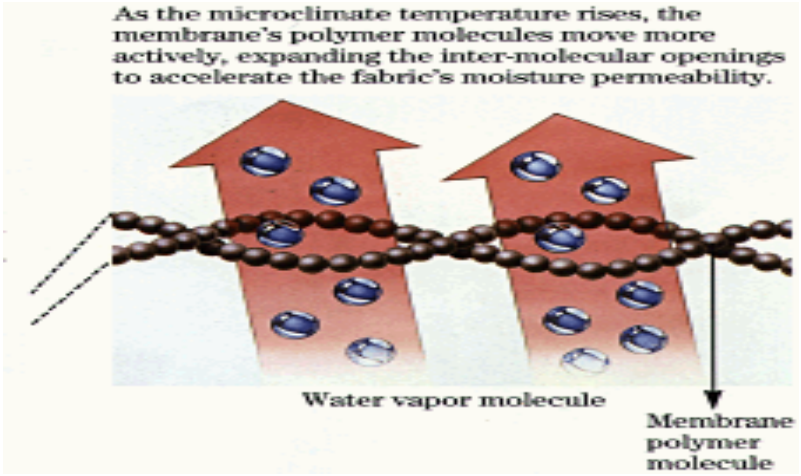
Optimer is carrying out research into the possibility of combining other hydrophilic fibres with polyester in order to create moisture controlling fabrics. One such fibre is wool.

Toray industries Inc.[12] is marketing successively a series of waterproof/breathable fabrics ‘entrant”. There are three main versions of “Entrant” and they are as follows:

"Entrant Dermizax EV " is a lightweight fabric having a feather smooth texture with excellent waterproof/moisture permeability and durable water repellency such as 20,000mm of water pressure resistance and moisture permeability of 30,000 g/m^2/24 hrs. It is an excellent and original active sportswear fabric with globally top class water proof/moisture permeability, as well as excellently durable water repellency. Its action of Waterproofing & moisture permeability is shown in Fig.4.



Waterproof, moisture permeable mechanism



Water vapor permeating mechanism

Fig 4 Entrant Dermizax EV

"Entrant HB" is a new generation fabric with hybrid structure that synergistically integrates the advantages offered by a coating (well-balanced moisture permeability) and lamination (high waterproofness). It has high resistance to water pressure and high durability against repeated washings (80 points or higher after 20 wash cycles). Its main application is outdoor wear.

"Entrant DT" is a microporous coated fabric offering a smoother and refreshing dry touch as well as attractive appearance through an innovative inner surface treatment technology. It has patterns printed on a coated membrane and a dry touch obtained by

improving the coated membrane as shown in fig.5. It features lightweight configuration, easy packing and high breathability/waterproofness.

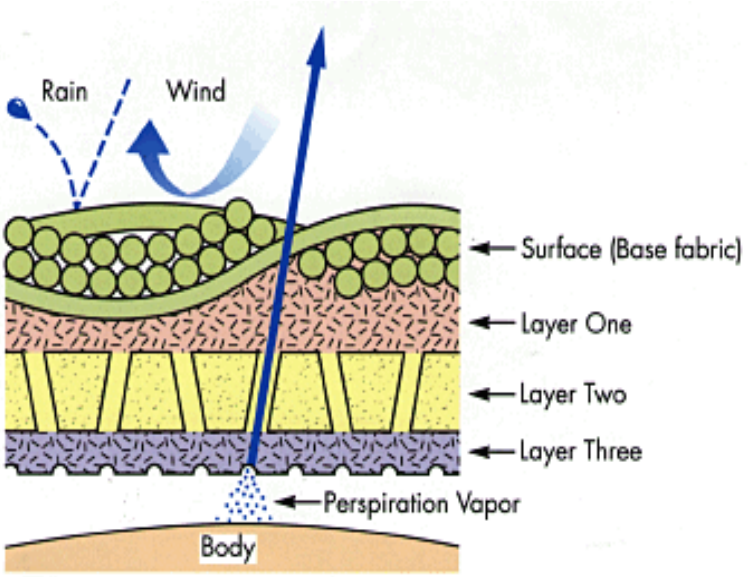


Fig 5 ENTRANT DT

In addition, Toray has developed "H_2OFF" made up of polyester microfiber fabric with a unique high-density weave structure comprising millions of microcrimped fiber loops (fig.6). It also feature superb and durable water repellency, superior breathability and wind-chill resistance and attractiveness with soft hand.

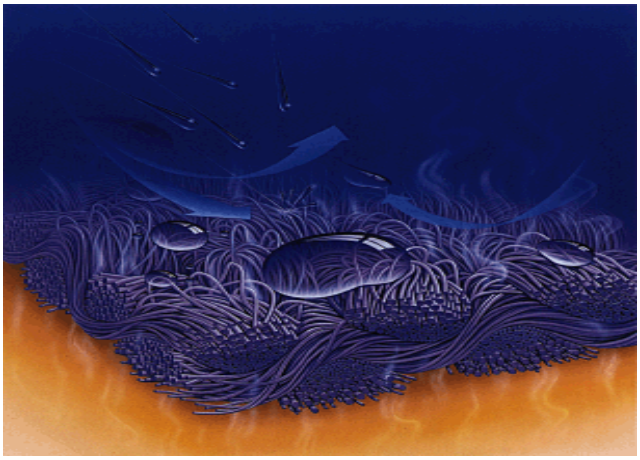


Fig 6 H_2OFF

Toray's "Fieldsensor" is a polyester filament multilayered knitted fabric that offers perspiration absorbing/quick drying properties. The inner layer absorbs perspiration from the wearer quickly, where it evaporates in the air. This mechanism makes use of capillary action. Their uses mainly include knitwear for athletic sports or lining for skiwear.

Naiva[30] : Unitika has developed N aiva fabric by combining the Naiva yarn with a

nylon microfibre14. Naiva is an Eval/nylon bicomponent filament yarn and Eval is nothing but a copolymer resin of ethylenevinylalcohol. Naiva yarn composition is 55% Eval (23% ethylene + 32% vinyl alcohol) and 45% nylon. In the Naiva fabrics there are many nylon microloops *(Fig* 7) on the surface, which are formed by making use of high thermal shrinkage property of Naiva yarn. Naiva fabric not only has good moisture permeability but also has some other positive features like lightweight, softness and has capability of secondary finishing. The fabric is very successfully used in mountaineering wear and other active sportswear.

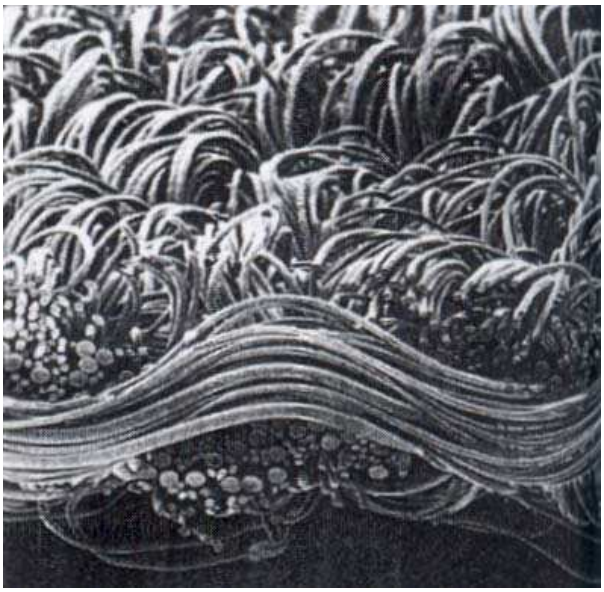


Fig 7: Naviva fabrics with microloops on the surface

Field Sensor[21]*:* Field Sensor is a very popular high performance fabric from Toray, which employs a multi. layer structure that not only absorbs perspiration quickly but also trans. ports it up to the outer layer of fabric very rapidly using principle of capillary action. It is composed of coarser denier yarn on the inside surface (in direct contact with skin), and fine denier hydrophobic polyester yarn in a mesh construction on the outer surface to accelerate quick evaporation of sweat (fig.8).

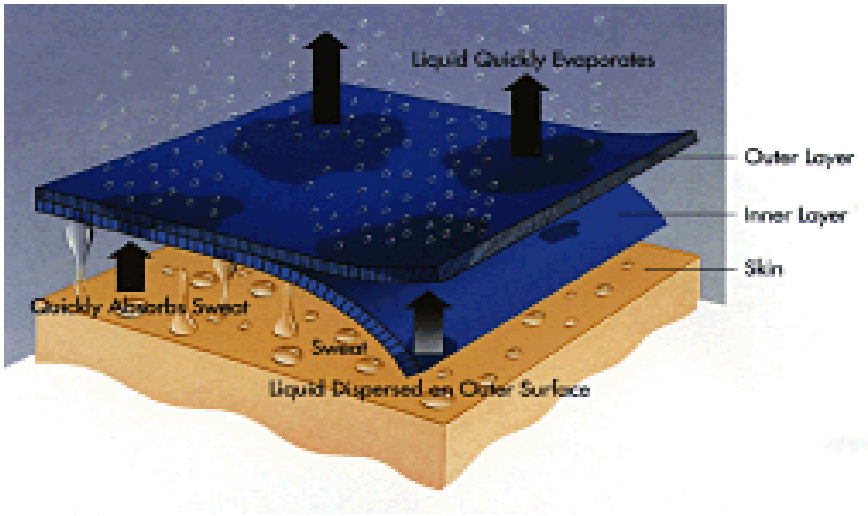


Fig 8: FIELDSENSOR

A variation of same concept is used for Cubesensor and Coolmagic woven fabrics and in Aerosensor, which is a two-way warp knitted fabric.

Reospec[31] : Toray has developed Reospec, which is a same base product as Aquapion but provided with stripe coating of water-repellent chemicals. Reospec has water friction resistance even lower than Acquaspec.

Dimplex[32] : Descente Ltd has developed Dimplex, which takes the dimple convex on the surface jump suits based on fluid mechanics and can substantially reduce air resistance during the run up and flight. It is generally used in skiwear.

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