THE MYSTERY VARIABLE: PART I


The apparel industry, as well as many others, has been subject to revolutions in materials. The emergence of the soft shell category is a manifestation of this. Although the definition of the physical attributes and performance properties of this category is still a work in progress, we can examine the needs that have generated this category.

Since the advent of seam-sealed e-PTFE (expanded polytetrafluoroethylene) laminated (hard shell) garments, the performance level of these materials had been used to set the gold standard. With the advent of these materials the consumer had two choices, waterproof or not. Comfort was an afterthought. These hard shell materials were water-proof (up to 25 psi) and wind proof, and allowed the diffusion of moisture vapor—revolutionary attributes. The extreme sport consumer had a clear and unequivocal pathway. Hard shell was the overwhelming choice for these activities.

As time passed, consumers examined evolving material choices and the trend towards hard shell began. The reasoning was not, “What exactly do I need?” but rather, “If it is good enough to climb Mt. Everest it must be good enough for me.” That is the consumer did not look at the strengths and weaknesses of this material, they simply acknowledged the material as working for a severe application and assumed it would work for their application.

Fast forward to newly emerging technologies that result in fabrics with a different matrix of performance benefits. Fabrics with different strengths (and weaknesses) have created a change in thinking. People are now beginning to ask, “What is available that best meets my needs?”

With the advent of more diverse technologies, the weaknesses of hard shell technology have become more apparent. Some of these weaknesses include lack of packability, total (not just passive diffusion) moisture vapor transport, high absorption, long drying times, durability, and maybe most importantly, comfort. The consumer is now asking, “If I’m not facing a life or death situation, which are the materials best suited to MY needs.” The garment choice is now contingent upon the activity, the duration, and the environmental conditions.

TESTING

The purpose of conventional fabric testing techniques done in a laboratory is to analyze and predict the performance of textile materials in their end use application. At best, current test methods do not completely and accurately predict that performance. There are two major reasons why conventional methods fall short in their predictive capabilities—bad tests and tests that yield data that does not correlate with actual field results.

Choosing a Test

There are a multitude of different test methods available for the evaluation of the properties of a fabric. The first challenge is choosing a good test. A good test must be reproducible, non operator dependant, provide accurate data over its range of use, and clearly differentiate materials. Additional criteria that would be helpful for a good test include low cost for the equipment and simplicity of operation. Cost control and ease of use do not ensure accuracy and precision, but allow for the test to be more easily accepted by a broader audience.

The second challenge is harder to address. A test in which there is a correlation between laboratory results and field performance has been, and continues to be, the goal for the textile industry.

Predicting Performance

Assuming that one has a “good test” (one that fits the criteria described) why wouldn’t it be predictive of end use performance? There are two major reasons. One reason is that the test data is used incorrectly. If the data is from a good test and it is utilized correctly, it should serve as an accurate predictor. However, if one were to get good data (i.e., data from a good test), say tear strength, and try to use that data to predict an unrelated property such as water resistance then there would likely be no correlation between test data (tear strength) and field results (staying dry).

This example tends toward hyperbole and may seem to be a stretch, but what if someone were to use AATCC Test Method 70 (spray test), and take the results and use them to predict percent moisture absorption for the fabric? This happens at times. However, consensus throughout the textile industry is that a 100 on the spray test does not guarantee zero absorption for that fabric under all field conditions.

The second reason that a good test is not predictive is that the field test is evaluated for more parameters than the lab test measures. If you execute a good test and use the data to predict what the test is capable of measuring, then the field results and lab results should correlate. But, what if your field evaluation had an unspoken, unnamed evaluation criterion that you did not measure in your lab test, but consciously or unconsciously evaluated in the field? Conceivably, you could get good positive lab results and fail in the field for reasons other than the parameters for which you tested. This mysterious variable could be “comfort” or some other subjective preference (e.g., garment fit, color, or brand).

What is Comfort?

Subjective evaluation comes into play, whether we like it or not, in live or field trials. The subjective criteria with the greatest impact is comfort. Comfort is defined as, “Performance parameter of apparel referring to wearability. Encompasses such properties as wicking, stretch, hand, etc.”

Taking the full scope of this definition into consideration, it is difficult to develop a good and quantifiable laboratory test that is an accurate predictor of comfort. Arguably, the most important
subjective criterion for apparel is essentially undefined. One could test a host of parameters in the lab (using "good" tests) and come out on top on all of them, yet fail in the field because the garment is not comfortable. To make matters worse, no one proclaims a garment as simply "uncomfortable." If a garment is deemed uncomfortable (for whatever reason) the wearer will often identify a host of other measurable, quantifiable, testable parameters that may bear no relation to the cause of the discomfort. Some examples are: “it doesn’t breathe well, it is too stiff, it is too crunchy, and the sun got in my eyes …” At the present, there are no lab tests that completely correlate with or accurately predict field test results. It is critical that if you have a good test and you use the test within the predictive scope, the field tester should evaluate the garment within the same fundamental environment that the laboratory has tested.

There is a massive amount of sensory information gleaned by the wearer of a garment. This information provides the basis for the determination and evaluation of the level of comfort. Unfortunately, this sensory information is both subjective and objective, while the "good lab tests" deal with the objective only (by definition – subjective measurements would be operator dependent). Comfort is usually not quantified or even specified in a material specification. This doesn’t mean that comfort or any of the other subjective criteria should be ignored, but we must find a way to take subjective criteria into account in the construction of a garment and its materials. If we do not, we could find ourselves in a situation where we are trying to modify an objective property of a material when a subjective property is the cause of the wearer’s displeasure.

**BREATHABILITY**

Breathability is a property that is universally accepted as important. The difficulty comes into play in that there is no universally agreed upon test, result required, or even definition of the word. Following is a description of the definition, mechanism, and some test methods used to measure and predict "breathability."

Fig. 1 shows two methods for measuring moisture vapor transport rate (MVTR). Ten methods could have been shown just as easily. The point here is not that one method is better than the other, but rather that there are a multitude of methods to measure MVTR. In fact, there are more than 10 industry accepted and widely practiced tests used to measure MVTR. When there are many different tests to measure the same variable it is usually because there is not a definitive, universally accepted method of testing. This is the case for MVTR. What are the reasons behind the disagreement? To understand why so many tests are used, one needs to examine the interrelationship between comfort and breathability and the physics of moisture vapor transport.

**Diffusion**

A thought experiment is laid out to illustrate diffusion and convection in Fig. 2. Diffusion is pictorially represented on the top left of Fig. 2. It is simply the system’s attempt to alleviate a concentration gradient. There is a higher concentration of water vapor molecules on one side of the permeable membrane than on the other. The molecules of water vapor are moving randomly (due to thermal energy). In some cases they impact the permeable membrane, and in some of those cases the orientation is such that they cross the membrane. The process described is completely passive, statistically random, and increases directly with the size of the concentration gradient and temperature.

The equilibrium condition is represented on the bottom left in Fig. 2. This is the condition in which the concentration of water vapor molecules is the same on both sides of the permeable membrane. There is no net movement of molecules across the membrane.

**Convection**

Convection is the movement of heat that is being carried by a gas or liquid. Further, a pump or blower can be used to induce forced convection. Since a gas or liquid is carrying heat, then perhaps the situation can exist where water vapor molecules can be moved across a membrane by gas “active” forced convection. The figure on the right of Fig. 2 is an attempt to show this.

In this case the equilibrium condition...
for diffusion is subjected to a moving gas (represented by the hair dryer). If the membrane is configured so that some of the gas can cross it, then the gas can carry some of the water vapor with it. In essence, the energy of the driving force (hair dryer) is being used to set up a concentration gradient in the opposite direction. If the driving force is removed the system will go back to equilibrium.

**MVTR and Barrier Properties**

Fig. 3 represents how the moisture vapor transport rate of a material can be affected by the material’s barrier properties. The microporous film in the middle represents the waterproof ePTFE membranes. The micropores of this material are so small that air from the driving force (the hair dryer) cannot cross the fabric at an appreciable rate, and this membrane only allows diffusion of moisture vapor. Additionally, the hydrophilic film represents the class of materials that are nonporous and do not allow air from the driving force to cross. Since these membranes are hydrophilic, water vapor molecules can diffuse into and then eventually through the polymer matrix. Both of these membranes allow only for diffusion of moisture vapor, but they do it by different mechanisms.

There have been many discussions about how some materials can have varying MVTR performance at different RH (relative humidity) while other materials do not. In fact, this can be clearly seen from the two classes of materials that have been described. The microporous materials behave according to Fick’s Law and are said to be Fickian.® For our case that means the change in concentration of the moisture vapor from one side of the membrane to the other is a function of size of the concentration gradient multiplied by a fixed diffusion constant. The resistance to mass transfers for this material is constant. One of the primary material requirements for this condition to be met is that the membrane must remain constant in its properties over the time that the diffusion is occurring.

The resistance to mass transfers for hydrophilic materials changes as water molecules work their way into, and become part of, the polymer matrix. The MVTR is still a function of concentration gradient, but the mathematical term for diffusion is not a constant. This is called non-Fickian behavior. In fact, hydrophilic materials perform better as humidity increases.

Both of these materials exhibit only passive diffusion, but the hydrophilic material demonstrates its best performance under the highest humidity conditions. This is in fact the genesis of the inverted cup method of MVTR measurement. In that method, the membrane is kept at essentially 100% relative humidity and the difference between the performance of microporous and hydrophilic materials is no longer evident.

As discussed previously materials are starting to be specified by the properties needed for their actual use conditions. For example, a garment for use in skiing may simply require a high level of water resistance, not complete waterproofness. If one must give up other important properties (such as breathability, drying time, and packability) to get the increased water resistance, absolute waterproofness becomes less important. As a material becomes less water resistant, the pores of the material essentially become bigger. There should be a pore size that allows for forced convection of moisture vapor as well as diffusion (Fig. 3). The generation of an additional mechanism for moisture vapor transfer holds out the hope for materials that exhibit an increase in MVTR.

**MVTR and Weather**

So far we have discussed the way certain specific material changes can affect MVTR. Next we will examine how other factors (e.g., weather and motion) can influence the MVTR. Fig. 4 shows the boundaries of a weather envelope. Temperature and humidity can be combined to result in a whole spectrum of conditions, from cold to hot and high humidity to dry. The reasons the conditions are important relate back to the physics for Fickian diffusion. Diffusion is a function of temperature and size of the gradient for the diffusing material. Temperature is directly related to rate of diffusion, so as the system goes from cold to hot, the diffusion rate increases. A very rough rule of thumb is that molecular movement (reaction rate of diffusion) doubles for every 10°C that the temperature of the system increases.®

As the concentration gradient for the diffusing material decreases (as the difference in concentration of water vapor from one side of the membrane to the other gets smaller) the rate of diffusion decreases. The humidity inside a garment in use is high (from perspiration). The humidity outside the garment is dictated by the weather. As the humidity outside the garment increases (moving toward 100%) the concentration gradient across
the garment from inside to outside decreases and the rate of movement of water vapor across the garment slows. From this discussion, it can be easily extrapolated that in an active situation in a hot, low-humidity environment the MVTR of a material will be high and in a cold, high-humidity condition the same material will exhibit lower MVTR.

**MVTR and Motion**

Motion also affects MVTR. Fig. 5 shows factors that affect MVTR. If all the factors are kept constant and the garment is worn sitting in a chair without movement and again while being active, in each instance there will be a difference in the amount of moisture vapor that moves out of the garment. When a body moves within a garment the air between the body and garment also moves. The moving air, which is under pressure, can escape through openings in the garment such as under the waistband or cuffs, or through vents. The moving air can possibly go across the fabric. This movement of air across the fabric would be the embodiment of forced convection that was discussed earlier. If the material from which the garment is made allows both diffusion and forced convection, then this moving air could carry moisture vapor in addition to the moisture vapor that diffuses through the fabric. However, if the material is not capable of forced convection, then only diffused moisture vapor will go through the fabric.

**THE LINK**

We have examined how materials, environmental conditions, and movement affect MVTR. The next issues to be addressed have to do with breathability (what it is and how it is measured) and the relationship between MVTR, breathability, and comfort. I think what people want to know is how comfortable something will be. As stated earlier, there are no laboratory tests for comfort that completely correlate with and predict field results. So researchers focus on a measurable property, breathability, and try to correlate it with comfort.

Interestingly there is no definition for breathability in the relevant dictionaries. Since there is no popularly accepted or published definition for the word breathability, there is a distinct possibility that not everyone has the same understanding of the phenomena. In the textile industry most people mean MVTR, the rate at which water vapor moves across a fabric, when using the word breathability. Fig. 6 is an attempt to show the relationship between breathability, comfort, and MVTR.

**SUMMARY**

The discussion presented here outlines the nature of the physical forces that drive MVTR in the real world. The forces that drive MVTR are gradients of water vapor concentration, the temperature, and in the case of forced convec-
tion, a pressure gradient. The resistance to MVTR is from the fabric and the construction of this fabric dictates whether the material will allow passive (diffusion) only or also active (forced convection) transport. A test that would be predictive of results analogous to those present in the real world may need to be established. Additionally, in essentially all of the MVTR tests performed in the industry, the liquid used is distilled water, which has a higher vapor pressure than sweat with its appreciable concentration of salt. The use of distilled water is a departure from the reality of actual sweat imparted into a garment.

Part I of this discussion examined in general terms the objective of testing, good and bad test criteria, and the mechanism and definition of breathability. Part II of this discussion will examine some of the tests currently used for breathability (MVTR), the interpretation of the data, and what is (and is not) reasonable to predict from the data.

References

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