Comparative Analysis of
Dynamic Moisture Movement Testers

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Abstract

The purpose of this research is to review testing principle, testing design and experimental results of the four dynamic moisture movement testers. The research analyzes Moisture Manager Tester (MMT), Alambeta Instrument, Dynamic Surface Moisture Movement Tester, and Gravimetric Absorbent Testing Method based on American Society for Testing and Material (ASTM) E 96 which is an international standard testing method. Although many of researches use ASTM E 96 to measure moisture movement on a fabric, it has several weaknesses, such as long experimental time and a physical change of sample by a holder of the frame. Hence, lots of researchers have studied and developed the new measurement systems measuring moisture management on a fabric or garment and ultimately mimic heat energy and perspiration created by the human body. These moisture management systems use a variety of parameters, such as electricity, color, and sensor to measure their movement in the fabric. Through comparison with the existing tester (ASTM E 96), the research recognizes the strength and weakness in the dynamic moisture movement testers.

Key Words : Measurement, Comfort, Heat Flow, Moisture Management, ASTM

Ⅰ. Introduction

The research reviews the dynamic moisture movement testers including Moisture Management Tester, Alambeta Instrument, Dynamic Surface Moisture Movement Tester, and Gravimetric Absorbent Testing Method. They focus on how to measure the moisture movement on the fabric because the moisture movement on the fabric is a main factor causing discomfort of the human body. The moisture movement is generally performed by wicking and wetting. Wallace defined the moisture management as "movement between moisture vapor and liquid

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from the surface of the skin to the atmosphere through a fabric"[1]. Hernett and Mehta explained that wettability is defined as "an ability of the surface to attract fluid when a fabric, yarn or fiber is brought into contact with liquid." Wickability is defined as "an ability to sustain capillary flow between fibers"[2].

Moisture management experiments of using functional fabrics have been tested through various and officially recognized testing apparatus in accordance with testing codes, such as those of the American Society for Testing and Materials (ASTM) E 96, British Standard (BS) 7209, and International Organization for Standard (ISO) 11092 (ASTM E96, 2000; BS7209, 1990; ISO11092, 1993)[3]. These published standard testing codes define the moisture management as water vapor transmission (WVT), water vapor permeability (WVP), or water vapor resistance.

For instance, Wallace measures moisture vapor transmission (MVT) rate which means the rate of moisture vapor passing through a fabric by using the open cup test method (ASTM E 96). The testing apparatus measures the amount of moisture vapor in grams that pass through $1m^2$ of fabric in 24 hours with a specific driving force. ASTM E 96 describes the open cup testing method to test the moisture vapor transmission

(MVT). The fabric is set up inside of the beaker containing water. Self-adhesive plastic tape secures the mouth of the beaker (3000 mm^2). Ambient temperature is about 29~30℃. The weight of each container is accurately checked within 0.1 mg as time passes. <Fig. 1> shows the moisture vapor tester, open cup testing instrument. During the testing time, temperature, pressure, and relative humidity should be appropriately controlled in the testing environment.

However, these officially confirmed testing methods have several weaknesses, such as testing time, costs, and physical change of an experimental object. In particular, the experimental testing time is a big issue because external conditions might significantly affect the experimental results. Therefore, this research introduces and reviews non-confirmed dynamic moisture management testers, moisture management tester, alambeta instrument (Permetest model), dynamic surface moisture tester, and gravimetric absorbency test system[4] covering the weaknesses of the confirmed testing methods. Through reviewing procedures and conditions of these testing instruments, the research provides information regarding which testing instrument is more suitable for dealing with moisture management relative to various end users' purposes[5].

<Fig. 1> Moisture vapor test - Open cup testing instrument.

Ⅱ. Research Review

1. Moisture Management Tester (MMT)

This testing instrument is developed by Hu and measures liquid moisture transport ability affecting the moisture sensation of the human comfort perception[6]. Li mentions that the human body automatically regulates its biological cooling system by emitting perspiration in order to respond to the external environment, such as temperature and relative humidity. However, the perspiration and vapor may cause discomfort, such as after-chilling and abrasion, between skin and a fabric in the microclimate. Therefore, a functional fabric tries to efficiently manage the perspiration and vapor to improve the tiny space and ultimately the comfort of the human body[7].

Therefore, this testing instrument and method explain how to measure the dynamic liquid moisture transport ability in a sample fabric. In particular, it evaluates the moisture management functionality in the fabric through comparison between quantitative information of the overall moisture management and subjective evaluations of the runner's discomfort e.g., damp and clammy. Even though many instruments have tried to measure simple absorbency and wicking based on ISO 9073-8, they don't seem to specialize in measuring the dynamic liquid transport ability of perspiration through fabric materials[8].

1) Apparatus Design

Hu has mentioned that this testing instrument takes advantage of a property of the electric resistance in a fabric. Since the fabric itself normally has a huge electric resistance, the electric current movement is prevented from passing through the fabric. However, Kraning mention that fabric saturated by water is changed into a conductor. This means that the water component and water content included in the fabric make the insulation property of the fabric change into a conductor type which allows electric current flow[9].

<Fig. 2> simply shows a simple model of the moisture management tester and its sketch. It shows that upper and lower sensors wrap the sample fabric and coppery ring between Vss and GND, and water is provided through a sweat gland. As the water is slowly spread from the top surface of the fabric to the bottom surface of the fabric, the coppery ring, which is inserted into the fabric, responds to electric voltage. A data logger records change in the electric resistance of the fabric. Temperature and relative humidity of the chamber room are adjusted to $21\pm1℃$ and $65\pm2\%$, respectively. This condition should be equally maintained for 24 hours at least before the test (ASTM D1776, 2004).

As a result of the experiment, the researcher is able to get information about the overall moisture management capacity (OMMC) consisting of 3 factors, such as moisture absorption rate (MAR) of the bottom side, one-way moisture transport capability (OMTC), and moisture drying speed of the bottom side (SS). Therefore, the OMMC can be defined as

$$OMMC = C_1MAR + C_2OMTC + C_3SS \qquad <\text{Eq. 1}>$$

Where C_1, C_2 and C_3 are the weights of the indexes of the MAR, OMTC and SS. These indexes are determined by the end users' purpose. Therefore, the researcher is able to measure and evaluate the dynamic liquid transport ability in the functional fabrics through numerical information of the OMMC.

(A)　　　　　　　　　　　　(B)
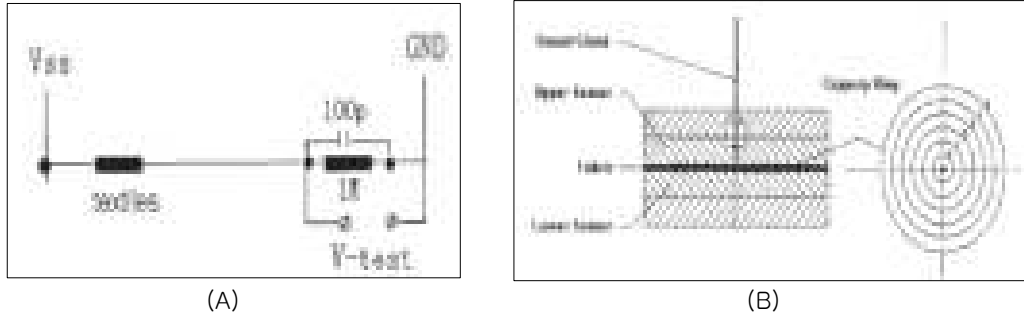
<Fig. 2> (A) A simple model of the testing method and (B) a schematic of tester sensor[10].

<Fig. 3> An actual model of Moisture Management Tester (MMT).
−http://www.sdlatlas.com/

2) Experiment Analysis

As a result of the fabric test using misture management tester(MMT), Hu gets numerical information about OMMC consisting of wetting time, maximum absorption time, maximum wetted radii, and spreading speeds. Also, Hu gets cumulative one-way transport capacity by the fabrics' properties, such as weight, thickness, fabric content, and fabric constructing. In addition, Hu compares subjective data regarding runners' comfort feelings, clamminess and dampness, with the objective data, the OMMC, to identify reliability of the experiment. To conduct a comparison experiment, twenty-eight female participants between ages 18 and 35 run on the treadmill for 20 minutes and then rest for 30 minutes repeatedly. The result of the experiment shows that their comfort sensations have significant co-relationship with the OMMC from 15 to 20 minutes, while they have no relationship with OMMC from 0 to 5 minutes respectively. <Fig. 3> show a model of Moisture Management Tester (MMT).

3) Advantages and Limitations

This testing instrument uniquely considers and uses electric properties to measure the dynamic liquid transport ability in the sample fabrics. As

another advantage of the experiment, it delivers numerical result regarding OMMC in a relatively short period of time. However, the principles of this testing instrument do not follow any international testing standards, and the result of this instrument from 0 to 5 minutes was not matched with subjective results, dampness and clamminess. In addition, the definitions of C_1, C_2 and C_3 are largely unclear, which means that weight of the indexes is too subjective because they can be determined by means of the end users' purpose. If the end users were different, they might have different results of the OMMC using the same sample fabric
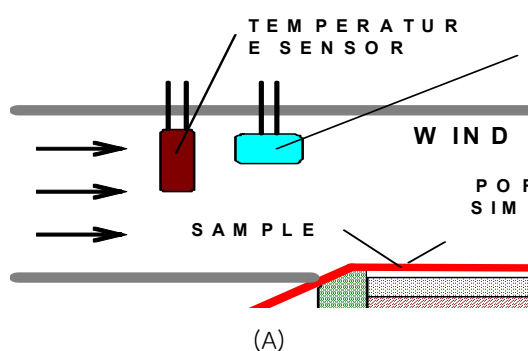
2. Alambeta Instrument

Mikolajczyk et al. mention that a current major issue in functional fabric market is how to measure and deal with water vapor permeability of sports and protective garments to improve comfort sensation of the human body. However, confirmed testing instruments have some weaknesses, such as too much time consumption and high testing cost, in measuring the water vapor permeability in the fabric. Therefore, an important purpose of the Alambeta testing instrument is to measure the water vapor permeability while eliminating the weaknesses of

the confirmed testing instruments. This testing instrument is designed by Lubos Hes[11].

In particular, Hes insists that current testing instruments measuring moisture and dry functions of fabrics are not reliable because of the length of experimental time required, i.e., more than 30 minutes. However, the Alambeta testing instrument he developed is capable of simultaneously measuring water vapor permeability, thermal resistance, and thermal conductivity in a short testing period[12]. Hes points out that experimental time might be a core factor in achieving precise results because external factors, such as relative humidity and temperature, significantly affect water vapor and the drying process of the sample fabric. Therefore, a main purpose of this instrument reduces the testing time in order to minimize involvement of the external environments affecting heat and energy flow. In addition, Lubos Hes states that, this testing instrument is able to analyze and evaluate the effect of structure and composition of the fabric.

1) Apparatus Design

<Fig. 4> shows a schematic of the Alambeta instrument and its photograph. The testing procedures are as follows: At first, prior to mounting

(A)   (B)

<Fig. 4> (A) A schematic of the Alambeta instrument and (B) its photograph.

<Table 1> Sensor and actuators[13].

No.	Quantity	Electric Range	Sensor
1	Heat Flow Density	$(-)0.6\cdots+10$mV	Heat Flow Sensor
2	Temperature Difference	$(-)0.25\cdots+1.25$mV	Differential TC type J
3	Head Temperature	$104\cdots120\Omega$, $52\cdots60$mV	RTD pt 100
4	Relative Humidity	$1.75\cdots3500$KΩ	Polymer Cell
5	Moisturizing	$1\cdots1000$KΩ	Electrodes

the sample fabric, the instrument measures heat value created by a wet porous copper plate with artificial wind. A sample fabric is then placed on the measuring head which has approximately an 80 mm diameter. The heat flow sensor is able to observe and measure the temperature drop of the fabric at that time. Finally, the first and second data sets are compared to analyze thermal comfort properties of the sample fabrics.

As a core system in the Alambeta, its measuring head consists of copper body, water inlet, heading element, thermal insulation, and temperature sensor. It normally regulates the temperature and supports even distribution of water vapor to the sample fabric. Hes states that temperature of the wind channel is higher than that of a chamber room. In addition, various electric sensors are set up and accurately measure the difference between the first heat value and the second heat value passing through the fabric in the measuring head. <Table 1> shows sensors and actuators to measure difference of the heat flow value.

2) Experiment Analysis

Hes has investigated thermal conductivity, thermal absorption, thermal resistance, and heat flow passing through a fabric by using this new equipment. According to his definition of thermal conductivity, it is the amount of heat transfer which passes from 1m^2 area of material through the distance 1m within 1second and creates the difference 1K. Fohr (2002) states that thermal properties of the fabrics are affected by various external environmental factors, such as temperature and relative humidity as well as unique fabric properties, such as structure, density, humidity, type of weave, surface treatment and air permeability[14].
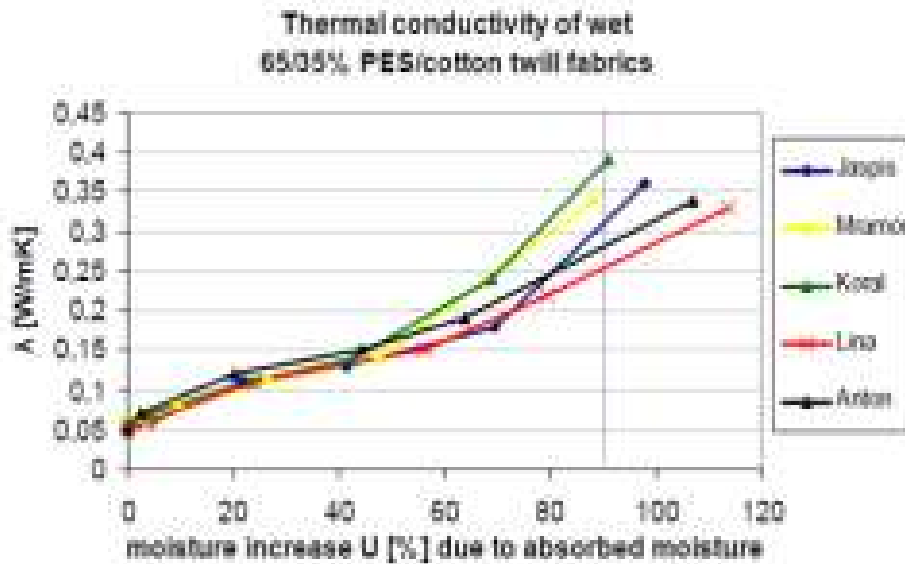
<Table 2> and <Fig. 5> show material properties of five wet polyester 65%/ cotton 35% twill fabrics and their experimental results regarding thermal conductivity, respectively. They demonstrates that, as the amount of moisture increases, thermal conductivity of the fabrics generally increases as shown in <Fig. 5>. In particular, since the thermal conductivity is proportional to the fabrics' square mass, the amount of Koral's thermal conductivity is the highest, while Lina's value is the lowest at 90% moisture in <Fig. 5>.

3) Advantages and Limitations

As Hes stated above, a significant issue of the currently confirmed moisture management testers, such as ASTM E 96 and BS 7209, is that they require a great deal of time to determine a testing result. However, the Alambeta testing instrument would complete an experiment to get a result within 30 minutes.

<Table 2> Characteristics of the polyester/cotton fabrics.

Sample Name	Square Mass (g/m^2)	Density (10 x 10cm)
Jaspis	225	320 x 200
Mramor 1	245	340 x 190
Koral	275	340 x 190
Lina	205	420 x 240
Anton	225	415 x 240

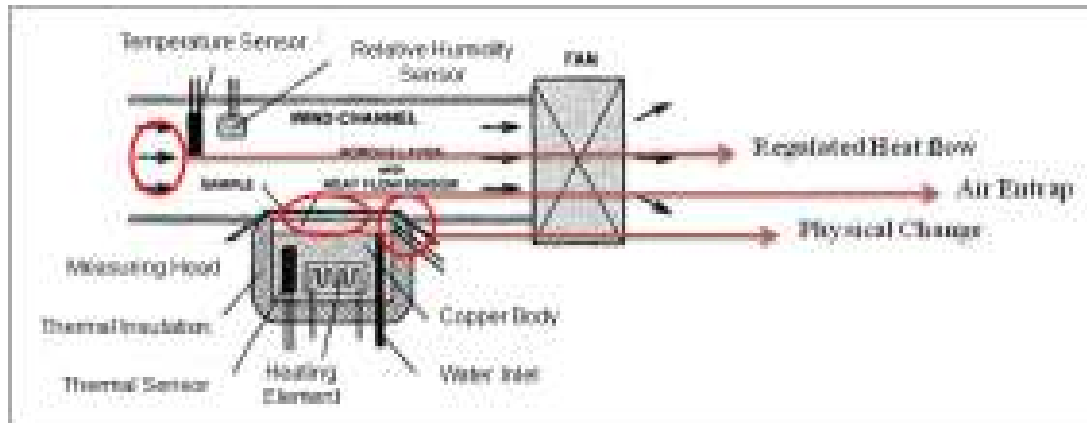<Fig. 5> Thermal conductivity values for wet polyester/cotton medium mass cotton woven fabrics[15].

This means that this testing instrument is able to minimize the influence of the external environments, e.g., temperature and humidity. Another advantage is that the standard methods and their testing instruments need a swatch from an original garment, while the Alambeta instrument is able to test directly a garment without damaging it[16].

However, the Alambeta instrument has several measurement limitations, such as moisture and air leakage in the joint between the measuring head and the sample fabric. In addition, it is difficult to maintain a constantly regulated heat flow in a given condition. Also, when the sample fabric is placed on the measuring head, there is a tiny distance gap between the measuring head and the sample fabric about 1~1.5 mm. This distance entraps air, which affects the accuracy of measuring heat flow from the copper body. Another issue is when the measuring head pressures the sample fabric to be fixed, a joint part causes a physical change in the sample fabric. <Fig. 6> shows the error points as noted by Hes.

<Fig. 6> Potential shortcoming the Alambeta instrument[17].

3. Dynamic Surface Moisture Movement Tester

The purpose of this instrument is to investigate co-relationships between skin comfort and contact with different types of fabric surfaces. Since dynamic moisture movement is related to comfort feeling for the human body in a given environment, this testing instrument focuses on the speed of movement of clothing next to the skin[18]. In addition, Scheurell mentions that heat energy transfer mechanisms causing dynamic moisture movement also influence the co-relationships between the comfort of the skin and the fabrics' surface[19].

Scheurell found that the amount of water giving rise to a sensation of discomfort in the human body is very small. Approximately 3~5% added moisture in the fabric was enough to cause the sensation of discomfort. Hence, Huang (2007) mentions that it is possible for this testing instrument to measure the dynamic moisture movement of the fabric by taking advantage of change in cobalt chloride in the experiment[20]. The color change of cobalt chloride paper is evaluated through comparison with Munsell

Hue's color index system. <Table 3> shows a level of dynamic surface wetness of the fabric based on Munsell Hue's color index system.

1) Apparatus Design

This system evaluates the level of dynamic moisture movement on fabrics, which have different ratios of cotton and polyester, by conducting subjective and objective tests together. As an objective method, Scheurell takes advantage of a new testing instrument, the dynamic surface moisture device. Even though this testing system looks simple, it sufficiently considers moisture management testing mechanisms, including skin, microclimate, fabric, temperature and relative humidity[21].
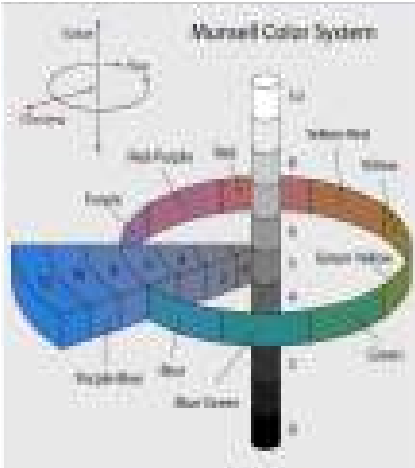
In this testing system, the testing equipment's devices simply consist of wet chamois replacing a sweating skin, hot plate representing a human temperature, and the cobalt chloride paper which is a moisture management simulator. As the hot plate steadily increases the temperature in the chamois and water, it gives rise to vaporization, which causes a color response of the cobalt chloride paper on the underside of the sample fabric[22]. This means that, using this
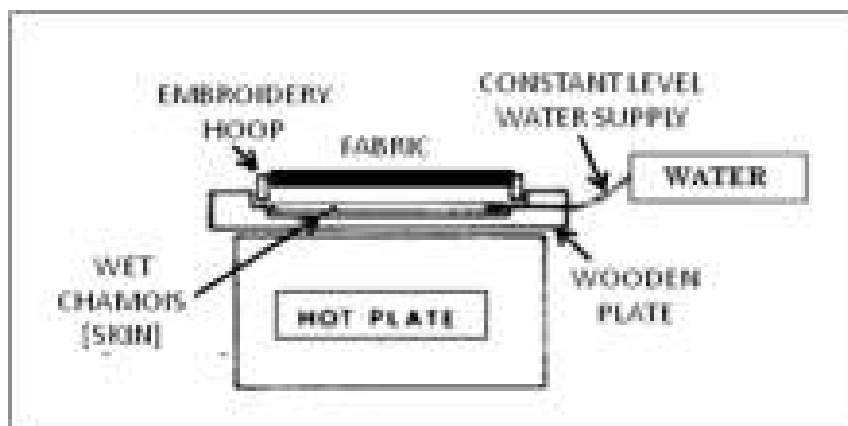
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simple testing method, the researcher is able to compare and confirm condensation levels of the sample fabrics through the color change of the cobalt chloride paper[23]. <Fig. 7> shows a schematic of the dynamic surface moisture device.

As a subjective method, experimental participants, who wear shirts having different cotton polyester blends, experience discomfort sensations, such as sticky, clammy, damp, and clingy, after running for 30 minute under a given condition of 35℃ and 30~90% R.H. After conducting

<Table 3> Level of dynamic surface wetness of the fabric and color index system of Munsell Hue.

Color Index	Color Description	Munsell hue	Munsell Hue's Color Index System
1	Royal Blue	5 PB	
2	Medium Blue	7.5 PB	
3	Dull Light Blue	10 PB	
4	Blue Lav Edge	2.5 P	
5	Lavender Blue	5 P	
6	Lavender	7.5 P	
7	Lavender Pink	10 P	
8	Pink Lavender	2.5 RP	
9	Pink Lav Center	5 RP	
10	Pink	5.1RP	

-http:/en.wikipedia.org/wiki/Munsell color system

<Fig. 7> Dynamic surface moisture device[24].

the subjective and objective experiments, Scheurell studies relationships between subjective rates in clammy and damp sensation, and the color response of the cobalt chloride paper based on the Munsell Hue color index system.
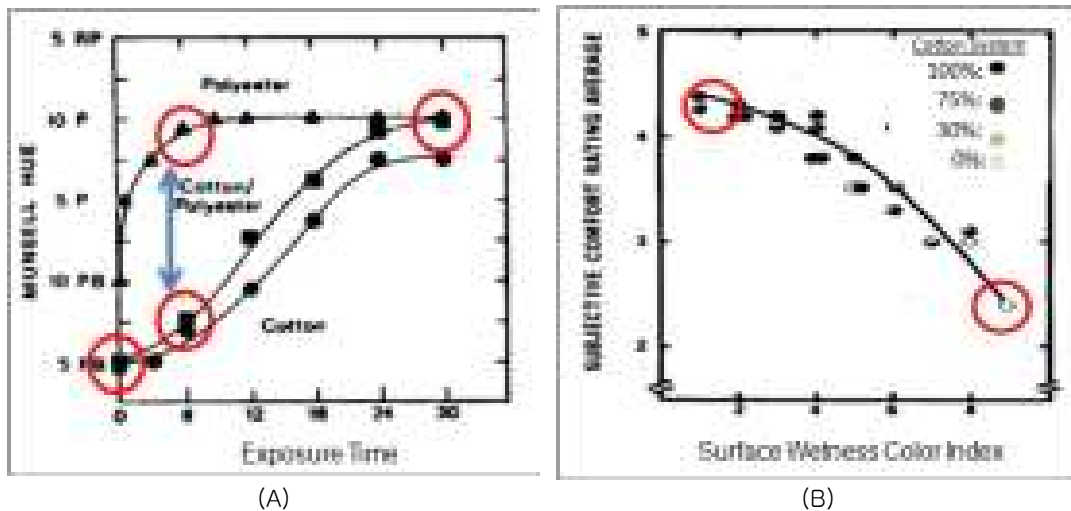
From the results of the comparison, it is possible to verify a relationship between wetness levels of the fabric and comfort feelings of the human body because the result of the color response showing the different wetness levels is related to the sensation of comfort, such as clammy and damp. In addition, the result informs which of tested fabrics having differing ratios of cotton and polyester, is more suitable for comfort in a given environmental condition. In addition, this testing process also shows how to convert objective data into subjective data.

2) Experiment Analysis

This experiment focuses on the moisture movement property in three types of fabrics, such as polyester, cotton/polyester blend, and

cotton, which are chemically finished[25]. Scheurell mentions that the weight, air permeability, and weave structure of the fabrics have a significant influence on the color change response in the cobalt chloride paper while the fabric is being condensed. <Fig. 8> (A) shows the wetness level of the fabric exposed to moisture in the simulated sweating device over time, while <Fig. 8> (B) illustrates relationships between subjective comfort rating average and the color index of the surface wetness of the fabrics which have different cotton ratios. In particular, the arrow obviously demonstrates a difference in moisture movement in polyester and cotton fabric at 6 minutes.

From <Fig. 8> (A), the researcher recognizes that moisture movement in the polyester is faster than that in cotton and cotton/polyester blends. However, water mobile films which are inside of the specifically finished cotton fibers produce a certain range of internal micropore sizes, which assists mobility of the moisture movement on the fabric, and finally enhances a comfort level

(A)   (B)

<Fig. 8> (A) A wetness level of the fabric exposed to moisture based on Munsell's color system and (B) Relationships between subjective comfort rating average and surface wetness[27].

of the human body[26]. In addition, since this method is a new testing method, Scheurell tries to obtain qualified reliability of this experiment by testing a human object at the same time.

3) Advantages and Limitations

The advantage of this testing instrument is an ingenious idea taking advantage of the color change of cobalt chloride paper as a simulator for checking a wetness level. Although this method is simple and cheap and doesn't require a great deal of time to achieve a data result, it creates a condition similar to a microclimate, which considers skin, small space between fabric and skin, perspiration, and external environments, such as temperature and relative humidity.

However, one limitation of this testing instrument is that color evaluation after conducting an experiment might be different in accordance with researchers' view. It is not easy to accurately assess some colors, such as between purple and blue, and purple and red, based on the Munsell Hue's color index system[28].

4. Gravimetric Absorbent Testing System

Yoo mentions that a purpose of this instrument studies is to study moisture vapor transmission (MVT) rate, which ultimately measures wet-ability of the fabric through absorbency rate, absorbency capacity, and evaporation rate[29]. Wallace explains that this testing instrument is also able to measure the drying rate of the fabric. Normally, the wetting phenomenon of fabric is conducted by a wicking property which is determined by contact angle as well as surface energy of the fabric between fabric surface and water molecule.
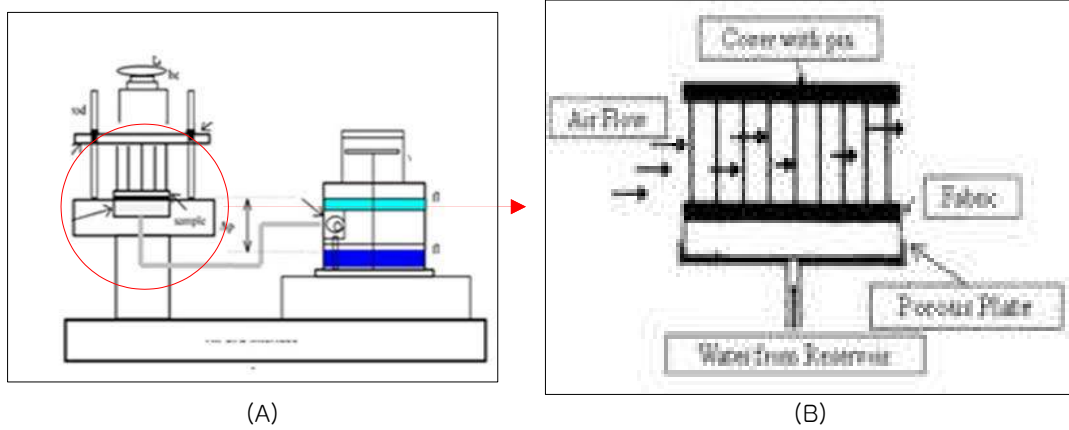
Therefore, a hydrophilic finishing process of the fabric to reduce the contact angle can be a critical strategy to improve the wicking phenomenon of the fabric. This means that the wicking property is closely related to the wet-ability of the fabric[30].

Laing states that a drying rate in the fabric is correlated with the relative humidity of microclimate. Therefore, each fabric's various properties, such as porosity, thickness, and hygroscopicity, can be a function which governs the drying time of the fabric[31]. In particular, Laing explains that this experimental instrument is helpful in recognizing relationships between fabric structure and vapor/water permeability.

1) Apparatus Design

The gravimetric absorbency testing system consists of several devices, including capillary pressure head controller, cover with pins, frictionless bearing, and porous plate. Water is fed to a porous plate which has the ability to appropriately distribute it into the fabric. In <Fig. 9> (B), the cover with pin is also helpful to distribute capillary power generated from a pressure head controller evenly[32]. The role of the pin reduces the space between porous plate and fabric. Under this setting, the sample fabric is placed on the porous plate and is pressed by the pressure head controller in order to test the wetting of the fabric. <Fig. 9>[33] shows a schematic diagram of the gravimetric absorbency testing system and a part of porous plate.

While the absorption test for this instrument is terminated when the sample fabric absorbs 0.01g water, the absorption capacity is evaluated by the weight difference between a fully wet fabric and dried fabric at that time. To conduct the drying test, the sample weight is measured by the change in the amount of the water moisture

(A)   (B)

<Fig. 9> (A) Schematic diagram of the gravimetric absorbency testing system and (B) Part of porous plate. −*100% cotton moisture management*

<Table 4> Fabric description.

Fabric Code	Structure	Fiber Content	Mass (g/m^2)	Thickness(mm)
KIA	Interlock	Wool	230.88	1.15
KRA	Rib 3118	Wool	219.28	1.12
KSA	Single Jersey 3118	Wool	356.2	1.24
KSC	Single Jersey 3009	Wool	150.92	0.68
KSD	Single Jersey 3029	Wool	197.46	0.8

−*100% cotton moisture management*

on the sample fabric before and after the test. In addition, Yoo explains that all of the sample fabrics tested in his experiment were washed at least three times, and the chamber room conditions, such as temperature and relative humidity, are controlled for 24 hours before the test. <Table 4>[34] shows information of the sample fabrics Laing tested.

2) Experiment Analysis

Laing finds that the absorption capacity of the sample fabrics is positively related to fabric weight and thickness. In addition, Laing mentions that correlations between fabrics' structure and exposure to water are significantly affected by the fabrics' density and the total water absorbed. However, Yoo explains that he cannot find a positive relationship between absorption capacity and thickness through his experiment. <Table 5> shows the results for the absorption capacity of the fabrics tested.

Normally, a fabric, which is treated by a hydrophilic wicking agent, has lower contact angle and is also quickly wetted[35]. The effect of the wicking agent dealing with contact angle between

<Table 5> Gravimetric absorption capacity[36].

Sample Name		KIA	KRA	KSA	KSC	KSD
Total Water Absorbed(g)	Mean	5.246	5.105	4.791	2.735	3.222
Evaporation(%)	Mean	16.68	17.25	17.72	26.11	22.72

fabric surface and water molecule has an influence on the absorption capacity in the 100% aramid fabrics. However, even though the wicking finish treatment affects hydrophilicity of the fabric, it cannot change the total amount of water absorbed in a fabric. In addition, Yoo recognizes that the water remaining on the fabric causes a damp and clammy feeling when conducting the drying test by using air flow.

3) Advantages and Limitations

The advantage of this testing instrument is that it prevents overestimation in absorption capacity of the sample by regulating capillary power using the sintered glass pillars of the pressure head controller[37]. It is useful for analyzing wicking phenomenon by experimental results which are related to an absorption rate and capacity of the fabric[38]. However, a limitation of this instrument is that it is not easy to evenly distribute capillary power into the sample fabrics and to maintain constant air flow when the researcher conducts absorption and drying experiments.

III. Discussion and Conclusion

The four experimental equipments and methods measured water movement or vapor flow or heat conductivity on the fabric. In order to accurately measure them, the equipments takes advantage of characteristics of electricity,

heat flow, color change, and capillary power on fabric respectively because they sensitively react to water movement or vapor flow. In addition, common sectors setting up the four experimental apparatus are heat energy source, fabric holder, and liquid or vapor flow.

These experimental methods exactly analyze a property of fabrics as well as recover weaknesses of the standard method (ASTM E 96). For instance, as their experimental time is reduced, experimental results can be more accurate because it is not easy to maintain an external environment affecting the experimental results for a long time. However, these experimental methods don't consider a role of microclimate between the heat energy source replacing a skin and fabric layer, even though a distance in the microclimate influences on water movement or vapor flow. Since the microclimate is air space which has low heat conductivity, these equipments must consider volume or distance of the microclimate between skin and fabric layer or between a layer and layer.

Finally, the advantages and limitations of the four dynamic moisture movement testers are as following; In the Moisture management tester, the advantages are uniquely consider electric properties to measure the dynamic liquid transport in the fabric, while its limitations is that definitions of are largely unclear. Alambeta instrument is capable of getting a result within 30 minutes. Therefore, it can minimize involvement in the factors, temperature and

relative humidity, of the external environmental causing experimental errors. In addition, its tester does not have to have a swatch without having any damage from an original garment. On the other hand, there is likelihood that moisture and air leakage in the joint between the measuring head and the sample fabric. It is difficult to maintain a constantly regulated heat flow in a given condition. As advantages of the Dynamic Surface Moisture Movement Tester, This method is simple and cheap and doesn't require a great deal of time to get data results. However, The color evaluation is too subjective. Gravimetric Absorbent Testing System is that it prevents overestimation in absorption capacity of the sample by regulating capillary power. Through the absorption rate and capacity of the fabric, wick-ability can be analyzed. As the gravimetric absorbent testing system's limitations, it is not easy to evenly distribute capillary power into the sample fabrics and to maintain constant air flow.

IV. Future Works

The research cannot find any data regarding comparison with the four dynamic moisture movement testers. Therefore, the research will conduct the moisture management by using the same fabrics and the four apparatus and then compare the results. In addition, since these e measurement apparatus is for one layer system, it is not easy to reflect moisture movement in an actual clothing system based on the layer-by-layer assembly. Therefore, the research will develop the new measurement system which is able to evaluate a multi-layered garment system.

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