ANALYSIS OF MODERN METHODS FOR MEASURING VAPOR PERMEABILITY PROPERTIES OF TEXTILES

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Abstract
There are great number of measuring methods of the characteristic and the terms describing vapor permeability phenomenon. In this paper such methods of vapor permeability investigation as ASTM E96; ISO 15496; BS 7209; JIS L1099; ISO 2528; ISO 11092 (EN 31092); ASTM 1868 are studied and analyzed; their features, advantages and disadvantages are noted; attempt to understand the reason of impossibility of comparison of the numerical data received by various methods is made.
Key words: vapor permeability, gravimetric method, “sweating hot plate” method

1. Introduction

Moisture transport through textiles is the important factor which influences on thermophysiological comfort of the human being. The moisture can be transferred through a textile material in the form of vapors and liquids. The analysis of the scientific literature shows high and constant interest to a problem of reliable determination of vapor permeability properties of textiles [1 – 12]. Many methods for measuring of vapor permeability and terms which characterize this phenomenon are exist. A variety of test conditions, designs of devices and approaches enables fundamental understanding and comprehensive studying of vapor permeability phenomenon. However, there is a problem of impossibility of comparison of the numerical values received by various techniques.

The purpose of this article is analysis of methods and terms for determination the vapor permeability of textile for estimation of expediency of choice known technique depending on research tasks.

2. Results of investigation

There are number of standard methods available for measuring of vapor permeability of textiles:

- *ASTM E96* Standard test methods for water vapor transmission of materials;
- *ISO 15496* Textiles – Measurement of water vapor permeability of textiles for the purpose of quality control;
- *BS 7209* Specification for water vapor permeable apparel fabrics;
- *JIS L1099* Testing methods for water vapour permeability of textiles;
- *ISO 2528* Sheet materials. Determination of water vapour transmission rate – Gravimetric (dish) method;
- *ISO 11092 (EN 31092)* Textiles – Physiological effects – Measurement of thermal and water-vapour resistance under steady-state conditions;
- *ASTM 1868* Standard test method for thermal and evaporative resistance of clothing materials using a sweating hot plate.

The methods can be divided on two groups:

- gravimetric methods;
- “sweating hot plate” methods.

Gravimetric methods are the most simple and commonly used methods (in instrument registration and on procedure of research). These methods are named also “cup method” and “dish method".

The principle of vapor permeability determination according to this method underlies such norms as: ASTM E96; ISO 2528http://www.iso.org/iso/rss.xml?csnumber=20676&rss=detail;

ISO 15496; BS 7209; JIS L 1099. The earliest testing standard, ASTM E96, was issued in 1953.
The principle of vapor permeability determination by "cup method" on example ASTM E96 and ISO 15496 is considered. These two norms most full cover different conditions and procedures of vapor permeability determination by this method.
According to ASTM E96 "cup method" can be realized by three ways:

– "desiccant method" – vapor transport is passed out from an environment to inside of cup (fig.1, *a*);
– "water method" – vapor transport is passed out from inside of cup to environment (outside of cup) (fig.1, *b*);
– "inverted water method" – method similar "water method", but cup inverted so, that textile is in contact to water (fig.1, *c*).

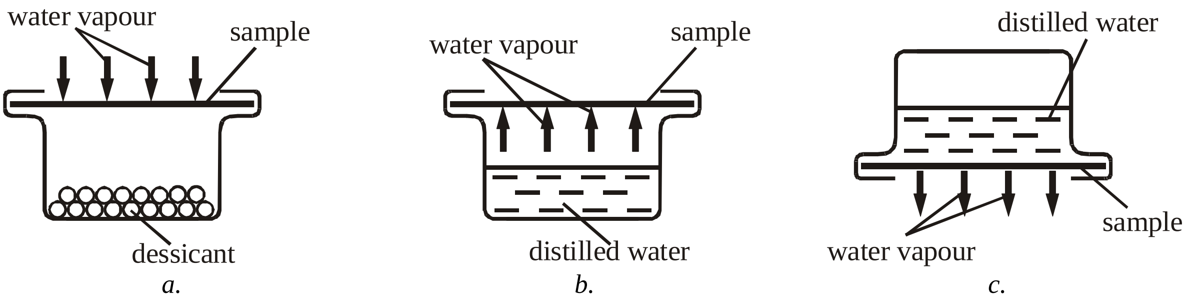


Figure 1. Schemes for measuring vapor permeability by "cup method" (ASTM E96):
a – desiccant method; *b* – water method; c – inverted water method

This norm has 6 different versions of the testing procedure (table 1). Average test time is 1 ÷ 24 hour (8 replicate observations).

Table 1. Characteristics of procedures for measuring vapor permeability by ASTM E96

Method	Procedure	Ambient temperature, ºC	Relative humidity of air, φ, %	
			inside cup	outside cup
Desiccant method	A	23,0	0	50
	C	32,2	0	50
	E	37,8	0	90
Water method	B	23,0	100	50
	D	32,2	100	50
Inverted water method	BW	23,0	100	50

During researching by "desiccant method", procedures A, C, E (ASTM E96) test cup is filled with dry calcium chloride or silica gel. The circular sample is tight covered the cup. The cup prepared for testing is located in the controlled environment (table 1). Because of a difference in concentration (pressure) water vapor from both side of a cup vapor diffusion occurs through a textile inside of cups. Vapor is sorbed by desiccant. The quantity of absorbed vapor is defined by weighting.
At research by "water method", procedures B and D (ASTM E96) test cup is filled with the distilled water. The circular sample is tight covered the cup. The cup prepared for testing is located in the controlled environment (table 1). Under action of a difference of concentration (pressure) water vapor inside of a cup and from the outside occurs vapor diffusion through a textile from a cup in an environment.
The analysis has shown, that vapor permeability, defined by "desiccant method" and "water method", describes a level of comfort at low physical activity (low sweating) more adequately, but does not give the information about condensation on a textile surface. There is the lack of vapor permeability, measured by these methods, depends not only on properties of

a material, but also from thickness of a air layer which adjoins to a textile surface (thickness of a material is much less as thickness of an air layer).

For textiles with water-repellent finishing it is recommended to use “inverted water method”, ASTM E96, procedure BW. Test cup is filled with the distilled water. The circular sample is tight covered the cup and this cup inverted so that textile sample contacted to water. The cup prepared for testing is located in the controlled environment (table 1). Cup with sample is weighted on the experiment start and on the expiration of demanded time.

According to ISO 15496 “cup method” is carried out by “inverted desiccant method”. Test cup is filled with the desiccant (a solution of potassium acetate) and covered by polytetrafluorinethylene (PTFE) membrane (fig.2, *a*). PTFE membrane is waterproof and vapor permeable. Textile sample together with layer of PTFE membrane are fixed in frame (fig.2, *b*). The PTFE membrane must be in contact with water. A cup with a desiccant is turned upside-down and placed on textile sample (fig.2, *c*). Vapor penetrations through PTFE membrane and is sorbed by desiccant (a solution of potassium acetate).

a. *b.* *c.*

Figure 2. Scheme for measuring vapor permeability by “inverted desiccant method”

The analysis has shown, that vapor permeability been measured by “inverted desiccant method”, describes a level of comfort at high physical activity (high sweating) more adequately because excludes influence of air layer. This gravimetric method is considered as prototype of new generation of “sweating hot plate” methods. PTFE membrane models a human skin because of membrane performance (simultaneous vapor permeability and water resistance). It became possibility to model the sweating by skin.

Let's consider terms which are used for the characteristic of textile vapor permeability by gravimetric methods:

1. Water Vapor Transmission Rate, *WTR* – the steady water vapor flow in unit time through unit area of a body, normal to specific parallel surfaces, under specific conditions of temperature and humidity at each surface. *WTR* is expressed in $\left[{}^{g}/_{m^2 \cdot hhhhhhh}\right]$ or $\left[{}^{g}/_{m^2 \cdot hhh24hhhhh}\right]$. *WTR* is calculated as:

$$WTR = \frac{G}{t \cdot A} \qquad (1)$$

where *G* – weight change, g;

t – time during which *G* occurred, h;

A – test area, m^2.

2. Water Vapor Permeance, W_d – the time rate of water vapor transmission through unit area of flat material or construction induced by unit vapor pressure difference between two specific surfaces, under specified temperature and humidity conditions. Therefore, water vapor permeance is the ratio of WVT to water vapor partial pressure between two sides of specimen. The commonly used unit is: $\left[{}^{g}/_{m^2 \cdot hhhhhhhhh \cdot Pa}\right]$. The equation (1), therefore, is modified to (2):

$$W_d = \frac{G}{t \cdot A \cdot \Delta p} \qquad (2)$$

where Δp – difference of partial pressure between two sides of specimen, Pa.

3. Water Vapor Permeability, *WVP* – the time rate of water vapor transmission through unit area of flat material of unit thickness induced by unit vapor pressure difference between

two specific surfaces, under specified temperature and humidity conditions. Water vapor permeability is the product of water vapor permeance and textile thickness. The commonly used unit is: $\left[g \cdot m / m^2 \cdot h \cdot Pa \right]$. *WVP* is calculated as:

$$WVP = G \cdot \frac{h}{t \cdot A \cdot \Delta p} \quad (3)$$

where h – textile thickness, m.

4. Relative Water Vapor Permeability, *RWVP* – the attitude of vapor quantity (G) which has evaporated through sample of textile, to vapor quantity (G_2) which has evaporated from a cup without sample of textile. The commonly used unit is [%]. *RWVP* is calculated as:

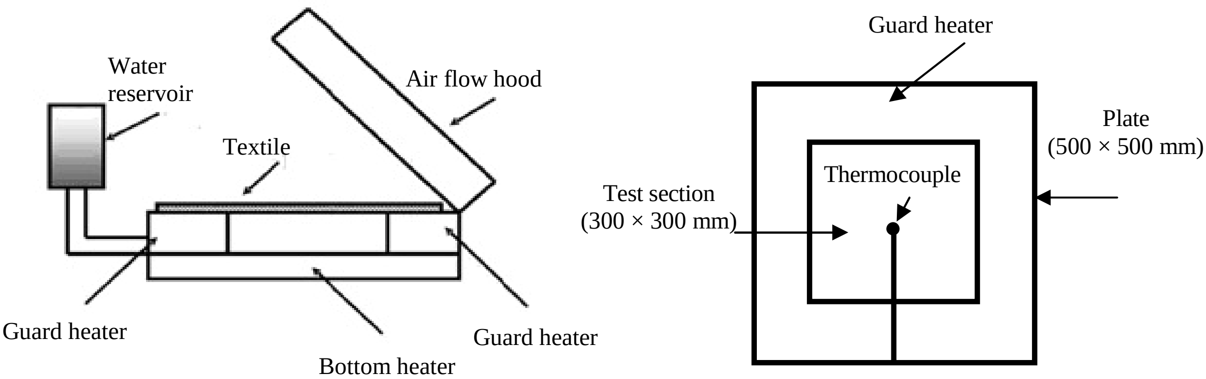
$$RWVP = 100 \cdot \frac{G}{G_2}. \quad (4)$$

"Sweating hot plate" methods (ISO 11092 (EN 31092) and ASTM 1868) are new generation of methods for determination of textile vapor permeability. These methods have wide use in modern investigations of the American, European and Asian researchers and manufacturers [7, 9]. These methods allow to fulfill the test at intimate contact of textile to a wet plate, so-called sweating plate. During researching the total mass of vapor (sorbed and passed) which characterizes ability of a textile to move off a moisture from underclothes spaces. Examples of such devices are SGHP-8.2 (fig. 3, *a*), PSM-2 (fig. 3, *b*) and PERMETEST (fig. 3, *c*).

a. *b*. *c*.

Figure 3. Instruments for measurement of vapor permeability by "sweating hot plate": *a* – SGHP-8.2 (USA); *b* – PSM-2 (Czech Republic); *c* – PERMETEST (Czech Republic)

By "sweating hot plate" method sample of textile (the size 300×300 mm) placed on a surface of a heated "sweating" plate which is covered by cellophane vapor permeable membrane (fig. 4). The plate and membrane models sweating process by human skin. Conditions of test: $T_{air} = T_{plate} = 35\ ^0$C; relative humidity of air = 40 %; air speed = 1 m/s. During measurement the plate temperature is supported at a constant level. Gradually water, passing through a plate and a membrane, evaporates. Energy which is spent for maintenance of constant temperature of plate, is considered at definition of the main parameter "water-vapor resistance". Duration of one sample measuring is from one till two hours.



a. *b*.

Figure 4. Scheme for measuring vapor permeability by "sweating hot plate" method on device SGHP-8.2 [ISO 11092 (EN 31092)]

For the characteristic of textile vapor permeability by "sweating hot plate" method are used following terms:

1. Water-Vapor Resistance, R_{et} – is water-vapor pressure difference between the two sides of specimen divided by the resultant evaporative heat flux per unit area in the direction of the gradient. The unit is: $[m^2 \cdot Pa / W]$. Water-Vapor Resistance is calculated as:

$$R_{et} = \Delta p \cdot \frac{A}{H - \Delta H_e} \tag{5}$$

where Δp – difference of partial pressure between two sides of specimen, Pa;
A – area of the measuring unit (plate), m^2;
H – heating power supplied to the measuring unit (plate), W;
ΔH_e – correction term, W.

2. Water-Vapor Permeability Index, i_{mt} – is ratio of thermal (R_{ct}) and water-vapor resistances (R_{et}) in accordance with equation:

$$i_{mt} = S \cdot \frac{R_{ct}}{R_{et}} \tag{6}$$

where S = 60 Pa/K.
Water-Vapor Permeability Index is dimensionless, and has values between 0 and 1. A value of 0 implies that the material is water-vapour impermeable, that is, it has infinite water-vapor resistance, and a textile with a value of 1 has both the thermal resistance and water-vapour resistance of an air layer of the same thickness.

3. Water Vapor Permeance, W_d $[g / m^2 \cdot h \cdot Pa]$ – characteristic of a textile depending on water-vapor resistance and temperature in accordance with equation:

$$W_d = \frac{1}{R_{et} \cdot \phi T_m} \tag{7}$$

where ϕT_m – latent heat of vaporization of water at the temperature T_m of the measuring unit (plate).
Analyze has shown that the "sweating guarded hot plate" method is characterized by high cost, complexity of design and service, time-consuming and require large amounts of textile specimens (300 × 300 mm).
Taking into account disadvantages of "sweating guarded hot plate" method Lubos Hes has developed a fast response measuring instrument (skin simulator), the PERMETEST [11, 12], for measuring of the water vapor permeability of textile fabrics, garments, nonwoven webs and foils (fig. 3, *c*). Skin simulator operates on the principle of heat flux sensing. The instrument provides all kinds of measurements very similar to the ISO Standard 11092. The differences in relation to this standard depend in smaller sample, application the 20 – 22 ºC isothermal laboratory temperature instead of 35 ºC (at the water-vapor resistance measurements) and by the application of the laboratory (environmental) water-vapor concentration (humidity) of the parallel air flow 45 – 60 %, instead of the air humidity level of 40 %. Principle of operation the PERMETEST is following. Slightly curved porous measuring surface is wetted (either continuously or on demand) and exposed to parallel air flow of velocity (1,5 or 3,0 m/s). The tested sample is located in the distance of 1,0 – 1,5 mm from the wetted area of diameter 80 mm and characterized by high thermal conductivity. The heat flow is generated by evaporation of water from the measuring surface and is measured by a special heat flow sensor integrated into the porous layer. The time of measuring is 2 minutes for measuring the permeability of synthetic and blend fabrics. This instrument provides the relative water vapor permeability of the textile in the steady state isothermal condition:

1. Relative Water Vapor Permeability, *RWVP* – the ratio of heat lost when the textile is placed on the measuring head to heat lost from the bare measuring head. The unit is [%]. *RWVP* is calculated as:

$$RWVP = \frac{\text{Heat lost when the fabric is placed on the measuring head}}{\text{Heat lost from the bare measuring head}} \times 100 \quad (8)$$

This method is the express-method which allows to receive relative values of textile vapor permeability. And as have shown the previous researches they have high correlation with the data measuring by “sweating guarded hot plate” method.

The analysis of test results by gravimetric method and “sweating guarded hot plate” method has shown, that it is impossible to establish clear correlation dependence between the value measured by various methods, even under condition of their recalculation to the common units of measure. It is explained by the big difference in conditions of researches, namely, in parameters of humidity and an ambient temperature, air speed, and also in the procedure of measurement. Change of one of the parameters of research condition leads to prevalence of one or another mechanism of vapor transport through a textiles.

The test results on textiles provided by gravimetric method and “sweating guarded hot plate” method cannot be applicable directly to clothing. This is because it ignores the amount of body surface area covered by textiles, the distribution of textile layers and air layers on the body, the looseness and tightness of fit, the increase in surface area for heat loss, namely clothing area factor, the effect of clothing design, the adjustment of garment features, variation in the temperature on different parts of the body, the effect of body position and movement.

3. Conclusion

Based on preceding, it is obvious, that each method has the advantages and disadvantages, however comparison of the test results received by different methods, is not possible. Researcher or manufacturer should be guided by functional application of a product, conditions of its operation, and also to consider material and labour expenditure for choice of vapor permeability determination method.

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