VARIATIONS OF THE AIR PERMEABILITY OF SELECTED WOVEN FABRICS DUE TO CHANGES OF THE AIR TEMPERATURE AND HUMIDITY

Lubos Hes, **Vladimir Bajzik**
Technical University of Liberec, Faculty of Textile Engineering, Liberec, Studentská 2,
46117, Liberec, Czech Republic
lubos.hes@gmail.com

ABSTRACT
Air permeability is one of the fundamental textile properties influencing the wearing comfort of clothing. Air permeability depends mainly on the fabric porosity and thickness and on the pores spatial geometry. Due to the certain importancy of this property, many studies were published in recent years, in which the effect of all the mentioned parameters on the fabrics air permeability was theoretically and experimentally analyzed. However, most of the studies refers to the fabric permeability at the standard laboratory conditions, but in the real life, fabrics are also used at diferent climatic conditions. In the paper, the effect of air temperature and humidity on the air permeability of selected woven fabrics are firstly alalyzed and experimentally determined.

Key Words: air permeability, textile fabrics, air temperature and humidity

1. INTRODUCTION TO THE FABRIC AIR PERMEABILITY

Permeability of fabrics for air given by their porosity contributes to heat and mass transfer through clothing by convection (when the pores are bigger) and to mass transfer by diffusion and consequent convection, when the pores diameter is in the range of micro and nanometers.

In summer, porosity of clothing is a positive property, whereas in the cold climate porosity is mostly considered a negative property. Due to this ambivalent effects of porosity, porosity became less important then other basic parameters of thermophysilogical comfort, but papers on the porosity of fabrics are quite abundant, as the determination of this parameter is quite easy [1-5]. However, most of the studies refers to the fabric permeability at standard laboratory conditions, but in the real life, fabrics are also used at diferent climatic conditions, see e. g. in [6]. Examples of the porous fabrics are shown in the next Figure 1.

Figure 1. Examples of the porous woven and knitted fabrics

Fabric porosity ε_ρ can be determined from the density [kg.m^{-3}] of the polymer component ρ_p and the fabric density [kg.m^{-3}] ρ_f, whereas the volumetric porosity is calculated from the specific volume [m^3/ m^3] of the polymer component ε_p and the fabric volume V_f [m^3/ m^3]. The third method used mostly for thin fabrics employs the cover factor C_f determimed e. g. by optical methods.

$$\varepsilon_\rho = 1 - (\rho_p / \rho_f) \qquad \varepsilon_v = 1 - (V_p / V_f) \qquad \varepsilon_C = 1 - C_f \qquad (1)$$

For thick fabrics the first type od porosity P_ρ is the most practical one. In this case, the fabrics is considered as a solid body containing relatively long pores, so that the air velicity laminar parabolic profile is achieved.

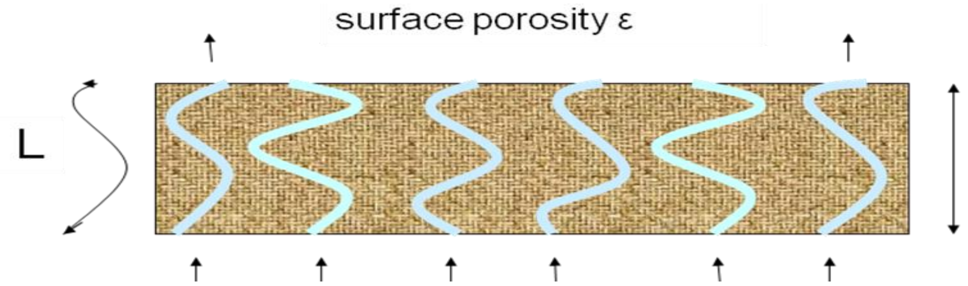


Figure 2. Textile fabrics as the solid body with channels

In this case, the Reynolds number Re should be first determimed:

$$Re = U_m.\ d/\ \nu, \text{ where} \tag{2}$$

U_m - mean air flow velocity [m/s] d_h - hydraulic diameter of a pore, m
ν - kinematic viscosity of the air [m^2/s]

According to kinetic theory, if the Reynolds number is below 2320, the flow in the tube is laminar and in such case $\lambda = 64$, n = 1. Then the friction coefficient f can be calculated

$$f = \lambda\ Re^n, \text{ where} \tag{3}$$

λ - coefficient of laminar or turbulent flow, n - a coefficient indicating the flow regime

Thus the pressure drop ΔP in the channel can be determined as follows

$$\Delta P = f.h.\ \rho.U_m^2 / (2\ d_h), \text{ where} \tag{4}$$

ΔP - The pressure drop [Pa] of the flow through a duct over the thickness of the fabric h [m]
ρ - air density [kg/ m^3]

For next calculations, the porosity ε should be determined, and used for calculation of the average air flow rate U_m and air velocity through pores U with diameter $d_{p\ and}$ section A:

$$U_m = \Delta P.\ d_h^2 /(32.h.\eta), \text{ where} \tag{5}$$

η - dynamic viscosity of the air [Pa.s], $U = U_m/\ \varepsilon$, $U = 0{,}785.\ d_p^2$ (6)

The total flow rate of the air Q [m^2/s] where m is number of pores per square meter

$$Q = m.\ A.U = \Delta P .m.\pi.\ d_p^4 / (128.\varepsilon.\eta.h)\ [m^3/s] \tag{7}$$

Then, the required air permeability of the fabric P [m/s] follows from the equation

$$P = Q/A_f, \text{ where } A_f \text{ is the tested fabric area } [m^2]. \tag{8}$$

Which parameters in the Equation (8) may affect the air permeability of the fabric P? With temperature, fabric porosity may change. To consider the effect of the fabrics temperature on their qeometry, the fabric temperatures t were roughly estimated from the equation (11). This equation presents heating of textile fabric of sqare mass m_s [kg.m^{-2}] with initial temperature $\mathbf{t_0}$ by convection in a hot impact air with temperature $\mathbf{t_H}$ (here $\boldsymbol{\alpha}$ means the heat transfer coefficient, approx. 500 [W/m^2.K] and $\mathbf{c_p}$ is the specific heat of the used polymer (1500 [J/kg.K]):

$$t = t_H - (t_H - t_0) \exp (- 2 \alpha \tau / m_s / c_p) \qquad (9)$$

Here, $\boldsymbol{\tau}$ means the time of the fabric heating, which corresponds to the time of permeability measurement. This time was always in the range of 6 to 9 sec. The used heat transfer coefficient $\boldsymbol{\alpha}$ depends on the approx. 500 [W/m^{2}K] air velocity, which corresponds with the fabric permeability P given in the next Tab. 1.

Table 1. The studied woven fabrics (yarn fineness of weft and warp yarns were 45 dtex)

Fabric parameters	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Standard air permeability P [m/s]	0,793	1,02	1,11	1,24	[illegible]
Material	100% POP	POP65%/Cot35%	POP35%/Cot65%	100%Cot	100% Cot
Structure	plain	plain	plain	plain	twill
Warp/weft density [n/10cm]	108/180	108/180	108/180	108/180	
Sq. Mass [gm^{-2}]	167	158,8	161,2	147	400
Thickness [mm]	0,65	0,60	0,55	0,51	0,90

For low air velocities presented in the Tab. 10 the heat transfer coefficient $\boldsymbol{\alpha}$ may reach the level of 200 [W/m^2.K], which would result in the low temperature increase of the studied fabrics describe also in the Tab.1. In order to get safe results regarding the fabric heating, the heat transfer coefficient was intentionally increased to 500 [W/m^2.K]. The highest fabric temperatures caused by the fabric heating in the testing instrument entrance see below [7].

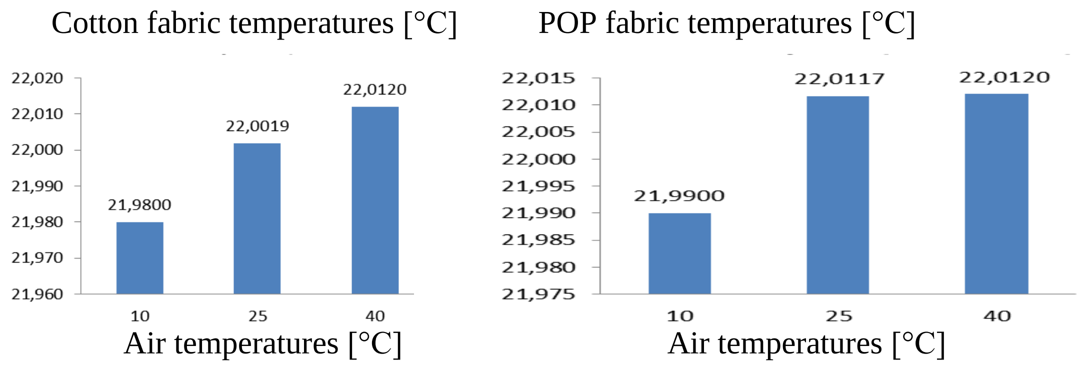


Figure 3. Temperature of cotton and POP fabrics after their exposition of air with different temperature in the measuring orifice if the FX 3300 instrument.

From the Fig. follows, that the initial temperatures of the tested fabrics (about 22°C) practically did not change during the testing process. What about the effect of the varying air humidity on the fabric porosity and consenquently also on the fabrics permeability? The fabric radial swelling due to the absorbed moisture might be quite significant factor, but determination of porosity of wet fabrics is not easy. In this study, the effect of moisture on fabric geometry was not subject to investigation. It can be expected, that samples consisting at least partly of cotton might by well influenced by the air humidity, whereas the samples made of 100% POP would not exhibit this effect.

On the contrary, the air temperature affects the air density and viscosity, which might exhibit certain impact on the determined air permeability of the fabrics, see in the Fig.

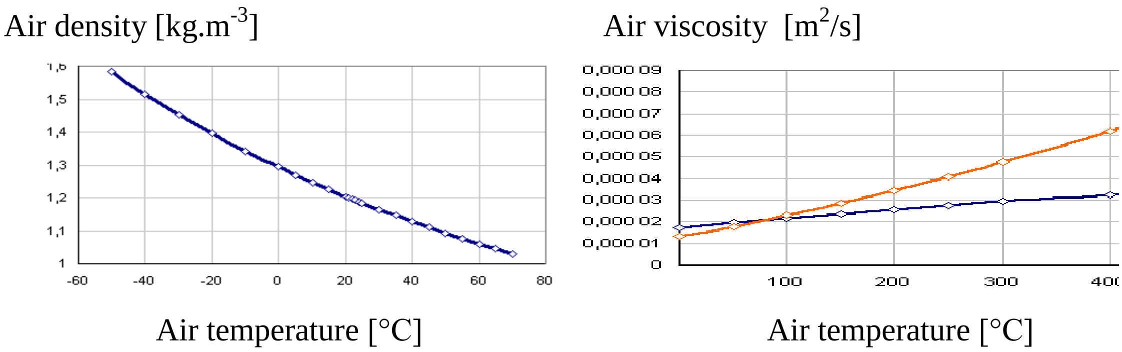
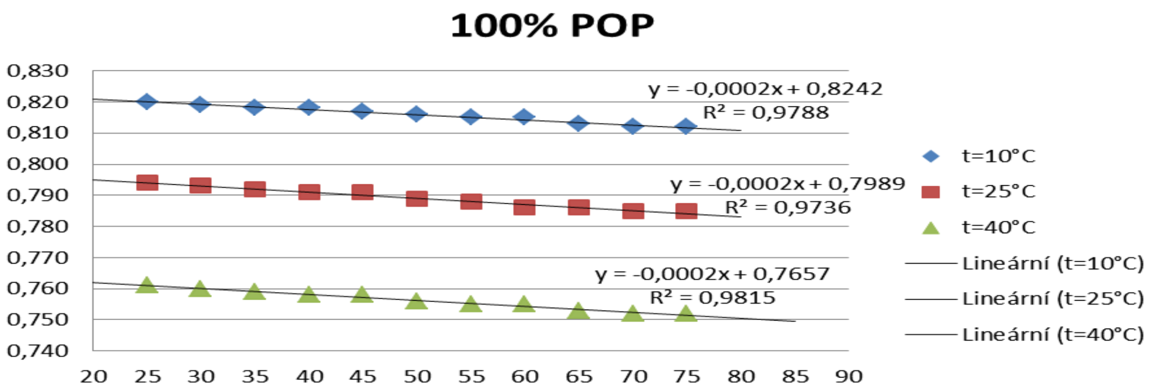


Figure 4. Effect of the air temperature on the air density and viscosity

2. EXPERIMENTAL SETUP AND RESULTS OD MEASUREMENTS

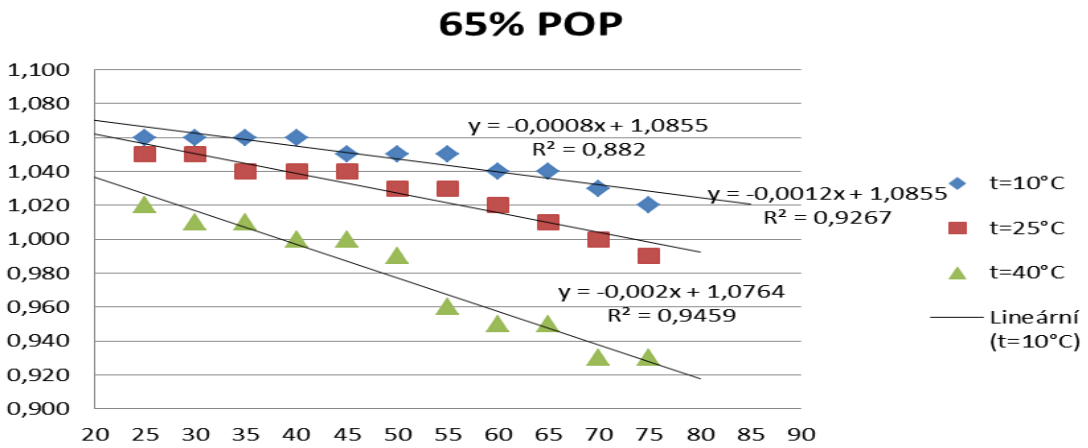
The purpose of our study was to investigate the effect of air temperature and humidity on the air permeability of 5 fabrics made of cotton and polypropylen – see their characteristics in the Tab.1. Air permeability measurements were performed with the Air Permeability tester FX 3300 I (Textest Instruments) at the pressure 100 Pa. The sucking orifice of the Tester was connected by means of large flexible tube with the climatic chamber Voetsch (see the Fig. 1), which served as a source of pressurized air with variable air temperature and humidity. In order to eliminate the effect of temperature and humidity changes during the air passage from the chamber to the tester, a precise air temperature and humidity sensor AHLBORN was placed in the sucking orifice od the FX 3300 tester.

Figure 5. Measuring setup: the source of hot and humid air VOETSCH, air permeability tester FX 3300 and the air temperature and humidity measuring system AHLBORN.



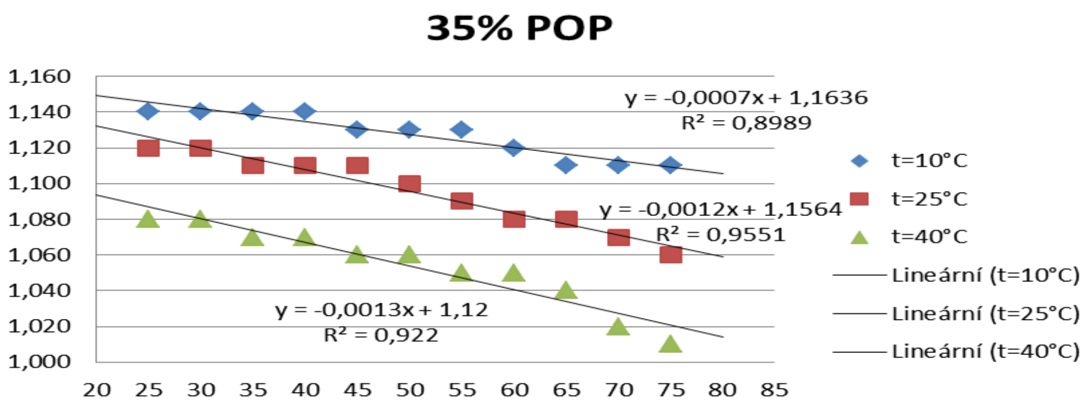
Air permeability [l/m²/s]   Air relative moisture content [%]

Figure 6. Effect of air temperature and humidity on air permeability of 100% POP fabric



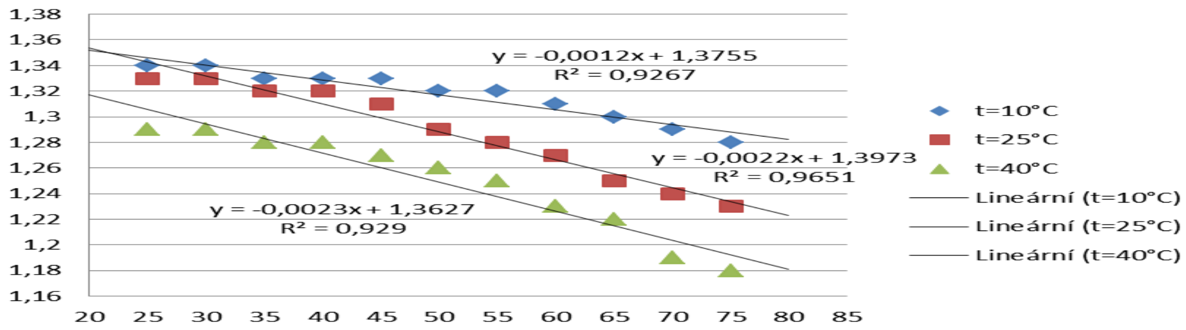
Air permeability [l/m²/s]   Air relative moisture [%]

Figure 7. Effect of air temperature and humidity on air permeability of POP/Cot 65%/35% fabric



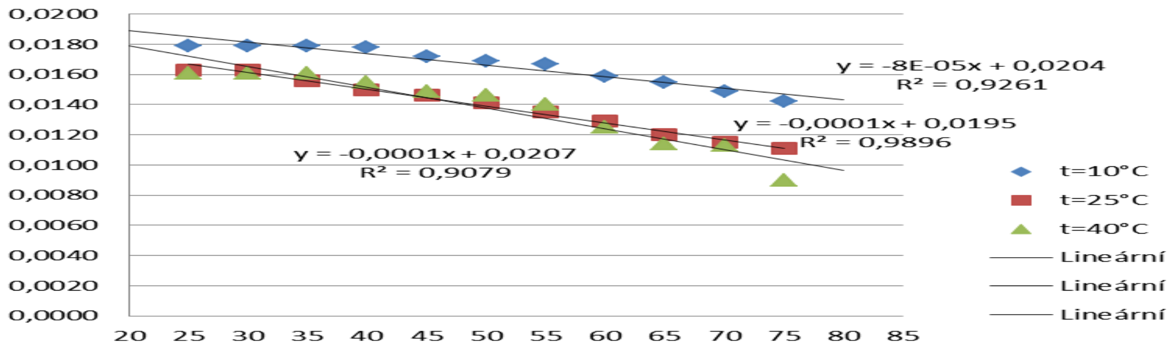
Air permeability [l/m²/s]   Air relative moisture [%]

Figure.8. Effect of air temperature and humidity on air permeability of POP/Cot 35%/65% fabric



Air permeability [l/m^2/s] Air relative moisture [%]

Figure 10. Effect of air temperature and humidity on air permeability of 100% cotton fabric



Air permeability [l/m^2/s] Air relative moisture [%]

Figure 11. Effect of air temperature and humidity on air permeability of the denim fabric

4. CONCLUSIONS

The experiments revealed, that in all cases, the air permeability decreased with the increasing air humidity and temperature. The observed effect of humidity was the lowest at the hydrohobic POP fabric. This can be explained by the lowest swelling of this fabric, contrary to the highest swelling of the hydrophilic cotton fabrics. The research works will continue.

REFERENCES

[1] KULITSCHENKO, A. Theoretical analysis, calculation and prediction of the air permeabilty of textiles. Fibre Chemistry, 2005, vol. 37 no. 5, pp. 371-379.

[2] HALEEM N. et al. Predicting the Air Permeability of PES / Cotton woven fabrics. Fibers and Polymers, 2013, vol. 4, no.7, pp. 1172 – 1178,.

[3] OGULAVA, R. 2006. Air permeability of Woven Fabrics. J.TaTM, vol.3, no. 2, pp. 1-10.

[4] MILITKY, J., TRAVNICKOVA, M., BAJZIK, V. Air permeability and light transmision of weaves. Internat. J. of Clothing Science and Technol.,1999, vol. 11, no. 2/3, pp.116 – 125.

[5] ÇAY, A and TARAKÇIOĞLU, I. Prediction of the air permeability of woven fabrics using neural networks. Int. J. Clothing Science and Technol. 2007, vol. 19, no.1-2, pp 18-35.

[6] HES, L., LOGHIN C. Heat, Moisture And Air Transfer Properties Of Selected Woven Fabrics In Wet State. J. of Fiber Eng. and Informatics, 2009, vol. 2, no.3, pp. 188-197.

[7] MATYAS M.: MSc Thesis, Technical University of Liberec, 2013, 80 pages.