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Air Permeability of Woven Fabrics

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ABSTRACT

Air permeability is an important property for wovens and it depends on many parameters of the fabric. Thus, a theoretical determination is highly complex and difficult in relating the parameters to the air permeability. Therefore, establish of the air permeability is usually made experimentally.

In this study, it has been attempted to establish a simple theoretical model for the air permeability of woven fabrics. For the purpose, a capillary model of porous systems on D'Arcy's law was used, and theoretical values were investigated.

Keywords: Air permeability, woven, fabric structure, warp and weft yarn.

Introduction

The air permeability is a very important factor in the performance of some textile materials. Especially, it is taken into consideration for clothing, parachutes sails, vacuum cleaners, fabric for air bags and industrial filter fabrics. The air permeability is mainly dependent upon the fabric's weight and construction (thickness and porosity).

Woven fabrics are produced by interlacing warp and weft yarns. The warp lies along the length of the fabric whereas the weft (or filling) lies across the width. Every warp yarn is separated from all the others. Thus, the warp consists of a multitude of separate yarns fed to the weaving apparatus. On the other hand, the weft yarn is usually laid into the fabric, one length at a time [1].

There are voids between weft and warp yarns in the fabric. The void volume within a textile fabric plays a major role in a variety of consumer and industrial applications, including apparel comfort, flammability, thermal insulation efficiency, barrier fabric performance, and the precision of filter media [2].

The void volume in woven textile fabrics causes air permeability. The air permeability of a textile fabric is determined by the rate of air flow through a material under a differential pressure between the two fabric surfaces [3]. The prescribed pressure differential is 10 mm of water [4,5].

The air permeability of a fabric is influenced by several factors: the type of fabric structure, the design of a woven, the number of warp and weft yarns per centimeter (or inch), the amount of twist in yarns, the size of the yarns and the type of yarn structure [6]. Therefore, establishing a more complex theory expressing the air permeability related to all fabric parameters will bring out difficulties. To simplify the case and close to the aim, some important parameters such as the pore in the fabric were taken into account in calculation the air permeability. Three factors are mainly considered related to the pores in the fabrics. Cross-sectional area of each pore, depth of each pore or the thickness of the fabric and the number of pores per unit area or the number of warp and weft threads per unit area.

So, in this study, these parameters are considered to develop a simple theoretical approach for the air permeability, examining a plain woven fabric, non-manufactured but imagined, i.e. assuming that the warp yarn count and density are Nm20 and 20 ends/cm respectively varying the weft yarn count. The results of model applications based on the assumed parameters of the imagined fabric are given and discussed in the end of the paper.

Determination of air permeability for plain woven

The woven textile fabrics have a porous structure. The porosity is defined by the ratio of free space to fiber in a given volume of fabric. The porous are by voids between weft and warp yarns in the fabrics. The air passes through the pores from the surface of the fabric.

The air permeability is defined as the volume of air in milliliters which is passed in one second through 100 s mm^2 of the fabric at a pressure difference of 10 mm head of water [5].

A woven fabric structure (plain woven) is shown in figure 1 and the cross-sectional fabric structure is shown in figure 2. During the transport of the air through the porous of woven fabrics part of the energy of the air is used to overcome the friction of the fluid on the fabric and the rest to surmount the inertia forces. When the size of the pores decreases, the fluid friction of the fabric increases [7].

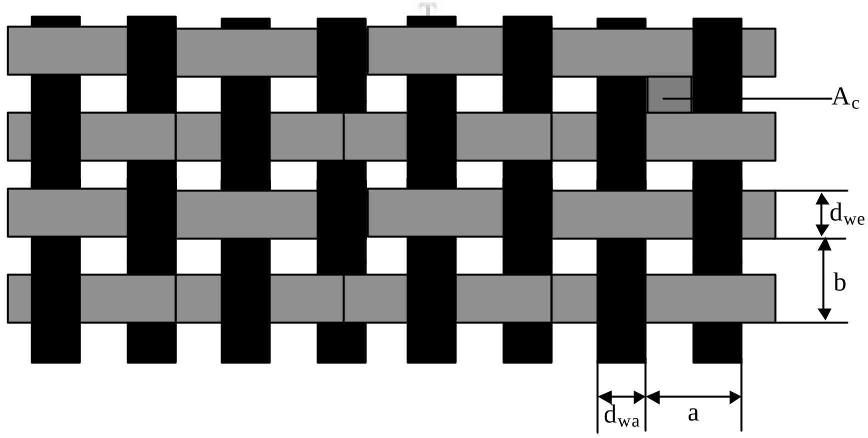

Figure 1. Plain woven fabric structure

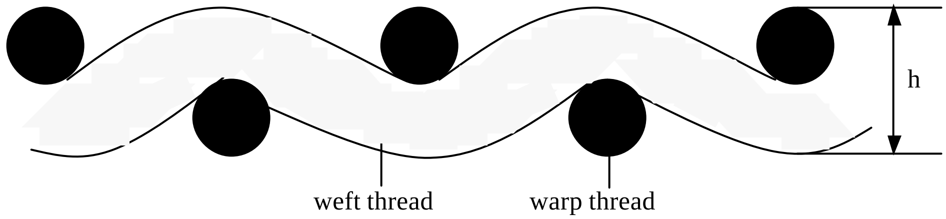

Figure 2. Cross-sectional fabric structure

The dependence of the friction coefficient f on the Reynolds Number Re for laminar and turbulent flow is described by the Blasius equation [8];

$$f = l.\mathrm{Re}^{-n} \qquad (1)$$

where l is the coefficient of laminar or turbulent flow, n is a coefficient indicating the flow regime.

Laminar flow: l = 64, n=1
Turbulent flow: l = 0.3164, n=0.25

The type of flow depends on Reynolds number. The Reynolds number represents the ratio of inertia force to viscous force. This result implies that viscous forces are dominant for small Reynolds numbers and inertia forces are dominant for large Reynolds numbers [8]. The Reynolds number is used as the criterion for determining the change from laminar to turbulent flow.

$$\mathrm{Re} = \frac{U_m.d_h}{n} \qquad (2)$$

Where U_m is the mean flow velocity, d_h is the hydraulic diameter. The hydraulic diameter is defined by [8],

$$d_h = 4.A_c/P \qquad (3)$$

where A_c is the cross-sectional area of a pore (figure 1) and P is the wetted perimeter of a pore. The pressure drop of the flow through a duct over the thickness of the fabric is related to the friction factor f by the following expression [9].

$$\Delta P = f\frac{h}{d_h} ? \frac{U_m^2}{2} \qquad (4)$$

where h is the thickness of the fabric, ρ is the air density. For simple woven structures, h depends on the structure phase d<h<2d (Figure 2, It is accepted $d_{wa}=d_{we}=d$) [7]. In this study, it is taken h=1,5.d . As known, the length of air flow paths through a fabric is effected upon air permeability.

The woven fabric is porous structure. For this reason, the air velocity in pores must be taken into consideration [7],

$$U = U_m/e \qquad (5)$$

where U_m is the air velocity through pores, ε is rate of void area. Porosity of a fabric is defined by the ratio of free space to fiber in a given volume of fabric [10]. It may be written as;

$$e = m.\,A_c/A_f \qquad (6)$$

where A_f is the surface area of the fabric, m is the number of pores in the unit fabric determined by the warp and weft densities as;

$$m = m_{wa}.m_{we} \qquad (7)$$

where m_{we} is the number of weft and m_{wa} is the number of warp in the unit fabric.

The air velocity through pores of the fabric has not usually a high value. Therefore, the fluid flow in the pores is laminar flow. For non circular ducts, the turbulent flow occurs for Re>2300. For this reason, the mean air velocity through one pore can be rewritten from equation (1) and (4) as:

$$U_m = (d_h^{\,2} / 32 h.h)\ .?P \qquad (8)$$

The flow rate of the air for the fabric with porous material Q becomes

$$Q = m.A_c.U \qquad (9)$$

The cross-sectional area of a pore is given by [8]

$$A_c = \frac{p.d_h^{\,2}}{4} \qquad (10)$$

Thus, equation (9) can be rewritten as;

$$Q = \frac{m}{e}.(p.d_h^4/128.?.h) \qquad (11)$$

Here the hydraulic diameter of a pore (d_h) is calculated by eq. (3). Hence, it needs the determined cross-sectional area and perimeter of a pore. The values of A_c and P can be determined as follows (see also figure 1) [11].

$$a = \frac{L}{m_{wa}} - d_{wa} \qquad (12)$$

$$b = \frac{L}{m_{we}} - d_{we} \qquad (13)$$

$$A_c = a.b \qquad (14)$$

$$P = 2(a + b) \qquad (15)$$

where d_{wa} is diameter of warp threads and d_{we} is diameter of weft threads.

As known, the yarns in the structure of fabric have not a smooth surface and a solid construction. There are a lot of emptiness in the yarns. Hence the cross-sectional area of the pore is increased almost 25%.

Results and Discussions

In this study, the theoretical model can be used to calculate the air permeability of woven fabrics. The construction factors and finishing techniques affects the air permeability. It is influenced by several factors such as the type of fabric structure, the design fabric density, the amount of twist in yarns, the size of the yarns, the type of yarn structure, the size of the interstices in the fabric and etc. [6].

The theoretical results are given in figures 3-5. The specific gravity value used was 1.5 gr/cm^3 for cotton [12], and dynamic viscosity of the air value taken 18.10^{-6} Pa.s [13] in the theoretical calculations.

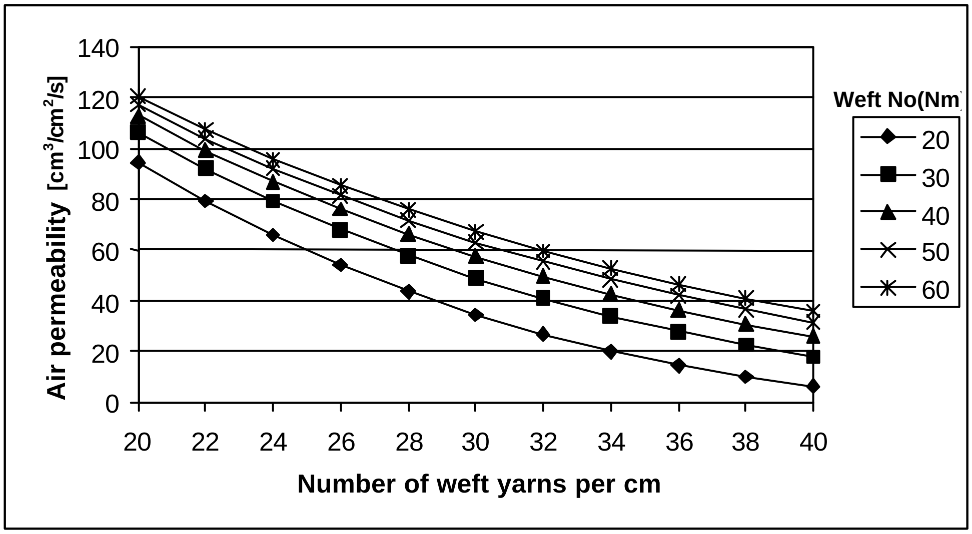

Figure 3a. The variations of the air permeability of the woven with the number of weft yarns per centimeter for different weft number (Warp no: 20 Nm, Number of warp yarns per cm:20).

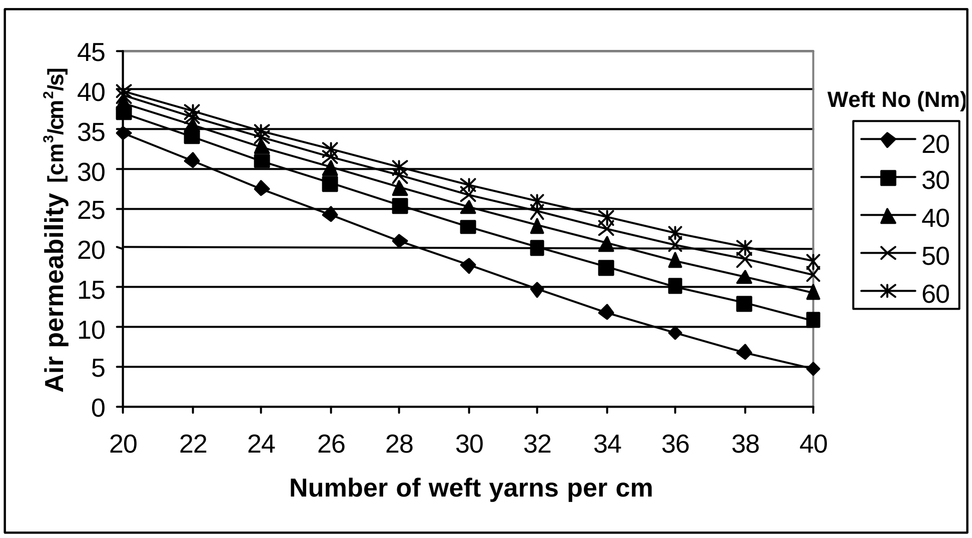

Figure 3b. The variations of the air permeability of the woven with the number of weft yarns per centimeter for different weft number (Warp no: 20 Nm, Number of warp yarns per cm: 30).

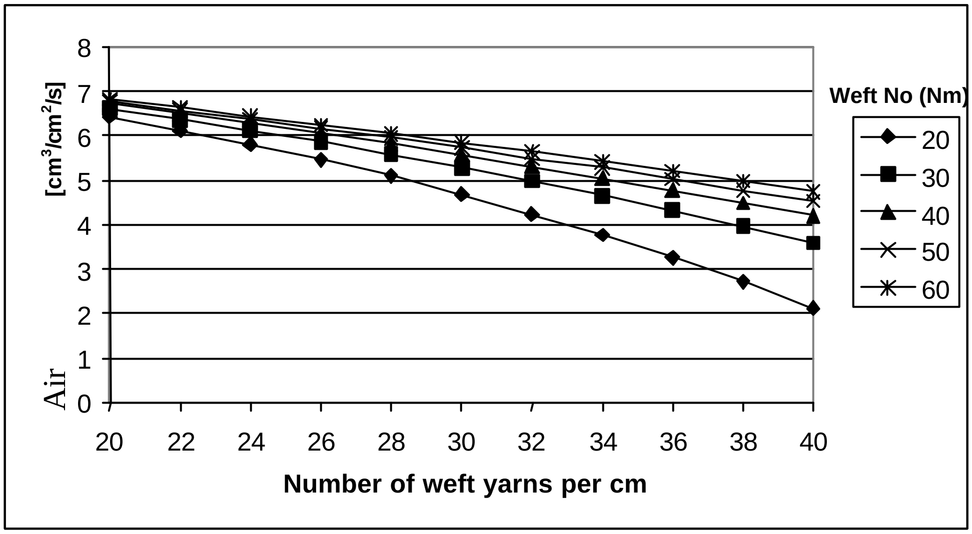

Figure 3c. The variations of the air permeability of the woven with the number of weft yarns per centimeter for different weft number (Warp no: 20 Nm, Number of warp yarns per cm:40).

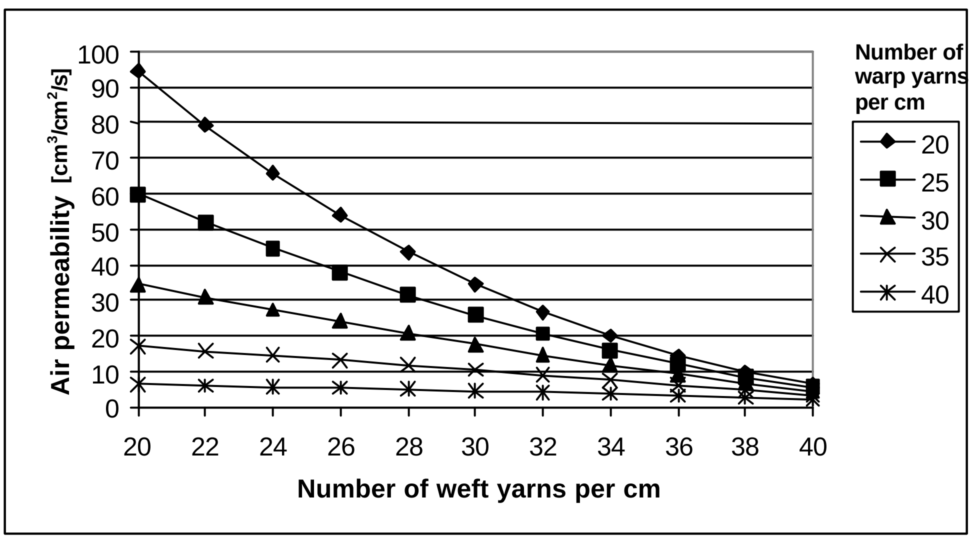

Figure 4a. The variations of the air permeability of the woven with the number of weft yarns per centimeter for different warp number (Warp no: 20 Nm, Weft no: 20 Nm).

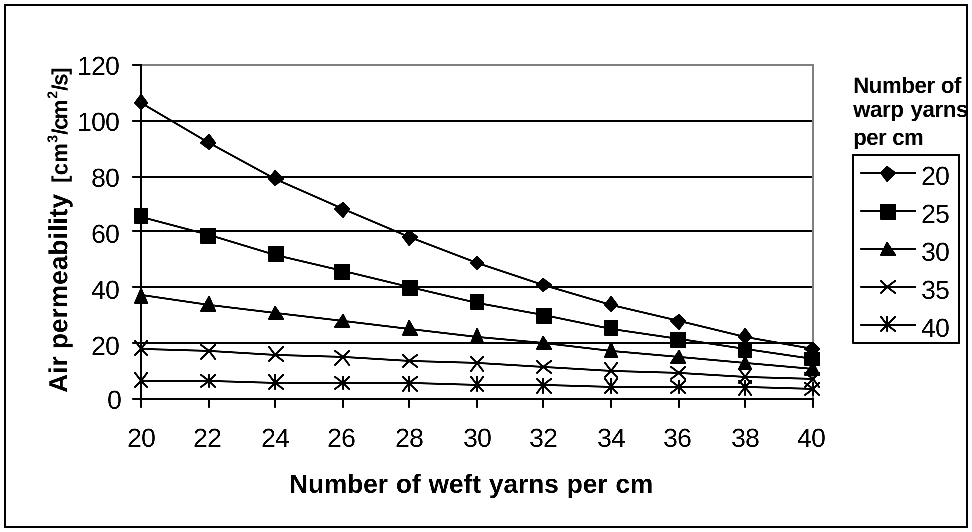

Figure 4b. The variations of the air permeability of the woven with the number of weft yarns per centimeter for different warp number (Warp no: 20 Nm, Weft no: 30 Nm).

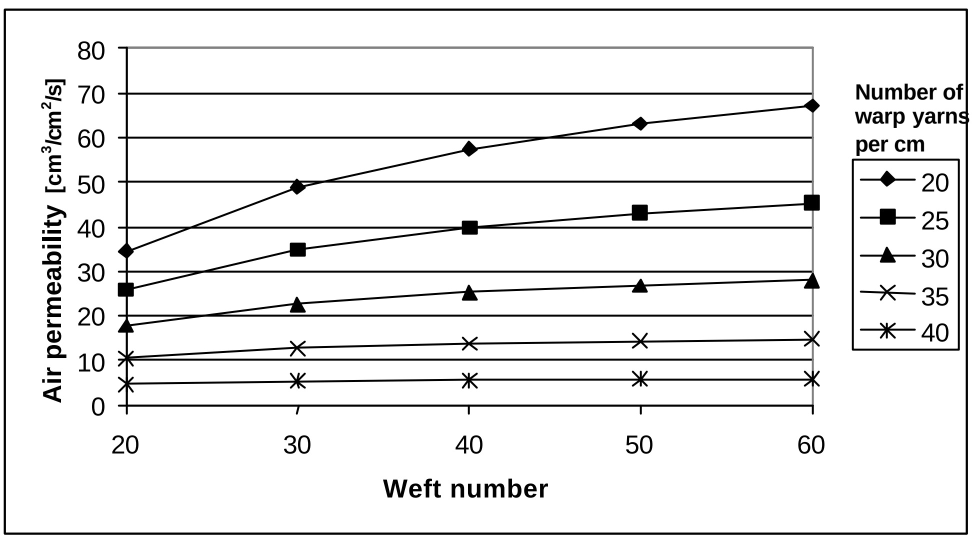

Figure 5a. The variation of the air permeability of the woven with the weft number for different the number of warp yarns per centimeter (Warp no: 20 Nm, Number of weft yarns per cm: 30).

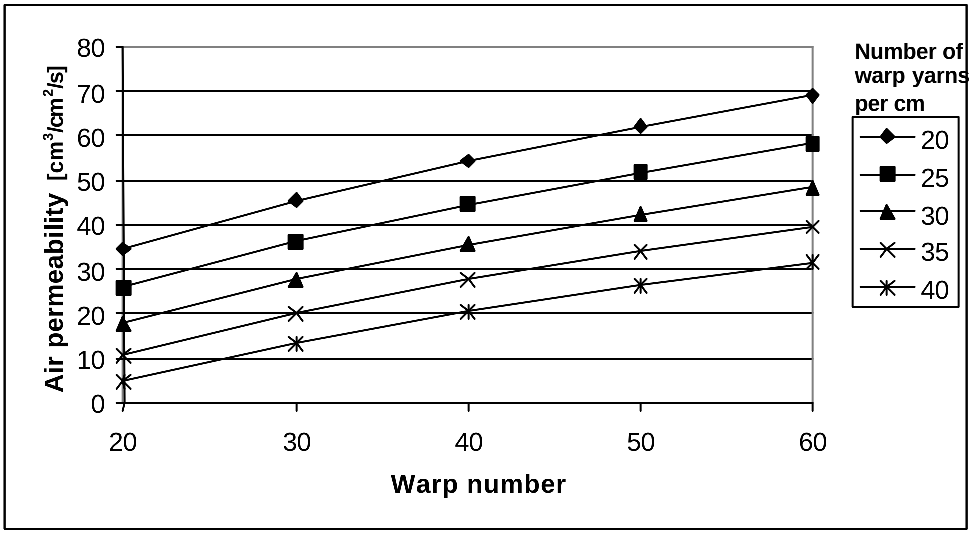

Figure 5b. The variation of the air permeability of the woven with the warp number for different the number of the warp yarns per centimeter (Weft no: 20 Nm, Number of weft yarns per cm: 30).

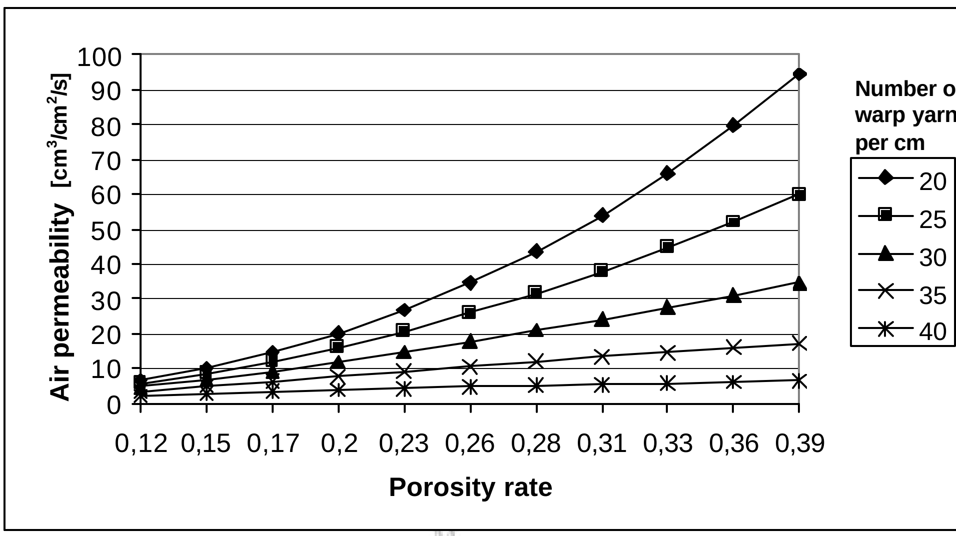

Figure 5c. The variation of the air permeability of the woven with the porosity rate for different the number of the warp yarns per centimeter (Warp no: 20 Nm, Weft no: 20 Nm).

The variations of the air permeability of the woven with the number of filling (or weft) yarns per centimeter (weft density) for different filling number are shown in figures 3a,b,c. It can be seen that, when the number of filling yarns per centimeter increases, the air permeability of the woven decreases. The higher the values of filling number cause decreases the air permeability of the woven. As known, increasing number of warp yarn per centimeter (warp density) results a tightly woven structure. So it is thought that the air permeability of the woven is reduced.

The variations of the air permeability of the woven with the number of filling yarns per centimeter for different warp number are shown in figures 4a,b. As seen the figures, the air permeability of the woven decrease with an increase for the number of filling yarns per centimeter. Also the increase in the number of warp yarns per centimeter leads to a decrease for the air permeability. An increase for the number of warp and weft yarns per centimeter decrease the porous rate. This decreases the air permeability.

Figure 5a shows the variation of the air permeability with the filling number for different. As seen, the air permeability increases with an increase in the filling number. It is also decreased with the higher the values of the number of filling yarns per centimeter.

Figure 5b shows the variation of air permeability with the warp number (warp count) for different the number of the warp yarns per centimeter (warp density). As seen in the figure, the increase in the warp number increases the air permeability of the woven. Also the higher the values of the number of the warp yarns per centimeter cause decrease the air permeability.

The permeability and porosity are strongly related to each other. If a fabric has very high porosity, it can be assumed that it is permeable. A fabric with zero porosity can be assumed to have a zero permeability in theory [10]. The variation of the air permeability with the porosity rate for different the number of the warp yarns per centimeter is shown in figure 5c. It is seen that the air permeability of the woven increases with the porosity rate. On the other hand, the increase in the number of warp yarns per centimeter leads to an decrease the air permeability of the woven.

Nomenclature

A_c cross-sectional area of a pore [m^2]
A_f surface area of the fabric [m^2]
d yarn diameter [m]
d_h hydraulic diameter of a pore [m]
d_{wa} diameter of warp thread [m]
d_{we} diameter of weft thread [m]
f friction coefficient [-]
h thickness of fabric [m]
L width and length of fabric [m]
m number of pores per squrae
m_{wa} number of warp per centimeter
m_{we} number of weft per centimeter
n coefficient indicating the flow regime [-]
P wetted perimeter of a pore [m]
Re Reynolds number [-]
Q total flow rate of the air [m^3/s]
U air flow velocity [m/s]
U_m air mean flow velocity [m/s]
λ the coefficient of laminar and turbulent flow
ρ air density [kg/m^3]
ε rate of void area [-]
ν kinematic viscosity of the air [m^2/s]
η dynamic viscosity of the air [Pa.s]
ΔP Pressure drop [Pa]

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