ISSN: 0974-5823 Vol. 7 No. 1 January, 2022

International Journal of Mechanical Engineering

A STUDY OF AIR PERMEABILITY OF TEXTILE MATERIALS

Ilqar Saleh Recebov

PhD, Associate Professor

Faculty of Engineering,

Department of Engineering and Applied Sciences

AzerbaijanStateEconomicUniversity (UNEC),

Istiglaliyyat str., 6, Baku, Azerbaijan, AZ1001

MahammadaliNuraddinNuriyev

Doctor of Technical Sciences, Professor

Faculty of Engineering,

Department of Engineering and Applied Sciences

Azerbaijan State Economic University (UNEC),

Istiglaliyyat str., 6, Baku, Azerbaijan, AZ 1001

Summary. *The article deals with the research of processes occuring during the passage of air from textile materials. In thearticle the effect of the type of fabric weaving, fibergeometry, fiber content of the material and themoisture content of the material on its air permeability as well as the process of air flow from textile materials have been investigated.Besides the process of air permeability from fabrics with different fiber, content and different structures have been investigated and the dependence of air velocity on pressure change for the studied materials has been determined. It was determined that the air flow from household fabricsin the studied ranges has laminar properties.*

Key words: *textile materials, air permeability fabric, coefficient of air permeability, porosity, wetness, pressure, linear density of fiber, thickness of materials,fiber content of materials,geometric properties of fibers.*

Introductory

Air permeability- this is the ability to transfer air to the other side during pressure changes on all sides of textile materials.

The breathable properties of textile materials are used both for technical purposes , for example, fabric of parachute (which is a key indicator and must be taken into account in the report on thedesign of the parachute), fabric of the sail of sailing- boat, industrial air filters etc. and in materials for clothing.

The air permeability of clothing has a substantial effect on the convective heat exchange between human body and environment and on the gas exchange between underwear environment and environment.It should be noted that even in ordinary everyday clothing and in dormant cases , air exchange take place between the human body and environment.Such air exchangeis caused by the temperature difference between the space under the clothes and the environment.In windy weather the effect of wind which is much greater than the effect of heat has a significant effect on the course of air exchange .Ventilation can be done with exposed parts of the garment (arms, neck, etc.) and through the material from which the garment is made [1].

If the material from which the garment is made is porous, the material reflects air filtiration in the passage of air through the material.

The aim and objects of the research.

The main purpose of the work is to develop theoretical modelsof the properties of textile materials.

The following tasks have been put to achieve the goal.

1.Determination of structural properties of materials which have a major impact on the value of the coefficient of air permeability of materials.

2. Measurement of air permeability of textile materials for clothing in laboratory conditions.

The current state of the problem and the processing of literature data.

Rubner was the first who studied the air permeability of fabrics and proposed the coefficient of air permeability as acharacteristic of this property.This ratio characterizes the passage of 1ml of air per second through the area of 1 sm of fabric at a pressure change of 0.43 mm.

$$B = \frac{0{,}43 \cdot S \cdot \tau}{V \cdot h \cdot \Delta P}, \qquad (1)$$

Here V- the volume of air passing through the material ml;

S - the area of study of the material sm^2

τ - time of passage of air through the material, second

ΔP –pressure change during the investigtaion mmwater column (w.c.)

h - material thickness, sm

The disadvantages of this method are as follows[2]:

a)The air permeability is not directly proportional to the pressure change ΔP the connection between them is complicated)

b) The air permeability indications are inversely proportional to the thickness of the material.

During the study of the dependence $B = f(\Delta P)$ for fabrics, E.B. Renkom [3]

has determined the dependence between the speed of air passing through the fabric

and the pressure change

$$\Delta P = \kappa \cdot \vartheta^n . \qquad (2)$$

Here κ and n – is the variability constant for the individual fabrics.

The value of κ - is less for sparsely woven fabrics and the value of n – is more and the value of k α n is less for densely woven fabrics.

B.Flarinski made the most valuable contribution to the study of air permeability [4].He proposes the study of the formula obtained by Forxheimer as a result of experiments in the calculation of air permeability [5].In the literature of textile materials science it is known as the " Rakhmatulin equation"[6].

$$\Delta P = a \cdot \vartheta + b \cdot \vartheta^2, \qquad (3)$$

here υ – air speed, m/ sec.

a and b - is a variable constant for individual fabrics.

Florinski has investigated two cases of pressure forces while air passes through the fabric.

The first case.- when the concentration of frictional forcesis very low, in this

case the work is carried out against the forces of inertia and is determined by (3)

equality.

$$\Delta P = b \cdot \vartheta^2 \qquad (4)$$

the second case – when the forces of density are more than the forces of inertia, (1.3) equality will be as follows:

$$\Delta P = a \cdot \vartheta \qquad (5)$$

In general the sum of both is observed.Equation of air permeability which is similar to equation (1.3) taking into account the properties of liquid and gases passing through the fabric, as well as the thickness and porosity of the fabric have been shown in Figure [7].

$$\Delta P = a \cdot \frac{l}{d^2} \cdot \mu \cdot \vartheta + b \cdot \frac{l}{d} \cdot \frac{Q \cdot \vartheta^2}{2} \qquad (6)$$

here Q and μ - is the density and viscosity of the medium in the liquid and gas.

d , l - are linear dimensions depending on the thickness and porosity of the fabric;

a and b – are dimensionless coefficients that determine the air permeability of fabrics.

Khanjonkova [8] and Zelenko [9] have confirmed linear and parabolic possibility of air flow through the grids in 2 modes.In work [9] have been given calculated data on the variation of ($\Delta P = a \cdot \vartheta$) experimentally ($\Delta P = b \cdot \vartheta$)(3) equation over a wide range. The possibility of applying this equation has been confirmed in other studies [10] .

The most comprehensive study of the air permeability of fabrics has been conducted by Arkhangelsky [11-13]. According to Arkhangelsky the air consumption through the fabric is determined by the following formula.

$$V = B_i \cdot S \cdot \tau \cdot f(\Delta P), \quad (7)$$

Here V - the amount of air passing through the fabric.ml;

B_i - permeability coefficient

τ - time , second

S - area.sm^2

ΔP -pressure difference, mm.w.c.

The value of B_i can be in the range of 0,2÷60 (for gauze 200 ÷ 250).For tightly woven fabrics ($B_i \le 1{,}5$) $\Delta P = f(\Delta P)$ air permeability ΔP is proportional pressure differences. $\Delta P^{0,5} = f(\Delta P)$ becomes for low density fabrics.Density rate indicators for medium –density fabrics varies in the range of 0,5 -1 and manifests itself as a more complex function. Arkhangelsky called it technical coefficient when the air permeability coefficient is ΔP= 1mm st. $B_i = C$ and he considered it expedient to accept this indicator as a standard property of air permeability. Air permeability is characterized by the function $B = f(\Delta P)$. ΔP increases and is determined depending on the value of (C) technical coefficient (C) of air permeability when $\Delta P \prec 50$mm.w.c.

$$B = C \cdot (\Delta P)^n \quad (8)$$

here the value of n is determined with $n = f(C)$ experimental equality. The interaction between B and ΔP has been presented as follows:

$$B = M \cdot (\sqrt{\Delta P + K} - \sqrt{K}) \quad (9)$$

here M and K –are different constants for different fabrics.

He considers such equality to be common and recommends the using for to calculate the air permeability of fabrics. For diverse fabrics the change of the coefficients a , b , M , K corresponds to a certain law and is dependent on the value of the technical coefficient (C). In the fabrics higher air permeability an increase in the technical coefficient increases the constant M and the constant K loses its significance [13].

The complex dependence of air permeability (ΔP) on the air flow makes it necessary to use air permeability B_P at given values of (ΔP) .Meantime:

$$B_P = \frac{V}{S \cdot \tau} \quad (10)$$

The air permeability of textile materials is characterized by theseindicatorsaccording to ГОСТ12088-77 measurements are carried at ΔP=5 mm.w.c.=49Pa pressure.

Air flow process in textile materials.

According to standardГОСТ 12088 - 77, pressure change occurs on both sides of the material from 0 to 1960 Pa (200 mm.w.c.).The choice of pressure change (P) depends on the volume of air velocity and is determined by the following ratio.

$$P = \frac{Q - \vartheta^2}{2} \qquad (11)$$

here (Q -density of air) $\frac{kq \cdot \sec^2}{m^4}$;

ϑ - air density m/sec

P - pressure kg, sec/m^2 or mm su.st

(1.11) conclusion on is as following:

$$\vartheta = \sqrt{\frac{2P}{Q}} \qquad (12)$$

According to climatic conditions when t= 20˚C,φ = 65% if we write the

values (mm.w.c.) and $Q = 0{,}122\left(\frac{kq \cdot sek^2}{m^4}\right)$ instead of (12) and if we assume

$Q = \frac{1}{8} \cdot \frac{kq \cdot san^2}{m^4}$ is to simplifythe calculations, then we will get

$$\vartheta = 4\sqrt{P} \qquad (13)$$

The value of $\vartheta$was calculated by formula (12), (13)has been given in table 1. The information given in the table of 1 explains the following:

Table 1. The dependence of air speed on pressure change

Pressure change mm.w.c.	Speed of moving air	
	m/sec	km/hour
1	4,0	14.4
2	5,6	20.2
3	6.9	24.8
4	8.0	28.8
5	8.9	32.0
6	9.8	35
7	10.6	38.2
8	11.8	40.7
9	12.0	43.2
10	12.6	45.4
11	13.2	47.5
12	13.8	49.7
13	14.4	51.8
14	14.9	53.6
15	15.4	55.4

The tests to determine the air permeability of clothing materials were carried

out at a pressure change of not more than P=10 mm.w.c.. And this in turn is appropriate to a wind speed of 12,6 m.sec. or 42 km/tm per hour. In the assessment of the air permeability of materials for clothing the standard value of pressure change P was selected 5 mm.w.c. (=49 Pa).Thusthe average windspeed in the territory of our republic is 8÷12 m/ sec.

The study of air permeability of fabrics with different fiber content and different structure.

As air passes through the pores of the fabric, part of energy is used to rub the air with the fabric and the other part to repel environmental forces. This is in turn affects the speed at which air passes through the fabric. If we consider the movement of air through the pores of the fabric as the movement of a liquid with a low density in the pipe, then the amount of frictional losses depends on the following factors:

1) from the diameter of the pipe and d (equivalent to the diameter of the pore)
2) from the length of the pipe L (thickness of the material)
3) from the density of the air Q
4) fromair viscosity μ
5) from the average flow velocity in the pipe ϑ (in the pore)
6) from the height of the roughness in the walls of the pipe h (pile of threads)two possible currents are described:

- regulated (or laminar);
- unregulated (or turbalent- vortex)

Reynold created the conditions for the existence of laminar and turbalent regimes, as well as the transition from one mode to another. The condition of the air flow in the pipe is related to the non- dimensionalparameter R.This parameter defines the main factors of movement and character.

- average of the pipe ϑ;
- diameter of the pipe d ;
- density of liquid and gas Q;
- absolute density of liquid and gas μ

Reynold number (R_e)is determined by the following formula

$$R_e = \frac{\upsilon \cdot d_{ekv} \cdot Q}{\mu} \quad (14)$$

or

$$R_e = \frac{\upsilon \cdot d_{ekv}}{\gamma} \quad (15)$$

here d_{ekv} - is the equivalent diameter of the pore, $d_{ekv} = \frac{\Delta\varepsilon}{a}$

$\Delta\varepsilon$ - total porosity of the material.

a - dynasity surface

γ - is the kinematic density of the fluid, $\gamma = \mu / Q$

The transition of the flow to the trubalent mode occurs in Reynold's R_{kr} values.At a critical price it is possible to find a critical velocity at speeds below this critical velocity, the flow of liquid or gas will be in laminar mode:

$$\vartheta_{kr} = \frac{\mathrm{Re}_{kr} \cdot \gamma}{d} \quad (16)$$

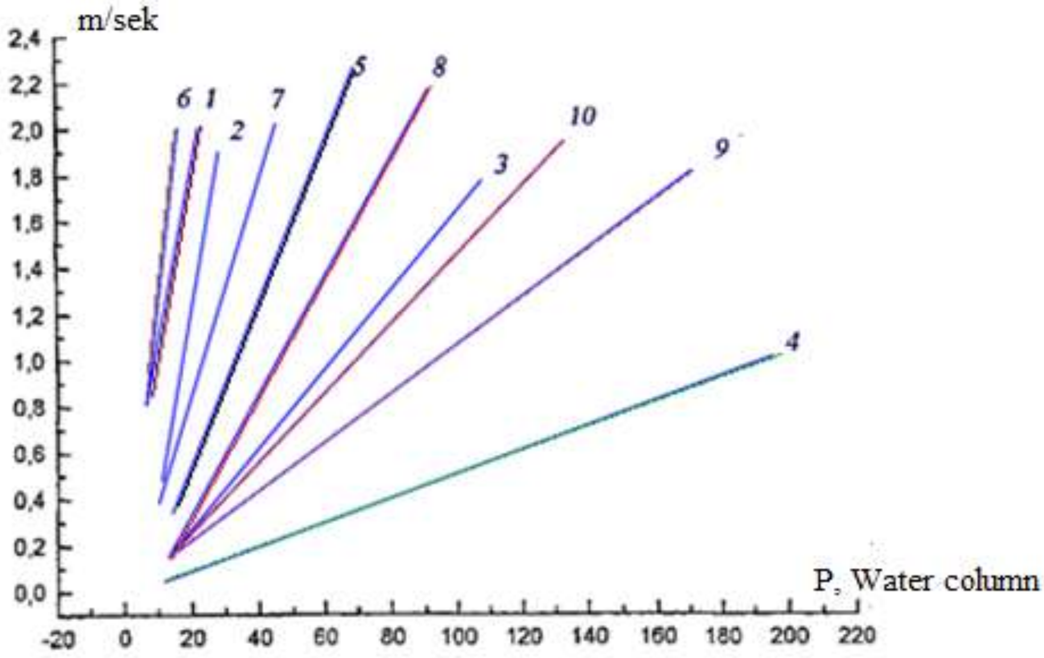
Laminar flow of liquid or gas is possible in small diameter pipes and at relatively low speeds.

In this study, the passage of air through fabricswith different fiber content and different structures has studied. The study has been investigated on the basis of measuring the velocity of air passing through a sample at different pressures from a 10 sm^2 working area. According to standard ГОСТ12088-77 measurements have been made at 5 points in each sample material. The variation of the pressure change was in the range of 5 mm. Su.st (49 Pa).The properties of the fabric samples used in the experiments have been presented in Table 2.

Table 2. General properties of the fabric samples used in the experiment

Sample number	Fiber content	Weaving	Surface density	Thickness mm(P=5)	processing
1	cotton	fabric	70,5	0,23	patterned
2	cotton	fabric	161,5	0,52	patterned
3	cotton	sarja	190,2	0,70	hard
4	cotton	sarja	276,3	0,63	elegantly colored
5	canvas	fabric	202,9	0,47	elegantly colored
6	wool	crepe	201,6	0,60	elegantly colored
7	wool	fabric	145,3	0,47	elegantly colored
8	wool,cap, nit	sarja	394,4	1,37	colorful fabric
9	acetate	atlas	110,0	0,15	patterned
10	lavsan	sarja	164,0	0,64	elegantly colored

Obtained results are illustrated in Figure 1. In this figure the graph of dependence of the air flow rate on the pressure change for the fabrics used in the experiment has been given.



Picture 1. Dependence of air velocity on pressure change for the materials under study

To determine the Reynold's number(R_e) from formula (15). It's necessary to know the average velocity of air flow the kinematic density of air (γ) which is normal climatic conditions $0{,}157\cdot10^{-1}$ m^2/ sec.)and the equivalent diameter of the pores (d_{equiv}). Equivalent diameter of the pores are defined as follows:

The lateral surface area of individual fibers

$$S_L = \pi d_L l$$

When $l = 1$

$$S_L = \pi d_L \quad (17)$$

here d_L -is the diameter of the elevator, which is determined by the following formula

$$d_L = 0{,}0357\sqrt{\frac{T_L}{\gamma_L}}$$

here T_L – is the linear density of the fiber, tex:

γ_L - volume is the mass. mg/mm

T_L and γ_L marks have been taken from the tables in the 19 th - 20th literature.

Volume of fibers is V_L= $V_L = \frac{\pi d^2{}_L}{4} \cdot l$

When the volume of individual is $l = 1$

$$V_L = \frac{\pi d^2{}_L}{4} \quad (18)$$

The weight of individual fibers

$$m_L = V_L \cdot \gamma_L = \frac{\pi d_l{}^2}{4} \cdot \gamma_L \quad (19)$$

the total length of the fiber and the study area of the sample is 10 sm^2 (or $10^3 m^2$)

$$L_{lif} = \frac{M_{nümun}}{m_l} = \frac{4M_{nümun}}{\pi d_L{}^2\ \gamma_L} \quad (20)$$

here, $M_{nümun}$ - is the mass of the sample. It is determined by weighting the
sample and calculating the area under study ($10^{-3}\,m^2$).The total surface area on the side of the sample. (in an area of $10^{-3}\,m^2$):

$$S_{lif} = S_{L.}L_{lif} = \pi d_L \cdot \frac{4M_{num}}{\pi d_L{}^2 \gamma_L}$$

or,

$$S_{lif} = \frac{4M_{nüm}}{d_L \gamma_L} \quad (21)$$

The total volume of fibers in the sample studied (in an area of $10^{-3}\,m^2$):

$$V_{lif} = V_L L_{lif} = \frac{M_{nüm}}{d_{L.}\gamma_L} \quad (22)$$

Total porosity of the material:

$$\varepsilon = \frac{V_{nüm} - V_{lif}}{V_{nüm}} \quad (23)$$

Here, $V_{nüm} = S_{nüm} \cdot h$

$$S_{nüm} = 10^{-3} m^2$$

h -is the thickness of the material and is determined experimentally by a thickness gauge.

Using (22) and (23)

$$\varepsilon = 1 - \frac{M_{n\ddot{u}m}}{\gamma_L \cdot S_{n\ddot{u}m} \cdot h} \quad (24)$$

The dynastic surface of the fabric pattern (area is 10^{-3} m^2) may be determined by the followingformula:

$$a = \frac{S_{lif}}{V_{n\ddot{u}m}} = \frac{4M_{n\ddot{u}m}}{d_L \cdot \gamma_L \cdot S_{n\ddot{u}m} \cdot h} \quad (25)$$

Equivalent diameter of pores between fibers,

$$d_{ekv} = \frac{\Delta\varepsilon}{a} \quad (26)$$

If we write (24) and (25) instead of (26), then we will get the formula equivalent diameter of the pore:

$$d_{ekv} = 4\left(1 - \frac{M_{n\ddot{u}m}}{\gamma_L \cdot S_{n\ddot{u}m} \cdot h}\right) \cdot \frac{d_L \cdot \gamma_L \cdot S_{n\ddot{u}m} \cdot h}{4M_{n\ddot{u}m}}$$

After simplification we get the following expression:

$$d_{ekv} = d_L\left(\frac{\gamma_L \cdot S_{n\ddot{u}m} \cdot h}{M_{n\ddot{u}m}}\right) \quad (27)$$

here, d_L fiber diameter, m:

γ_L - is the volume mass mg/ mm^3;

$S_{n\ddot{u}m}$ - is the area of the sample($S_{n\ddot{u}m}$ = 10^{-3}m^2);

h -is the thickness of the sample, m;

$M_{n\ddot{u}m}$ - is the mass of the studied sample in the area of 10^{-3} m^2

using (25) and (27) formulas , we find Reynold's (R_e) number:

$$R_e = \frac{\vartheta}{\gamma} \cdot d_{ekv} = \frac{\vartheta}{\gamma} \cdot d_L\left(\frac{\gamma_L \cdot S_{nem} \cdot h}{M_{n\ddot{u}m}} - 1\right) \quad (1.30)$$

The values of the equivalent pore diameters(d_{ekv}) for the fabric samples used in this experiment were calculated according to the formula(27) and presented in Table 3. Then, R_e has been calculated by taking into account the presence of $\gamma = 1{,}57 \cdot 10^{-4}$ m^2/ sec.for air and the passage of air flow through the studied fabric samples at different speeds.The results have been noted in table 4.

As mentioned earlier, during the application of the criteria of D'Arsi's law, the property of the linear dependence $\vartheta = f(P)$ on the maintenance of the laminar flow regime of liquid (gas) from the porous area of the fabric appears as the number Re

Different sources give different values forRe_{kr}.The results of the Re number

Table 3. İnitial and calculated values of the equivalent diameter of the pores of the studied fabric samples

Number of the sample	Linear density of fiber T. tex	Fiber densityγ, $\times 10^6$ kq/m^3	Sample area S, m^2	Thickness $h \cdot 10^{-5}$, m	Surface density$G$	Equivalent diameter of pores $d_{ekv} \cdot 10^{-7}$, m
1	0,153	1,53	10^{-3}	23	70,5	451
2	0,153	1,53	10^{-3}	52	161,5	444
3	0,153	1,53	10^{-3}	70	190,2	523
4	0,153	1,53	10^{-3}	63	276,3	281
5	300	1,40	10^{-3}	47	202,9	370
6	0,330	1,31	10^{-3}	60	201,6	519
7	0,400	1,35	10^{-3}	47	145,3	653
8	0,240	1,22	10^{-3}	137	394,4	515
9	0,200	1,32	10^{-3}	150	110,0	236
10	0,170	1,30	10^{-3}	64	164,0	525

of the studied fabrics (lookat table 4), the comparative analysis of the Re_{kr} show that the value of the Re number does not exceed one in all ranges of pressure change. (except sample 3 which P=20 mm.w.c..)

From these data, it is clear that the air flow from household fabrics in the

studied ranges is laminar.This is confirmed by the graph $\vartheta = f(P)$ (picture 1.0)of the dependence of the velocity of air passing through the fabric on the pressure change.

All the obtained graphs are close to the graphs of the linear function.Thus, it is useful in assessing the air permeability of textile materials for clothing at different pressure variations according to real conditions when the air flow has a laminar property.In this case, the dependence of $\vartheta = f(P)$ is as follows:

$$\vartheta_P = \vartheta_1 \cdot P$$

here ϑ_1- is the velocity of air passing through the material P=1

Table1 4. Values of the Reynold's number (Re) at different pressure changes (P) and the velocities of air passing through the sample fabric according to these changes

Sample number	Pressure change mm.	Air speed	Value of the Re
1	2	3	4
	5	0,71	0,204
	10	1,20	0,345
	15	2,07	0,595
2	5	0,45	0,127
	10	0,74	0,209
	20	1,33	0,376
	30	1,95	0,551
3	5	0,15	0,500
	10	0,29	0,966
	20	0,47	1,566
	50	1,00	3,331
	100	1,68	5,596
	110	1,83	6,096
4	5	0,06	0,011
	10	0,10	0,018
	20	0,16	0,029
	50	0,32	0,057
	100	0,58	0,104
	150	0,84	0,150
	200	1,08	0,193
5	5	0,37	0,087
	10	0,62	0,146
	20	1,02	0,240

	50	1,83	0,431
	65	2,20	0,518
6	5	0,74	0,245
	10	1,25	0,413
	20	2,04	0,674
7	5	0,39	0,162
	10	0,68	0,283
	20	1.20	0,499
	40	2,13	0,886
8	5	0,17	0,056
	20	0,64	0,210
	50	1,34	0,440
	90	2.18	0,715
9	5	0,13	0,020
	10	0,23	0,035
	50	0,80	0,120
	100	1,28	0,151
	150	1,68	0,253
	175	1,89	0,284
10	5	0,12	0,040
	10	0,23	0,077
	50	0,88	0,294
	100	1,58	0,528
	130	1,97	0,659

Conclusion

1.In the standards studied in the measurement of air permeability, when the value of the pressure change applied to household materials is 49 Pa, this level corresponds to the wind speed of 8: 15 m / sec., which is characteristic of the climatic conditions of the Republic of Azerbaijan.The air permeability coefficient of textile materials varies idely over a pressure change of 49 Pa.Practically beginning from airtightness varies within 7000 dm^3 (m^2· sec).

2. Measurement of air permeability of textile materials for clothing in laboratory conditions.Laminar flow mode is observed.In this case, B= f (P) dependence is linear.

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