An Investigation into Air Permeability of Terry Fabrics Regarding the Processes of Finishing

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The paper presents the investigations and dependencies of air permeability regarding the parameters of finishing processes. Terry fabrics used in the experimental work were woven using cotton and linen yarns. 28 different terry pure linen and linen/cotton fabric constructions, with different structures and finishing treatments, were investigated. Wetting phenomena has a significant effect on air permeability of the fabric as do the following finishing processes: washing with a detergent and without one, washing with detergent and conditioner, softening, calendering, and tumbling. It was observed that air permeability of the fabrics not exposed to any finishing operation is highest, while tumbled fabrics exhibit the lowest air permeability. Terry fabrics shrink in finishing processes, especially after washing. It was found that with the increase of washing time the air permeability of the fabrics investigated tends to decrease. Washing process for 2 hours without detergents decreases air permeability by 2.0 times for the investigating linen/cotton fabric with unbleached pile and by 2.4 times for the investigating linen/cotton fabrics with bleached pile warps, if compared with the fabric that has undergone no finishing. Washing process lasting for 1 hour, with a detergent and conditioner, decreases fabric air permeability by up to 238.7-202.1 mm/s.
Key words: *air permeability, terry fabrcs, washing, softening, calendaring and tumbling process*

1. Introduction

Terry fabric is described as a textile product made with a loop pile on one or both sides, the pile generally covering the entire surface. There are three groups of yarns in terry fabrics, meaning these fabrics are produced by three systems of yarns: the ground warps, the wefts and the pile warps. Terry fabrics are woven as 2, 3, 4 or more pick terry weaves. The most common type is a 3-pick terry weave. The pile can be formed on one or both sides using the pile warps. However, one-side pile terry fabrics have low water absorbing capacity, so they are not so popular. Pile structure is one of the most important aspects of the fabric, since it has a significant effect on the structure of the terry fabric and on end-use properties as well. Raw material to be used for weft, ground warp, and pile warp yarns, as well as the pile structure (height) are the key parameters for design properties. Clearly, the classification of some terry fabrics, like towels, can be made according to the weight, production, pile presence on fabric surfaces, and finishing [1, 2, 3].
Properties that are required of the yarns to be used in terry fabrics are high absorbency, high wet strength, good wash-ability, and soft handle. When high quality is required, two or more ply yarns are used. When absorbency is increased, the fabric gains resistance to pile stability. Use of two-ply yarns also improves visual appearance. Pile loops generally consist of more highly twisted yarns, which, while very absorbent, are quite abrasive, thus actively stimulating the skin when dry [1, 4, 5]. Pile yarns make the fabric thicker and give it a high level of heat insulation. Air contained among the fibres and within them provides thermal insulation. Pile loops form rough textured surface, thus giving the fabric a dull appearance [5, 6]. Koc E. and Zervent B. have compared the performance properties of terry towels made from open-end and ring-spun yarns. They proved that there was no difference in water absorption rate, while maximum absorption was found at lower fab-

ric density [7]. Flax and cotton are most popular raw material to be used in the production of terry fabrics. Flax has very good water absorption properties. Besides that, it represents textiles of high usability and ecological qualities such as aseptic properties (bacteria) and properties beneficial for human physiology, protection against UV radiation, and lack of allergenic affects [8]. The structure of terry fabric is also very important.

Air permeability is the ability of the air to flow through the fabric. There are different requirements on the air permeability of various textile materials. Air permeability is an important factor in the performance of numerous textile products, such as filters, clothing fabrics, hot air balloons, and parachutes [9 - 11]. The knowledge of permeability of certain textiles allows for the evaluation and comparisons necessary to determine the end-use performance in such products as rain coats, tents, shirting, sail cloths, industrial filters, and pillow cases [9]. Air permeability is related to the thermal comfort of the garment as well. In some products, such as sportswear, high air permeability is desirable. In the products such as tents, sleeping bags and protective textile products, low air permeability is required to keep the wearer comfortable. However, when terry fabric is produced for bathrobes, towels, and slippers, air permeability should be as high as possible, since discomfort results if it too low. Most of terry fabrics are produced from cotton yarns, but at present linen, bamboo, and hemp gain on popularity, too. Cotton fibres are hydrophilic, which allows the fabric made of it to absorb softener into the fibres. However, the absorbed rinse cycle softener within the fibres could block the air space among them or the yarns, which could result in decreased air permeability [5, 6].

According to [5], the most important characteristics, which exhibit the highest impact on air permeability, are the number of warp and weft yarns per decimetre, the density of the pile warp yarns and the density of the ground warp and weft yarns, together with the twist of these yarns.

Guo J. [5] states that the ability of the fabric to inhibit air, or allow it to go through it freely, is mainly dependent on the thickness, porosity, construction and geometry of the fabric. As porosity increases and thickness decreases, air permeability tends to increase as well. The combined yarn elements and small parts stifle the airflow within the fabric. Yarn twist also has an effect on air permeability. When it is increased, the circularity and density of the yarn rise; the yarn diameter and cover factor are reduced, and air permeability increases. If yarns are permitted to extend more easily, the extension will open up the fabric, increasing the free area as well as the air permeability of the fabric. The results of some investigations [5] show that a significant difference in air permeability exists among different fabric softener treatments and fabric types.

However, there are limited studies that deal with air permeability of terry fabrics, regarding wetting and various finishing operations like washing, softening, tumbling, calendering, etc.

The aim of the research presented here is to investigate air permeability of various terry fabrics regarding the finishing processes they have been exposed to.

2. Materials and methods

2.1. Fabric structures

The experiments were carried out with three kinds of terry fabric structures. The terry fabrics used in the research were woven using linen and cotton yarns. The structure and weave repeat can be seen in Fig.1 and Fig.2. The investigations were conducted with the fabrics that have pile loops on both sides. As can be seen in Fig. 1 and 2, the ground warp G1 that was up at the beginning went down and the G2, which was down, went upward through the two yarns. Back side pile (BP) warp was always in opposition to the front side pile (FP) warp. When the BP warp made the first loop on one side of the fabric, the second loop was formed on the other side. The FP warp behaved in the same manner.

Three types of yarns were used in the production of terry fabrics. The nominal pile highness was 9 mm. Fabric composition and linear density of the yarns are presented in Tab. 1.

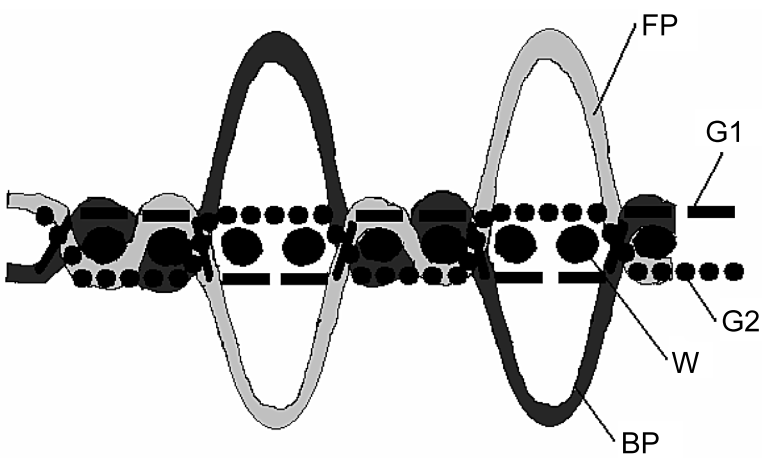


Fig.1 The structure of the terry fabric: FP- front side pile warp, BP- back side pile warp, G1- first ground warp, G2 - second ground warp, W- weft

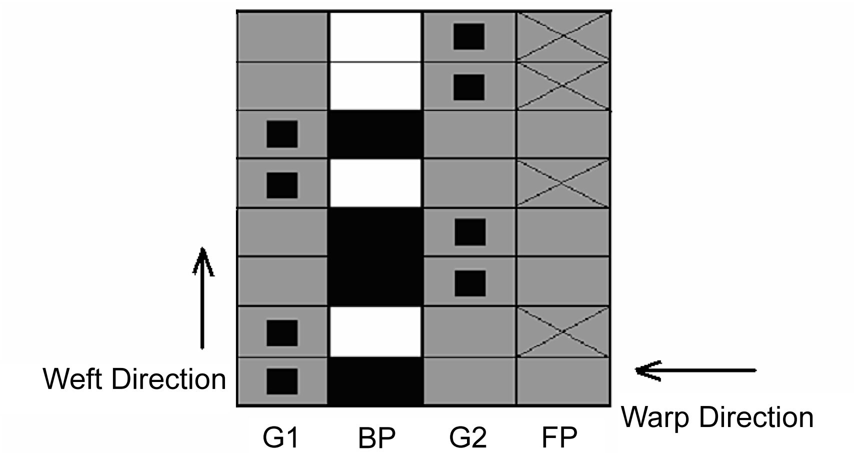


Fig.2 The weave repeat of the terry fabric: G1 and G2 ground warps, FP - front side pile warp, BP- back side pile warp, ▪ - ground warp is over the weft, ▪ - front side pile warp is raised over the weft, ☒ - back side pile warp is raised over the weft, ☐ - warp is lowered behind the weft, ■ - pile warp is over the weft

Tab.1 The characteristics of terry fabrics

Fabric variant	Raw material content	Yarn linear density, tex			Yarn density, dm^{-1}	
		pile warp	ground warp	weft	pile and ground warp	weft
A1-A13	linen 60% cotton 40%	68 unbleached linen	25x2 cotton	50 cotton	250	200
B1-B13	linen 60% cotton 40%	50 bleached linen	25x2 cotton	50 cotton	250	200
C1, C2	linen 100%	68 unbleached linen	56 unbleached linen	56 unbleached linen	250	180

2.2. Finishing applied

Some samples of the investigated terry fabrics were exposed to no finishing treatment, because some consumers instead of soft and fluffy woven terry products prefer fabrics that are rough and not finished using chemical treatments. In addition, ecological finishing is attractive nowadays, since chemical treatment is far from being friendly to the nature and human environment.

The investigations were performed with 28 samples of terry fabrics, treated in different finishing operations. The finishing processes applied are presented in Tab. 2. As can be seen in Tab. 2, there are 3 different variants of fabrics without any finishing applied. At the beginning, the samples were made of the A1, B1, and C1 fabrics, without any finishing applied. 7 samples of the A1 and 7 samples of the B1 variant terry fabrics were manufactured in the following phase. The first pair – the A1 and the B1 variants of the terry fabric samples without finishing were tested. The second investigation was done with the A2 and the B2 fabrics, wetted with water at room temperature, because wetting process changes fabric structure significantly. After wetting, the samples were dried in the air. The next 3 pairs of the A1 and the B1 variant samples were washed with water only, without any detergent, for 10, 30, and 120 min respectively. They were marked as A3, A4, A5 and B3, B4, B5.

The other 2 pairs of the manufactured terry fabric samples were washed: the first one - with a detergent only - A6, B6, and the second one - with a detergent and a conditioner - A7, B7. New chemical softener, conditioner, offered softly, fluffy and nice handle surface to the fabric. The detergent Felosan NOG CHT R. Beitlich GmbH (Germany) was used for washing. The samples were washed at 60 °C for 60 minutes. After washing, the samples were softened with the silicone con-

Tab.2 Finishing process description

Fabric symbol	Description of the finishing processes and its duration	
A1, B1, C1	Without finishing	
A2, B2	Wetting	
A3, B3	Washing with water without a detergent	10 min
A4, B4		30 min
A5, B5		120 min
A6, B6	Washing with a detergent (60 min.)	
A7, B7	Washing with a detergent and a conditioner (60 min + 60 min)	
A8, B8	Calendering	
A9, B9	Tumbling	30 min.
A10, B10		60 min.
A11, B11		90 min.
A12, B12		120 min.
A13, B13		150 min.
C2		120 min

ditioner Tubingal SMF CHT R. Beitlich GmbH (Germany), at the temperature of 40 °C, for 60 minutes, with the aim to get soft hand. After washing, the samples were centrifuged and air-dried.

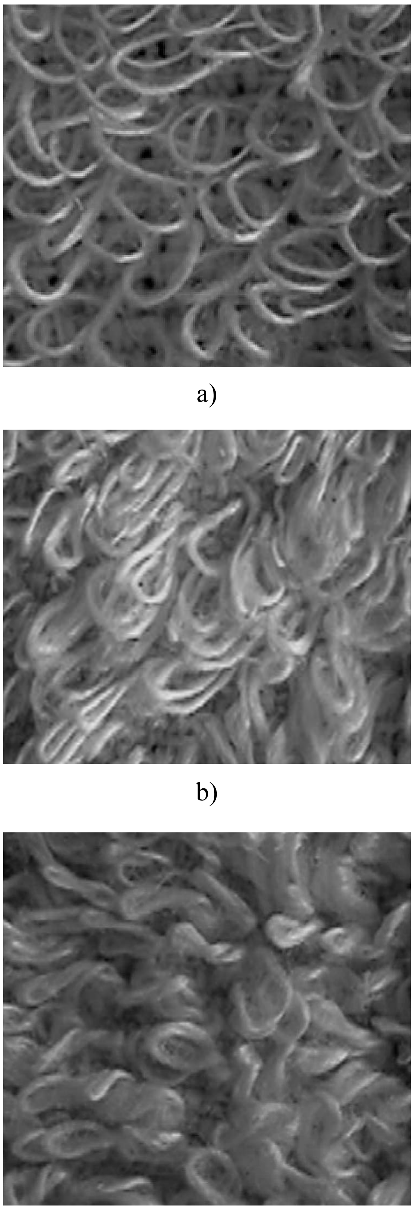
Calendering was the next finishing process applied. The manufactured samples were washed with the detergent and later calendered in a calender machine - A8, B8.

For the tumbling process, 5 pairs of the A1, the B1 fabric variants and the C1 fabric were manufactured. The samples were washed with a detergent and a conditioner (60 min + 60 min). After washing, the samples were centrifuged and tumble-dried in the tumble drier Aipress 15, model Frofix (Germany), for 30 min (A9, B9), 60 min (A10, B10), 90 min (A11, B11), 120 min (A12, B12, C2), and 150 min (A13, B13).

The fabric was turned, shaken and dried with hot air masses in a tumble drier. Dry treatment imparts fuller volume and dimensional stability, together with dryness. The terry fabric was given a fluffy and soft hand and some particles were removed during the tumble process as well.

The international standard ISO 6330:2000 [12] for domestic washing and drying procedures, as well as the Methodology of joint-stock company "A Grupe" (in Jonava, Lithuania), [13] for washing with detergent, calendaring and tumbling procedures were implemented.

The surface of the terry fabric not subjected to any finishing treatment is different than the ones treated in various finishing operations. Fabrics samples without finishing - B1, and after the finishing processes - B8, B10 are shown in Fig. 3.



a)

b)

c)

Fig.3 Linen/cotton terry fabrics: a) B1 variant (without finishing), b) B8 variant (after calendering), c) B10 variant (after tumbling for 60 min); microscopic graphs were obtained by a stereomicroscope and photographed using a digital camera

2.3. The experiments of air permeability

The working principle of the Air Permeability Tester is that the air is drawn through a specified area of the fabric, adjusted to suit specific textiles being evaluated. The rate of the airflow is adjusted until a specified pressure difference between the two fabric surfaces (front and back) is achieved. In the investigation described, the air permeability tests of terry fabrics were conducted according to the EN ISO 9237:1997 [14]. The Air Permeability Tester of Model Karl SCHRODER K6 (Germany) was used. The rate of airflow passing perpendicularly through the know area of the test specimen was adjusted to get a pressure drop between the two fabric surfaces. The test head areas of 5 cm^2 and 20 cm^2 were used. The airflow rate was measured analysing 40 tests per a fabric variant. The airflow rate determined the air permeability of the test specimens, so after the tests the values of air permeability were calculated using the equation [14]:

$$R = \frac{q_v}{A} 167 \quad (1)$$

where: R is air permeability (mms^{-1}); q_v is mean of airflow yield (dm^3 min^{-1}); A is specified area (cm^2), 167 is factor for transforming dm^{3}min^{-1}cm^{-2} in mms^{-1}.

The test fabric specimens were preconditioned and tested under standard atmosphere conditions.

3. Results and discussion

3.1. Investigations of the air permeability of the fabrics without any finishing

The loop pile in a terry fabric exposed to no finishing is stiff, especially when using linen yarns in the pile warp system. Additionally, the loops are of a regular shape and stand perpendicular to the fabric base, so that the air flow does not meet strong resistance in its way, Fig.3 a).

It was found that the values of air permeability of fabrics without finishing were 625.4 mm/s, 688.0 mm/s, and 1079.7 mm/s for the A1, B1, and C1 variants respectively. It means that the terry fabric in which the ground wefts and warps were made from linen yarns and pile warps from linen yarns too, had highest air permeability, i.e. the air permeability of the C1 fabric was by 72.6% higher then the air permeability of the A1 fabric and by 56.9 % higher compared to the B1 fabric. Varying density of the weft yarn had the strongest influence on these results. We can assume that the bleaching of pile warp yarns and their linear density caused that the air permeability of the A1 fabric was by 9.1% lower than of the B1 fabric.

3.2. The investigation of the air permeability of the fabrics after water treatment, washing and softening, as well as after calendering

The changes of air permeability after wetting and the first finishing operation – washing were analysed. Consequently, the A1 and B1 fabrics were wetted or washed with no washing agents, using water only, or were washed with a detergent, while the other samples were washed with a conditioner as well. Such choice was motivated by aim to investigate the significance of the wetting process or washing operation on the air permeability, using different kinds of chemical agents in the process. The results of the air permeability of linen/cotton terry fabrics after different washing processes are presented in Fig.4.

The analysis of the results showed that the air permeability of the fabrics decreased after wetting. It was found that the air permeability of the A2 and B2 fabrics decreased from 625.4 to 569.5 mm/s i.e. by 1.1 times and from 688.0 to 497.2 mm/s i.e. by 1.4 times respectively, if compared with the fabric with no finishing.

It is important to note that the duration of washing without a detergent and a conditioner had an important influence on the investigated fabrics. The significant difference between the air permeability of the wetted fabric and the fabric that was washed without a detergent for 10 minutes period was found, i.e. air permeability decreased up to 362.4 mm/s with the A3 variant fabric and up to 318.2 mm/s with the B3 variant fabric, meaning by 1.6 times.

When the duration of washing without a detergent was lengthened from 10 min to 2 hours, air permeability decreased by 1.8 times with the A5 and B5 fabrics, compared with the wetted ones. It was found that the air permeability of the fabrics washed with water only for three different durations - A3, A4, A5 variants, i.e. for 10 min, 30 min, 2 hours respectively, decreased accordingly by 1.7, 1.8, 2.0 times, while the air permeability of the B3, B4, B5 variants decreased by 2.2, 2.3, 2.4 times respectively, compared with the fabrics with no finishing.

It was found that the air permeability of the A6 and B6 fabrics, washed with a detergent and without a conditioner, decreased up to 260.1 mm/s i.e. by 2.4 times and up to 215.6 mm/s i.e. by 3.2 times, compared with the fabrics with no finishing. The air permeability after washing and softening operations decreased as much as by 2.6 and by 3.4 times with the A7 and B7 fabrics respectively, compared with the fabric with no finishing.

The structure of the terry fabric was modified in calendaring, Fig.3 b). The loops were bent and pressed to the ground fabric. Loops touched each other and sometimes covered each other. Such a structure of terry fabric determines different properties of air permeability, compared with the fabric with no finishing. It was found that the air permeability of the calendered A8 fabric dropped to 292.9 mm/s, i.e. by 2.1 times, compared with the fabric with no finishing. The air permeability of the calendered B8 variant fabric decreased to 213.5 mm/s, i.e. by 3.2 times, compared with the fabric with no finishing. Meanwhile, the air permeability of the A8 and B8 variants decreased by 1.9 and 2.3 times respectively, compared with the wetted samples. Obviously, bending of the loops and the changes of porosity had a significant effect on fabric air permeability.

3.3. The investigation of the air permeability of the terry fabrics, related to tumbling time

Terry fabrics become soft and fluffy when tumbled, some loops stand

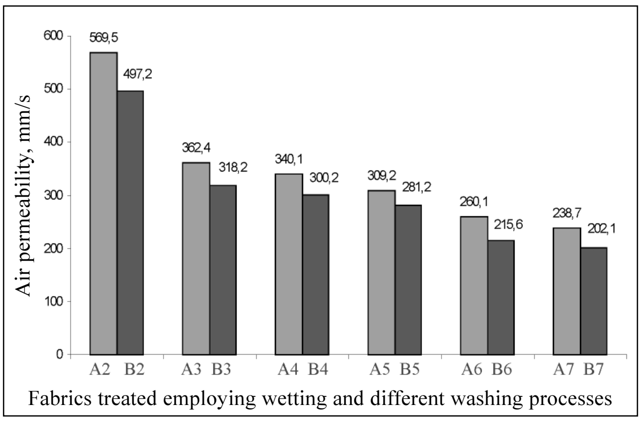


Fig.4 Air permeability of linen/cotton terry fabrics after wetting and different washing processes: washing for 10 min; for 30 min, and for 2 hours, without a detergent or a conditioner, washing for 1 hour with a detergent; washing for 2 hours with a detergent and a conditioner

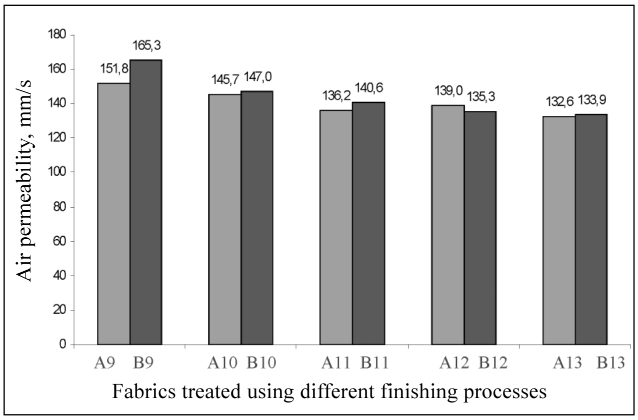


Fig.5 Air permeability of the linen/cotton terry fabrics washed for 2 hours with a detergent and a conditioner, after tumbling lasting from 30 to 150 min

vertical, others get stiffer structure, and they can all be a bit droopy, Fig.3 c). Sometimes the loops obtain spiral structure after tumbling. The results of measuring the air permeability of the linen/cotton terry fabrics after tumbling are presented in Fig.5. After model experiments, it was decided to choose tumbling period of 30 minutes, because such interval changes the structure of the fabric significantly. The first test was made after 30 minutes and the last one after 2 hours and 30 minutes. During this period, the air permeability of the A9 - A13 and the B9 - B13 fabrics decreased from 151.8 mm/s to 132.6 mm/s and from 165.3 mm/s to 133.9 mm/s respectively. It was obvious that with the increase of tumbling time the air permeability had a clear tendency to decrease. The air permeability of the A13 and B13 fabrics, which were tumbled for the maximum duration, decreased by 4.7 and by 5.1 times respectively, compared with the fabrics with no finishing. Additionally, the air permeability of the prolonged tumbled (for 2 hours 30 minutes) fabrics deceased by 1.6 – 2.2 times, compared with the calendered fabrics. The air permeability of the pure linen fabric tumbled for 2 hours (the C2 variant) decreased from 1079.7 mm/s to 392.5 mm/s, i.e. by 2.8 times, compared with the variant with no finishing (the C1 variant). Obviously, the pure linen terry fabric after such a finishing process exhibited higher air permeability then the linen/cotton terry fabrics.

4. Conclusions

After a series of experiments carried out on air permeability of the pure linen and the linen/cotton terry fabrics, with no finishing, after wetting and after different finishing processes, the following conclusions were drawn:

- the air permeability of the pure linen terry fabric, produced from unbleached linen pile warp and unbleached linen ground warp and weft, not exposed to any finishing is highest - 1079.7 mm/s. The air permeability of the investigated linen/cotton fabric with no finishing, produced using unbleached linen pile warp is by 9.1% lower, compared with the linen/cotton fabric, produced using bleached linen pile warp;
- wetting phenomenon and finishing processes such as washing without a detergent washing with a detergent, washing with a detergent and a conditioner and softening have a significant effect on air permeability. The linen/cotton terry fabric with unbleached pile warp has, after wetting, air permeability of 569.5 mm/s. The air permeability of the investigated linen/cotton terry fabric with unbleached pile warp and linen/cotton terry fabric with bleached pile warp decreased after wetting by 1.1 times and by 1.4 times respectively, compared with the fabrics with no finishing. Washing for 2 hours without a detergent decreases air permeability by 2.0 - 2.4 times, while washing with a detergent and softening decreases it by 2.6 to 3.4 times, compared with the fabrics with no finishing. As the washing time increases, air permeability has a clear tendency to decrease;
- the air permeability of the washed and calendered terry fabrics decreases by 2.1 - 3.2 times, compared with the fabrics with no finishing;
- tumbling time has a significant effect on the air permeability of terry fabrics. After tumbling for 30 minutes, the air permeability of the investigated fabrics decreases to 151.8 mm/s and after prolonged tumbling time (2 hours and 30 minutes) to 132.6 mm/s. The air permeability of the prolonged tumbled fabrics decreases by 1.6 - 2.2 times, compared with the calendered ones.

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