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Experimental Analysis of Air Permeability of Terry Fabrics with Hemp and Linen Pile

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The study deals with experimental investigation to determine the air permeability of terry fabrics using different pile height, yarn types, and finishing applied. Terry fabrics were manufactured using hemp and linen warp yarns. It was determined the important effect of water/heat/mechanical impacts as well as finishing processes, i. e. industrial washing, tumbling, on air permeability of the fabrics. The air permeability of grey terry fabric with hemp pile was found to be the highest, i. e. 478 $dm^3/(m^2s)$. Due to swelling phenomena of fibre and decreasing in pore sizes the fabrics are less permeable after wetting. The drop in air permeability after wetting of all tested fabrics was within the range of 1.1 – 2.0 times if to compare with the grey fabrics. Washing with detergent or without it changes fabric's structure. It was found that the air permeability of fabrics washed with detergent decreased down to 153 $dm^3/(m^2s)$, i. e. in 3.1 times for the investigated hemp/cotton fabrics and down to (106 – 242) $dm^3/(m^2s)$, i. e. in 1.4 – 2.3 times for the investigated linen/cotton fabrics. The influence of tumbling also the duration of process on air permeability was determined.

Keywords: air permeability, finishing, hemp pile, linen pile, terry fabric.

1. INTRODUCTION

Air permeability is vital quality in such end-use applications like filtration, fluid barriers, and thermal insulation. The application of permeability tests to textile products as well as determining permeability and porosity has long been subjects of interests [1]. The so called clean room textiles protect an atmosphere against particles emitted from human body and vice versa, also provide protection against particles evolved from clothing. The permeability uniformity can be used as a criterion for estimation of clean room textiles quality [2]. Air permeability being biophysical feature of textiles determines the ability of fabric to carry out gaseous substances, significantly influences thermal comfort of the human body, secure the support of the proper body temperature [3]. Air permeability [4] along with other comfort properties of hemp textiles for hospital uses was investigated.

It is logical to expect that fabric's structure influences air permeability that lies on porosity. However, there is limited experimental proof in the literature that these properties correlate [1]. It was determined that nonwoven fabric weight is more important parameter for air permeability if to compare with thickness, fibre diameter, and density [5]. Daukantienė and Skarulskienė [6] stated that the air permeability increased with the increase of porosity of the fabric or decrease of its thickness. The use of spacer fabrics with air supported layer for excellent air permeability and thermoregulation was interesting textile-technological solution for medical applications [7]. Wilbik-Halgas et al. [8] indicated that air permeability was a function of knitted fabric thickness and surface porosity.

The system has been designed for investigating phenomena associated with dynamic air flow through a flat textile material as well as for measuring the dynamic air permeability of textiles [9], dynamic and static permeability also was investigated in [10, 11]. A method of modelling of woven fabric permeability features by means of neural nets is presented in [12].

Air permeability regarding starch finishing and the elastomeric finishing was investigated in [3]. It was shown that the air permeability decreases considerably after finishing operations due to blocking up the pores of the fabrics. Guo showed in [13] that the significant difference existed in air permeability using different fabric softeners, fabric type, and number of laundering cycles. The air permeability of denim decreased after simple and silicone softening, washing with chlorine solution, enzyme and double enzyme washing and it was influenced by changes of fabric's structure [14].

Terry fabrics for home textiles display certain properties such as appropriate softness, hydrophility, dimensional stability, air permeability, of which the latest one is especially important quality parameter for bathrobes, headgears, slippers, sauna towels, etc. In [15, 16] it was confirmed that pile and fabric structure, washing process as well as softening have an important effect on the physical and usage properties of terry material. Karahan et al. [17] presented the investigation of structural properties of terry fabrics regarding washing process. The experimental model suitable for quality evaluating of terry towels affected by different processes such as bleaching, printing, dying, softening was developed [18].

The aim of our investigations was to determine the influence of the kind (water/heat/mechanical/chemical) and duration of treatment on the air permeability of terry woven fabrics.

2. OBJECT OF INVESTIGATION AND TEST METHOD

The cotton-linen and cotton-hemp terry fabrics used in the experimental work were woven in a joint-stock

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company "A Grupė" (Jonava). Pile loops were embedded by four picks and designed on both sides of the fabric. Structural characteristics of the fabrics are presented in the Table 1 (these characteristics are nominal and presented by the producer). The largest part of samples were woven using linen yarns having in mind that flax [19] provided the best environment for natural all-round comfort and the unique property to breath helped keeping warm when it is cold and keeping cool when it is hot. Linen pile warp yarns were grey for I and II fabric variants, while bleached for III and IV variants. Hemp pile warp yarns were bleached. The samples also differed by impact of water, also mechanical and chemical impacts in order to ascertain in what way the kind and period of such treatment influence the air permeability of fabrics.

Table 1. Structural characteristics of terry fabrics

Characteristic	Variant of terry fabric				
	I	II	III	IV	V
Weft yarns, linear density, tex	cotton yarn, 50				
Pile warp yarns, linear density, tex	linen yarn, 68		linen yarn, 50		hemp yarn, 72
Ground warp yarns, linear density, tex	plied cotton yarn, 25 tex × 2				
Weft density, cm^{-1}	20				
Pile and ground warp density, cm^{-1}	25				
Pile height, mm	6	12	6	12	9

For wetting procedure the specimens (300 × 500) mm in dimension were placed into water for 2 s – 3 s needful for complete wetting, and then dried in the air. The procedure of washing without any detergent lasted in periods of 10, 30, 120 min. Washing temperature was 40 °C.

The research was performed also with the samples of terry fabrics treated using different finishing processes to obtain soft terry material that is in great demand of consumers (finishing processes were performed in "A Grupė").

During whole industrial washing cycle, fabric is affected by the complex of factors such as washing solution, heat, abrasion, bending strain, compressive deformation, etc. Therefore, significant changes in fabric's structure lead to intensive transformation of its physical and mechanical properties. In our research the detergent NOG CHT R. Beitlich (Germany) for industrial washing was used, washing temperature was 60 °C. Washing procedure was performed in rope bath BK (Russia).

Tumbling process gives fluffy handle surface, fuller volume to the fabric. For this purpose samples were washed with detergent, softened, centrifuged, and tumble-dried in different periods: of 30, 60, and 90 min in tumbler Aipress 15, model Frofix 7126 (Germany). The silicone conditioner Tubingal SMF CHT R. Beitlich (Germany) was used for softening.

The air permeability tests of the investigated terry fabrics were provided according to EN ISO 9237:1997 [20], using an equipment L14DR (Karl Schröder Co.) with the head area of 20 cm^2 and pressure difference 100 Pa. 15 – 20 tests per sample were performed.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The results of air permeability measurements of the terry fabrics regarding different impacts and industrial washing are presented in Figs. 1 – 5. Relative errors of the experimental results (at 95 % confidence level) are presented in the Table 2.

It was determined the air permeability tests of grey terry fabric with hemp pile is the highest. The air permeability of III and IV fabrics are in 53.7 % – 60.1 % higher as compared with I and II fabrics. Such differences in values could be conditioned by changes in fabric's structure after pile warp bleaching operation also by the difference in linear density of pile warp. The bleached loop pile is stiffer, so the grey fabrics are more permeable to the air flow.

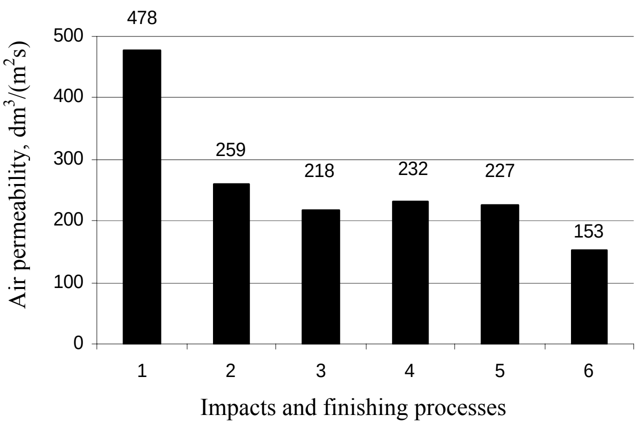

Fig. 1. Air permeability of terry fabrics with hemp pile regarding impacts and finishing process: 1 – without finishing (grey fabric); 2 – wetting; 3, 4, 5 – washing in 10, 30, 120 min without detergent; 6 – washing with detergent in 60 min

To our mind, fibre swelling and decrease in pore sizes are the main reasons of the decrease in air permeability of the fabrics. Our data coincide with those obtained by other authors. Holmes [21] confirmed that when the fabric surface was wetted by water the fibres swelled transversally reducing the size of the pores in the fabric. Berkalp [1] stated that the air permeability of spun-laced fabrics was inversely proportional to pore's size.

It was also found that the air permeability of fabrics decreased after wetting process. The drop in air permeability of wetted fabrics of all tested samples was within the range of 1.1 – 2.0 times compared with grey fabrics. The difference between the air permeability of grey fabrics with bleached linen pile of 6 mm height (IV variant) and wetted ones is especially intensive – in 2.0 times. The air permeability of fabrics with hemp pile after wetting impact decreased up to 259 $dm^3/(m^2s)$, i. e. in 1.8 times.

The washing process is the first finishing operation of the terry fabrics. Meeren et al. [22] stated the treatment with conditioner did not affect porosity and pore size of terry fabric. We investigated two cases: the fabrics that were washed without any washing agents and industrially washed with the detergent ones. The possibility to refuse from chemical treatment is interesting from ecological point of view, especially considering that chemical treatment is far away from being friendly to the nature and

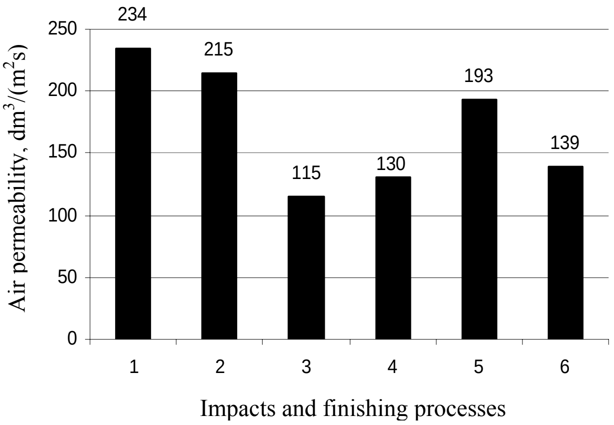

Fig. 2. Air permeability of terry fabrics with linen pile of I variant regarding impacts and finishing process: 1 – without finishing (grey fabric); 2 – wetting; 3, 4, 5 – washing in 10, 30, 120 min without detergent; 6 – washing with detergent in 60 min

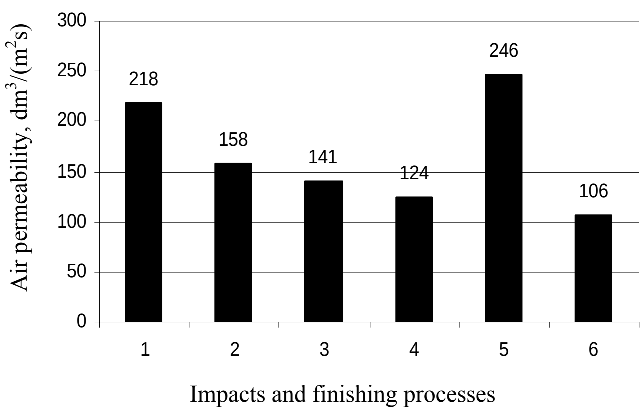

Fig. 3. Air permeability of terry fabrics with linen pile of II variant regarding impacts and finishing process: 1 – without finishing (grey fabric); 2 – wetting; 3, 4, 5 – washing in 10, 30, 120 min without detergent; 6 – washing with detergent in 60 min

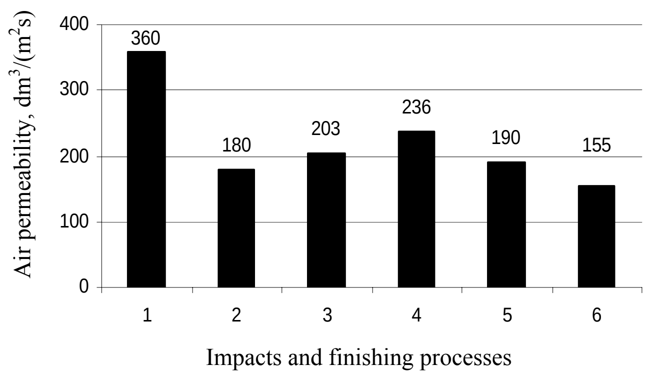

Fig. 4. Air permeability of terry fabrics with linen pile of III variant regarding impacts and finishing process: 1 – without finishing (grey fabric); 2 – wetting; 3, 4, 5 – washing in 10, 30, 120 min without detergent; 6 – washing with detergent in 60 min

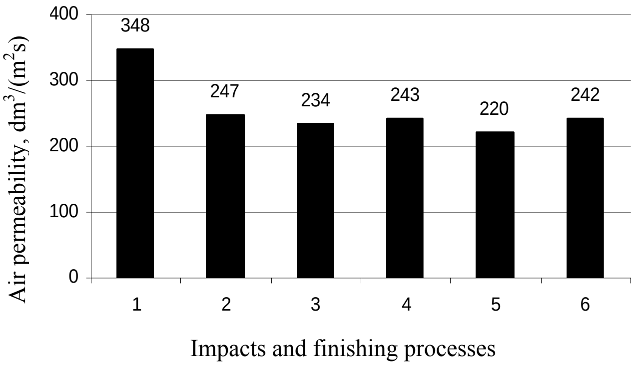

Fig. 5. Air permeability of terry fabrics with linen pile of IV variant regarding impacts and finishing process: 1 – without finishing (grey fabric); 2 – wetting; 3, 4, 5 – washing in 10, 30, 120 min without detergent; 6 – washing with detergent in 60 min

Table 2. Relative errors of the experimental results

Index	Impact, finishing process	Variant of terry fabric				
		I	II	III	IV	V
Relative error of a mean air permeabi-lity, %	1	5.0	4.7	4.8	4.8	5.6
	2	3.5	4.4	5.1	4.9	4.9
	3	5.1	5.2	4.4	3.4	4.8
	4	5.1	4.5	4.2	4.5	4.5
	5	4.8	4.0	4.9	4.9	4.5
	6	5.2	4.8	4.8	4.2	2.7
	7	2.5	5.5	3.6	3.5	3.8
	8	4.0	4.2	3.4	3.5	3.7
	9	3.6	3.2	2.8	4.9	3.3
1 – without finishing (grey fabric); 2 – wetting; 3, 4, 5 – washing in 10, 30, 120 min without detergent; 6 – washing with detergent in 60 min; 7, 8, 9 – tumbling in 30, 60, 90 min						

human environment. Besides that, it was important to establish the long duration impact of water as compared with wetting procedure. The air permeability of hemp pile fabrics washed without detergent in 10, 30, 120 min varies within the range of (218 – 232) dm^3/(m^{2}s). Having in mind the confidence interval of approximately 20.8 dm^3/(m^{2}s), such differences are hardly noticeable. The fabrics with unbleached linen pile are very sensitive to the washing process, especially if it continues long – up to 120 min. It was found that the air permeability of I and II fabrics increased after washing periods in 68.4 % and 74.0 % respectively. It is important to note that the air permeability of the fabrics with grey pile washed without detergent reached its highest values after 120 min washing impact. Such differences in air permeability could be determined by the changes in fabric porosity. After prolonged washing the small particles from grey yarns of composite flax fibre could be dropped and due to increase in pore sizes the textile became more permeable to air flow. In the case the pile is high (12 mm) the long duration washing without detergent is especially effective for increasing the air permeability of fabrics with grey linen pile warp. Washing in 30 min increases the air permeability of III and IV fabrics up to (236 – 243) $dm^3/(m^2s)$. The biggest difference between air permeability of the fabrics with grey and bleached linen pile also with hemp pile is noticeable for fabrics washed in 10 min – 2.0 (I variant) and 2.2 times (V variant), in 30 min – 1.8 times (II variant), in 120 min – 1.9 (III variant) and 1.6 times (IV variant) if to compare with grey fabrics.

Microscopic surface views of some investigated fabrics obtained by the optical microscope and photographed by the digital camera are presented in Fig. 6. It is reasonable to expect that the changes in terry fabric's structure have the significant effect on air permeability because of changes in porosity, pile geometry, pile density, etc. Such structural changes after investigated treatments or finishing processes are obvious analysing microscopic surface views of the samples.

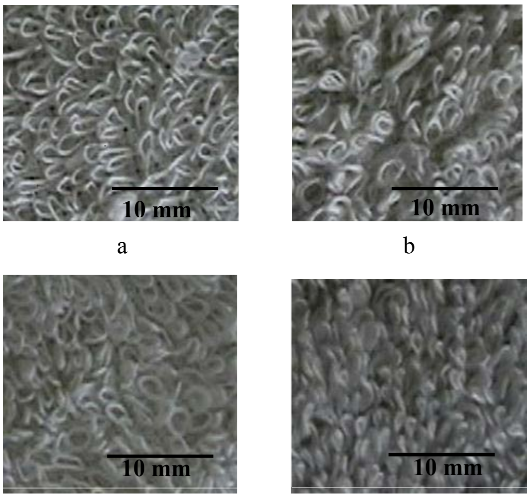

Fig. 6. Microscopic surface views of the terry fabrics with hemp pile: a – without finishing (grey fabric); b – washed in 10 min without detergent; c – washed in 120 min without detergent; d – after tumbling in 90 min

The loop pile in the grey fabric is stiff; the loops are of regular geometry and located perpendicularly to the base of fabric. The more the impacts the more intensively changes the fabric's structure – wetting and especially washing determine the loss of loop regularity. The structure of terry fabric is modified much more after tumbling process. The loops touch or cover each other; the yarns in the loops become bulk. Sometimes it can be found the spiral structure of the loops after tumbling. So, the terry tumbled fabrics become soft and fluffy.

It was found that air permeability of the industrially washed fabrics decreased even in 3.1 times for the fabrics with hemp pile and in 1.4 – 2.3 times for the fabrics with linen pile if to compare with grey fabrics. The drop of air permeability of the fabrics with linen pile of II variant is more significant compared with the fabrics of IV variant (see Figs. 3, 5). Such change could be conditioned by the large amount of fly split from the grey high warp loops during such intensive finishing procedure and trapped in the fabric.

The air permeability as a function of fabric's tumbling time is presented in Fig. 7. The results show that the longer is the time of tumbling process, the lower is the fabric air permeability.

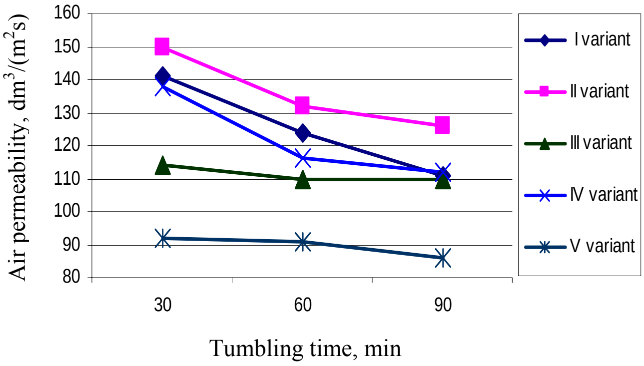

Fig. 7. Air permeability of the terry fabrics versus tumbling time

It was found that the values of this parameter during investigated tumbling period significantly decreased analysing I, II, and IV variant of terry fabrics – in (24.2 – 30.5) $dm^3/(m^2s)$, i.e. from 150 $dm^3/(m^2s)$ to 126 $dm^3/(m^2s)$ (II variant) and from 141 $dm^3/(m^2s)$ to 111 $dm^3/(m^2s)$ (I variant). In the case of fabrics with hemp pile (V variant) and linen pile (III variant) the differences are not considerable but the general tendency is evident. The air permeability decreases after this finishing process because the heat and mechanical impact changes the fabric's structure and the pores of the fabric are blocking up. Besides that, such intensive finishing like tumbling causes an increase in the density of the fabric and decrease in the fabric's porosity, which in turn diminishes the air permeability. The air permeability of terry fabrics with hemp pile warp, which were tumbled over the maximum period (90 min), decreased in 5.6 times if to compare with the grey ones. Other tested fabrics also showed corresponding considerable decrease of air permeability: in 2.1 (I variant) – 3.3 (III variant) times. The differences in these decreases of air permeability of the fabrics with low loops (6 mm) are substantially major if to compare with the fabrics having high loop (12 mm) structure.

4. CONCLUSIONS

1. The air permeability of the fabrics with bleached linen pile warp is in 53.7 % – 60.1 % higher if to compare with the fabrics having grey linen pile yarns, hither the linear density of pile warp also could influence the air flow.
2. Supposedly, the fabrics are less permeable after wetting impact due to swelling phenomena of such hydrophilic components like linen and hemp fiber and decreasing in pore sizes. The drop in air permeability of wetted fabrics of all tested variants was within the range of 1.1 – 2.0 times as compared with the grey ones.
3. The fabrics with grey linen pile yarns are very sensitive to the durable washing even without detergent.
4. Industrial washing changes fabric's structure significantly because the complex of impacts affecting the fabric. The air permeability of such treated fabrics with hemp pile decreased down to 153 $dm^3/(m^2s)$, i. e. in 3.1 times as compared with the grey samples. The similar air permeability was determined analysing fabrics with

bleached linen pile of 6 mm height. The decrease down to (106 – 242) $dm^3/(m^2s)$, i.e. in 1.4 – 2.3 times was determined for fabrics with linen pile.

5. The results proved that the longer is the time of tumbling, the lower is the fabric air permeability. Air permeability of the fabrics with hemp pile, which were tumbled over the maximum period, decreased in 5.6 times as compared with the grey ones. Other investigated fabrics also showed considerable decrease in air permeability with the tendency of substantially major differences for the fabrics with low pile.

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