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# The Influence of Antimicrobial Treatment on Air Permeability and Water Absorption of Knits

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Antimicrobial finishing is increasingly used for various purposes in textile products. Therefore, it is important to determine whether the antimicrobial finish changes comfort properties (air permeability, water absorption, etc.) of knits. The objective of this research was to establish the influence of antimicrobial treatment conditions on air permeability and water absorption properties of plain plated knits. The investigations were carried out with three groups of single plain plated knits. The ground and plating yarns of I group of knits is pure fiber cotton, man-made bamboo, polyester. The ground yarns of II and III groups of knits are accordingly polyamide and elastane threads. The plating yarns in mentioned groups are the same as in I group – cotton, man-made bamboo, polyester yarns. Part of the knits of all groups were treated in an antimicrobial solution of iSys AG and organic-inorganic binder iSys MTX (CHT, Germany) as well as the other part of the knits were treated in the same conditions as treated in antimicrobial solution, however, an antimicrobial material and binder were not used. It was established that air permeability of investigated knits changed insignificant by regardless of whether reagents providing an antimicrobial effect were used or not used in finishing process. This means that the chemical substance used for antimicrobial finishing do not worsens an air permeability of knits. Meanwhile, the water absorption of antimicrobial treated knits was significantly (44 % ÷ 91 %, according to fiber composition of investigated knits) lower than of blank treated knits because the organic-inorganic binder, used in antimicrobial treatment, forms the sol-gel layer on the surface of fiber.

*Keywords*: antimicrobial treatment, air permeability, water absorption, plain plated knit.

## 1. INTRODUCTION

Textile materials and clothing play an important role in every day human's life. Increasing demands for comfort, aesthetic, functional and protective textile products with different properties causes the development of new and contemporary techniques for processing and designing textiles [1, 2]. The wear comfort is important qualitative criterion that affects performance, efficiency and well-being of human [3].

Comfort includes three main aspects: thermo-physiological, sensorial and psychological [4]. All above requirements are particularly important for sport and active leisure clothing comfort and also for athletes' personal hygiene. It is important, to maintain human's body stable internal temperature during exercising or active leisure workout. The body releases sweat while cooling itself, therefore in order to feel comfortable the clothing have to absorb sweat and let them to evaporate out [5, 6]. If sweat is not fully evaporated it creates favourable conditions for bacterial growth, the clothing and skin remain a damp and person feels discomfort. For this reason, the inner layer of sports and active leisure wear usually is knitted of synthetic fibers such as PES, PA, PP, while external layer consists of natural or man-made fibers, such as cotton, bamboo, viscose or combinations of some [5].

The growth of microorganism's on textiles causes an unpleasant odour, results many skin troubles (allergic sensitisation, itching, acne, rashes) and a loss of textile properties including fabric rotting, staining, discolouration and quality deterioration [7, 8]. In order to prevent growth of microorganisms and to ensure the protection of human hygiene, the antimicrobial finish are becoming more frequent applies not only in the medical field, but also for sports and outdoor clothing, hosiery, footwear, home textiles, etc.

Antimicrobial finish on textiles allow to control the growth of microorganisms, such as bacteria, fungi and to prevent deterioration of strength and quality, staining, odours, and health concerns caused by microorganisms [9]. There are many ways to control microbial growth on textiles such as incorporating antimicrobial agents into fibres during the spinning process by coating and padding. Also antimicrobial agents can be applied to the textile substrates by exhaust, pad-dry-cure, coating, spray and foam techniques [10]. A well-known technique for textile modification is the sol-gel method. The sol-gel process allows the production of inorganic polymer coatings with embedded inorganic (e. g. Ag, Cu or boric acid) or organic biocides [11]. Nano-silver particles have an extremely large specific surface area, thus increase their surface contact with bacteria and fungi and vastly improve their bactericidal and fungicidal effectiveness [12]. The organic-inorganic binder is used together with nanoparticles of metal ions to form a sol-gel layer on the fiber [13].

Many of agents (zinc, tin, silver ions, chlorine derivatives of phenols, ammonium salts) have possible harmful or toxic effect. On the other hand, silver is a relatively non-toxic disinfectant that can significantly reduce many strains of bacteria and fungi [14]. However, silver ions must be sufficiently anchored on the textiles in order to provide durability of antimicrobial properties [2].

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Many scientists [5, 15, 16] investigated an air permeability of pure fiber (cotton, man-made bamboo, viscose, etc.) knits and their combinations with synthetic (polyester, polyamide, etc.) threads. They stated that the main parameters, which have an influence on the air permeability of knits, are the type of fibre (natural, synthetic or blended), linear density and structure of the yarns, the course and wale densities, area density, knitting pattern and fabric thickness. Higher air permeability increases comfort of wear, which is very important property for user. If clothing materials and structure of garments can allow the evaporation of perspiration and ventilation in addition to thermal protection, this will also affect the heat balance of the body [15].

Many scientists [5, 17, 18] stated that comfort properties of fabrics depend not only on the air permeability but also on water absorption. They stated that natural and pure fiber knits absorb more water than knits blended with synthetic fibers, which are hydrophobic and tend not to get wet. Therefore, it was concluded that ability to absorb a certain amount of water (or sweat) depends of fiber composition and yarn structure parameters. However, there is lack of papers with investigations on influence of antimicrobial treatment on the air permeability and water absorption of plain plated knits.

The main goal of this research was to establish the influence of antimicrobial treatment on changes of air permeability and water absorption of plain plated knits. This research is unique, as it analyzes, explores and identifies the impact of antimicrobial treatment substances and conditions on air permeability and water absorption of plain plated knits.

## 2. EXPERIMENTAL

### 2.1. Materials

The experimental samples were knitted in plain plated pattern on the circular 14E gauge single bed weft knitting machine. There were three groups of samples made for this research. In each group there are six variants of knits – three variants with cotton, two variants with man-made bamboo, and one variant with polyester plating yarn.

The ground yarns used for knitting of samples of I group are cotton, man-made bamboo and polyester (the same yarn as the plating one). The ground yarn used for knitting of samples of II group is polyamide, and for samples of III group – elastane thread.

The main characteristics of investigated samples are presented in Table 1.

### 2.2. Methods

For antimicrobial finishing, one part of knits of each group was treated in an antimicrobial solution of iSys AG and organic-inorganic binder iSys MTX (CHT, Germany). The main conditions of antimicrobial treatment were: aqueous solution of 25 °C, 2 g/l iSys AG and 10 g/l of iSys MTX, pH 5.5, 10 min. All samples were centrifuged for 12 min at 1200 rpm and tumble dried, permanently treated for 1 min at 160 °C. The samples treated according mentioned conditions were named as antimicrobial treated.

Another part of samples in each group were treated in the same conditions as the ones treated with antimicrobial solution, however, antimicrobial substance and binder were not used. Samples treated according these conditions were named as blank treated.

The structure parameters of knitted samples were calculated according to standard LST EN 14971:2006.

Air permeability of the plain plated knits was measured using an L14DR air permeability tester machine (Karl Schröder KG, f. Germany). Air permeability was investigated according to the European Standard EN ISO 9237:1997 using a head area of 5 cm$^2$ and pressure difference of 100 Pa. Permeation direction was from inside to reverse side of a knitted fabric. The air permeability $R$ (dm$^3$/(m$^2$·s)) of plain plated single jersey knit was determined from formula:

**Table 1.** The characteristics of investigated plain plated knitted samples

| Group | Indication of knitted samples | | Fiber composition, % | Nominal linear density, tex | Wale density $P_h$, cm$^{-1}$ | Course density $P_v$, cm$^{-1}$ |
|---|---|---|---|---|---|---|
| I | C1 | Cotton 29.4 tex + Cotton 29.4 tex | 100 | 58.8 | 7.85 ±0.07 | 6.25 ±0.08 |
| | C2 | Cotton 14.8 tex × 2 + Cotton 14.8 tex × 2 | 100 | 59.2 | 7.75 ±0.08 | 6.60 ±0.06 |
| | C3 | Cotton 25 tex + Cotton 25 tex | 100 | 50.0 | 7.80 ±0.08 | 6.15 ±0.07 |
| | B1 | Bamboo 29.4 tex + Bamboo 29.4 tex | 100 | 58.8 | 8.20 ±0.08 | 6.00 ±0.00 |
| | B2 | Bamboo 14.8 tex × 2 + Bamboo 14.8 tex × 2 | 100 | 59.2 | 8.00 ±0.00 | 6.20 ±0.08 |
| | P3 | Polyester 25 tex + Polyester 25 tex | 100 | 50.0 | 7.10 ±0.06 | 6.77 ±0.08 |
| II | C1PA | Cotton 29.4 tex + Polyamide 10 tex × 2 | 60 / 40 | 49.4 | 8.40 ±0.06 | 7.50 ±0.10 |
| | C2PA | Cotton 14.8 tex × 2 + Polyamide 10 tex × 2 | 60 / 40 | 49.6 | 8.00 ±0.00 | 8.00 ±0.07 |
| | C3PA | Cotton 25 tex + Polyamide 10 tex × 2 | 56 / 44 | 45.0 | 8.55 ±0.09 | 7.40 ±0.06 |
| | B1PA | Bamboo 29.4 tex + Polyamide 10 tex × 2 | 60 / 40 | 49.4 | 8.75 ±0.08 | 7.35 ±0.07 |
| | B2PA | Bamboo 14.8 tex × 2 + Polyamide 10 tex × 2 | 60 / 40 | 49.6 | 8.30 ±0.11 | 7.50 ±0.10 |
| | P3PA | Polyester 25 tex + Polyamide 10 tex × 2 | 56 / 44 | 45.0 | 8.25 ±0.08 | 7.80 ±0.08 |
| III | C1EL/PA | Cotton 29.4 tex + Elastane 2.2 tex, PA 7.8 tex | 75 / 20 / 5 | 39.4 | 10.10 ±0.06 | 9.00 ±0.00 |
| | C2EL/PA | Cotton 14.8 tex × 2 + Elastane 2.2 tex, PA 7.8 tex | 75 / 20 / 5 | 39.6 | 10.05 ±0.05 | 8.90 ±0.06 |
| | C3EL/PA | Cotton 25 tex + Elastane 2.2 tex, PA 7.8 tex | 72 / 22 / 6 | 35.0 | 10.00 ±0.07 | 8.98 ±0.09 |
| | B1EL/PA | Bamboo 29.4 tex + Elastane 2.2 tex, PA 7.8 tex | 75 / 20 / 5 | 39.4 | 10.75 ±0.08 | 9.25 ±0.08 |
| | B2EL/PA | Bamboo 14.8 tex × 2 + Elastane 2.2 tex, PA 7.8 tex | 75 / 20 / 5 | 39.6 | 9.85 ±0.07 | 8.80 ±0.08 |
| | P3EL/PA | Polyester 25 tex + Elastane 2.2 tex, PA 7.8 tex | 72 / 22 / 6 | 35.0 | 10.30 ±0.08 | 9.65 ±0.12 |

$$R = \frac{D_n}{A} \cdot 167\,, \qquad (1)$$

where $D_n$ is the mean of airflow yield in $dm^3$/min (l/min); $A$ is the sampling area in $cm^2$.

The water absorption was measured according to Bureau Veritas Consumer Products Service internal test method. Samples were conditioned in standard atmosphere conditions, cut in to pieces (10 × 10) and their weight was measured. Then the samples were kept for one minute in distilled water. After being removed from the water and hung for 3 minutes to remove excess water from them, the weight of the wet samples was measured. The static water absorption was calculating using the following formula:

$$S_w = \frac{m_w - m_d}{m_d} \cdot 100\%\,, \qquad (2)$$

where $S_w$ is the static water absorption in %; $m_w$ is the weight of wet sample in g; $m_d$ is the weight of dry sample in g.

The thickness of samples was measured with an automatic micrometer Louis Schopper Leipzig Automatic Micrometer (f. Germany) according to European Standard EN ISO 5084:1996.

Average values of air permeability and water absorption were calculated from the five conducted. The coefficients of variation for all tests did not exceed 5 %.

All experiments were carried out in a standard atmosphere for testing according to the standard ISO 139:2002.

## 3. RESULTS AND DISCUSSION

The significant changes of structure, geometrical properties (such as thickness), air permeability and water absorption of knits may occur in different treatment processes while knits are affected by heat, moisture or chemical finishing [4, 6, 19].

The structure parameters, thickness, air permeability and water absorption of knits manufactured from pure fiber yarns and their combination with textured polyamide or elastane threads, after blank and antimicrobial treatment, were investigated.

Results presented in Table 2 show that the wale and course densities of knits have been changed after both – blank and antimicrobial treatments, comparing with the untreated knits (initial characteristics are presented in Table 1). The changed values after blank and antimicrobial treatment are very similar (till 5 % for wale density and till 7 % for course density), i. e. chemical substances used for antimicrobial finishing do not influence the loop density in the knit as well as porosity of knit. The changes of wale and course density values are mainly influenced by fiber composition and linear density of yarns.

Comparing results in all three experimental groups, the highest differences between the wale density values after blank and after antimicrobial treatment were estimated for knits of III group (up to 20 %). Such results were obtained because of presence of elastane thread, which is very sensitive to higher temperature, and lower total linear density of yarns used for knitting of samples of this group [20]. The course density of all investigated knits increased significantly after both types of treatment comparing with the knits before treatment (15 % ÷ 90 %, depending on the samples group; see Table 1). The influence of fiber composition and linear density of yarn on course density after blank and antimicrobial treatment has the similar character as in case of wale density.

The low differences between the wale and course density values of knits after blank and antimicrobial treatment give also similar values of area density (see Table 2). The difference between values of area density of knits after blank and antimicrobial treatment does not exceed 6 %.

**Table 2.** Structure characteristics of the knits

| Group | Sample code | Wale density $P_h$, $cm^{-1}$ | | Course density $P_v$, $cm^{-1}$ | | Area density $M$, $g/m^2$ | |
|---|---|---|---|---|---|---|---|
| | | $P_{h(b)}$ | $P_{h(a)}$ | $P_{v(b)}$ | $P_{v(a)}$ | $M_{(b)}$ | $M_{(a)}$ |
| I | C1 | 7.85 ±0.07 | 7.70 ±0.08 | 8.45 ±0.05 | 7.65 ±0.10 | 211 ±0.02 | 198 ±0.02 |
| | C2 | 7.65 ±0.07 | 7.65 ±0.10 | 8.55 ±0.05 | 8.30 ±0.08 | 210 ±0.01 | 206 ±0.01 |
| | C3 | 7.95 ±0.09 | 8.00 ±0.10 | 8.15 ±0.07 | 8.05 ±0.09 | 171 ±0.01 | 170 ±0.01 |
| | B1 | 6.90 ±0.06 | 7.05 ±0.09 | 7.70 ±0.08 | 7.40 ±0.06 | 186 ±0.20 | 184 ±0.02 |
| | B2 | 6.85 ±0.07 | 7.65 ±0.10 | 7.95 ±0.09 | 6.85 ±0.10 | 188 ±0.01 | 186 ±0.02 |
| | P3 | 6.35 ±0.07 | 6.70 ±0.08 | 8.00 ±0.00 | 7.80 ±0.08 | 147 ±0.01 | 150 ±0.01 |
| II | C1PA | 8.35 ±0.07 | 8.35 ±0.07 | 9.80 ±0.08 | 9.90 ±0.06 | 196 ±0.02 | 198 ±0.01 |
| | C2PA | 8.35 ±0.07 | 8.40 ±0.06 | 10.10 ±0.06 | 10.10 ±0.06 | 201 ±0.01 | 202 ±0.02 |
| | C3PA | 8.60 ±0.06 | 8.60 ±0.06 | 9.80 ±0.08 | 9.85 ±0.07 | 179 ±0.20 | 180 ±0.02 |
| | B1PA | 8.60 ±0.06 | 8.60 ±0.06 | 10.55 ±0.09 | 10.65 ±0.07 | 210 ±0.01 | 211 ±0.01 |
| | B2PA | 8.55 ±0.05 | 8.65 ±0.07 | 10.40 ±0.06 | 10.40 ±0.10 | 208 ±0.02 | 209 ±0.02 |
| | P3PA | 8.30 ±0.08 | 8.35 ±0.07 | 9.85 ±0.07 | 9.90 ±0.06 | 175 ±0.01 | 177 ±0.01 |
| III | C1EL/PA | 10.20 ±0.08 | 10.15 ±0.07 | 14.45 ±0.11 | 15.00 ±0.10 | 218 ±0.01 | 224 ±0.01 |
| | C2EL/PA | 10.85 ±0.07 | 10.70 ±0.08 | 14.50 ±0.07 | 15.25 ±0.11 | 227 ±0.01 | 233 ±0.01 |
| | C3EL/PA | 10.75 ±0.11 | 11.85 ±0.10 | 15.20 ±0.08 | 16.45 ±0.19 | 202 ±0.02 | 225 ±0.02 |
| | B1EL/PA | 12.30 ±0.08 | 12.40 ±0.06 | 17.50 ±0.12 | 17.70 ±0.11 | 278 ±0.02 | 282 ±0.02 |
| | B2EL/PA | 11.80 ±0.08 | 11.85 ±0.07 | 16.30 ±0.08 | 16.45 ±0.09 | 259 ±0.20 | 262 ±0.02 |
| | P3EL/PA | 11.45 ±0.15 | 11.30 ±0.08 | 15.35 ±0.10 | 15.40 ±0.12 | 209 ±0.02 | 207 ±0.02 |

Note: *b* – blank treated knits; *a* – antimicrobial treated knits.

It is known that finishing can have an influence on the thickness of knits. The finishing processes remove knit emergent internal stresses, which occur during knitting process. Therefore the knits acquire a fixed equilibrium state, and they become more stable, thicker and heavier [21].

**Table 3.** The thickness values of knits after blank and antimicrobial treatment

| Group | Variant of knit | Thickness, mm | |
|---|---|---|---|
| | | $b_{(b)}$ | $b_{(a)}$ |
| I | C1 | 0.814 ±0.01 | 0.832 ±0.02 |
| | C2 | 0.762 ±0.02 | 0.744 ±0.01 |
| | C3 | 0.720 ±0.01 | 0.822 ±0.01 |
| | B1 | 0.582 ±0.01 | 0.584 ±0.01 |
| | B2 | 0.590 ±0.01 | 0.628 ±0.01 |
| | P3 | 0.554 ±0.01 | 0.558 ±0.01 |
| II | C1PA | 0.988 ±0.02 | 0.950 ±0.02 |
| | C2PA | 0.956 ±0.01 | 0.946 ±0.01 |
| | C3PA | 0.958 ±0.02 | 0.952 ±0.01 |
| | B1PA | 0.954 ±0.02 | 0.936 ±0.01 |
| | B2PA | 0.960 ±0.01 | 0.970 ±0.01 |
| | P3PA | 0.942 ±0.02 | 0.940 ±0.01 |
| III | C1EL/PA | 1.202 ±0.01 | 1.198 ±0.01 |
| | C2EL/PA | 1.254 ±0.01 | 1.256 ±0.02 |
| | C3EL/PA | 1.198 ±0.01 | 1.176 ±0.02 |
| | B1EL/PA | 1.260 ±0.01 | 1.296 ±0.01 |
| | B2EL/PA | 1.294 ±0.01 | 1.260 ±0.01 |
| | P3EL/PA | 1.112 ±0.01 | 1.124 ±0.01 |

Note: *b* – blank treated knits; *a* – antimicrobial treated knits.

The results of knits thickness measurements after blank and antimicrobial treatment are presented in Table 3. Knits with elastane thread (III group) are the thickest. Elastane thread relaxes more and has higher shrinking capacity after thermo-setting and relaxation processes comparing with other thermoplastic fibres (polyamide, polyester). The differences between thickness values of blank and antimicrobial treated knits of all groups were insignificant (approx. till 4 %).

Air permeability is an important property of textiles, which influences the flow of vapour from the human body to outside and the flow of fresh to human body.

Results of the air permeability of blank and antimicrobial treated knits are presented in Fig. 1. The results show that the knits of II and III groups have significantly lower air permeability compared with the knits of I group. The reason of such is higher loop density in the knit, especially for the knits of III group (with elastane thread). As well these knits had the highest area density. It is evident that air permeability decreases when the area density and thickness increases. The same tendency was found and by other researchers [15].

The results of air permeability investigation after blank and antimicrobial treatments give us very important information (Fig. 1). The differences of air permeability values between blank and antimicrobial treated knits are very low – in most cases up to 2 %. The higher differences of air permeability values are obtained for knits C1, C2, C3 (pure cotton knits in I group), nevertheless these differences did not exceed 6 %. It can be stated that differences between the air permeability values of blank and antimicrobial treated knits were insignificant. This means that antimicrobial treatment does not impair the ventilation (respiration) property and does not worsen garment comfort.

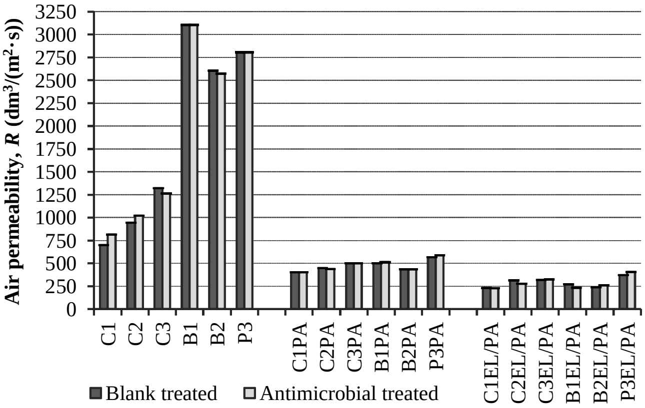


**Fig. 1.** Air permeability of blank and antimicrobial treated knits

The correlation between air permeability and thickness of treated knits has an exponential character and these dependences subject to raw material of knit are presented in Fig. 2 (after blank treatment) and Fig. 3 (after antimicrobial treatment). The results demonstrate that the exponential dependence between those parameters exists and is strong (the coefficient of determination $R^2$ for blank treated knits vary from 0.8899 up to 0.9899, and for antimicrobial treated knits – from 0.8399 up to 0.9792).

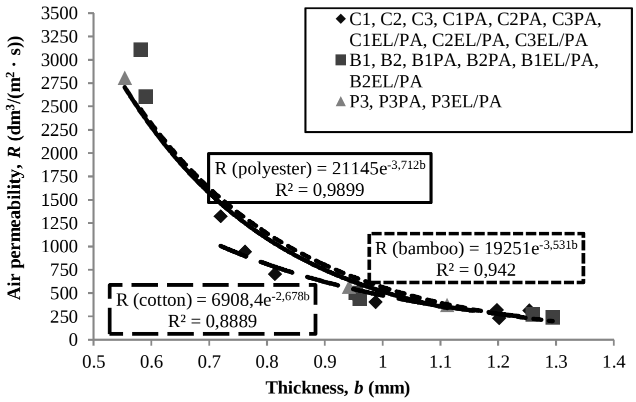


**Fig. 2.** The influence of thickness on the air permeability of blank treated knits

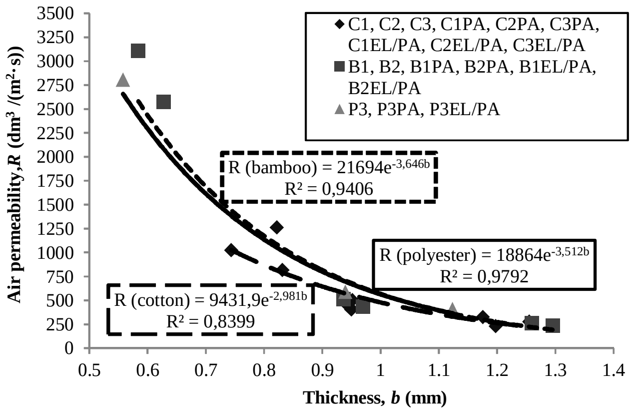


**Fig. 3.** The influence of thickness on the air permeability of antimicrobial treated knits

The highest values of air permeability after blank and antimicrobial treatments were determined for pure man-made bamboo B1, B2 and polyester P3 knits. The man-made bamboo yarns and polyester threads have smoother surface than cotton yarn, therefore the pores between yarns bent into the loops are not covered with elementary fibres [5, 22]. In addition, bamboo fibres have many micro spaces and it provide a good air permeability properties.

Another important physical property that can have influence on functionality of textile is water absorption ability. Results of the water absorption of blank and antimicrobial treated knits are presented in Fig. 4. The results show that the usage of antimicrobial materials in the finishing process significantly changed sorption characteristics of investigated knits.

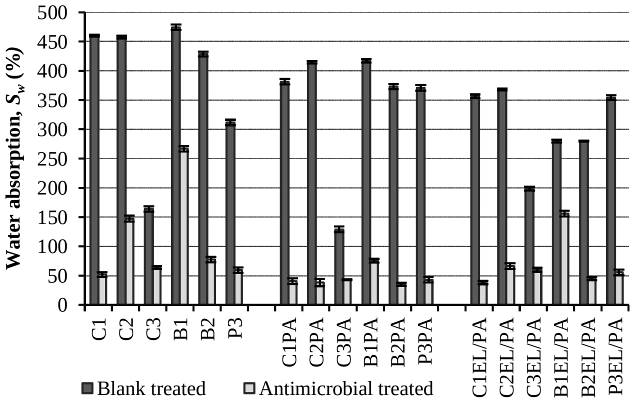


**Fig. 4.** The water absorption of blank and antimicrobial treated knits

The results obtained after investigation on water absorption demonstrate that antimicrobial treatment of investigated knits significantly reduced ability to absorb the water. The water absorption of the I and III group knits decreased from 44 % (B1, B1EL/PA) up to 89 % (C1, C1EL/PA), and of the II group knits from 67 % (C3PA) up to 91 % (C2PA). The lowest ability to absorb water distinguishes C3, C3PA, C3EL/PA knits because the cotton yarns used for knitting of samples of *C3* variant were dyed with disperse dyes. It is known that disperse dyes reduce the ability of water absorption. Similar results were obtained by other researchers [23], which stated that knits have a lower percentage of water absorption after treatment with hydrocarbon based polymer, than untreated.

On the other hand, fibre composition had influence to the water absorption also. Knits with synthetic yarns in the structure, especially with elastane threads absorb lower amount of water than knits of pure natural fibres.

Nevertheless, the influence of antimicrobial treatment on the water absorption ability is much more evident. The slight water absorption mainly depends on the organic-inorganic binder, which was used in antimicrobial treatment and forms the sol-gel layer on the surface of fibre. This layer blocks the way of water molecules inward the fibres and yarns and significantly reduces the water absorption.

This effect of antimicrobial treatment can be applied to products, which requires antimicrobial effect and ability to repel water (surgical gowns, etc.). However, it not applies to napkins, panty liners, bed linen, etc.

## 4. CONCLUSION

In this research, it was estimated marked changes of knits structure parameters (15 % ÷ 90 % for course density and till 20 % for wale density) after antimicrobial and blank treatments (these changes occur in the knit by force of action of humidity and temperature). However, the differences between the values of loop density, area density and fabric thickness after blank and after antimicrobial treatment are very low and in generally vary in the range of error. The values of wale density after blank and antimicrobial treatment differ just 0 % ÷ 5 % and the values of course density respectively – 0 % ÷ 7 %. The present low differences determine the similar porosity of knits after both blank and antimicrobial treatments.

It is very important, that insignificant differences of porosity of the blank and antimicrobial treated knits influence the similar permeability to air after mentioned treatments. The differences of air permeability values between blank and antimicrobial treated knits are up to 2 %, just for pure cotton knits these differences were up to 6 %. This means that chemical substances used for antimicrobial treatment do not impair the air permeability, i. e. the ventilation (respiration) property.

Meanwhile, the water absorption results of knits after blank and antimicrobial treatment have been obtained significantly different. It was found that water absorption of antimicrobial treated knits is significantly lower than the blank treated knits (in 44 % ÷ 91 %) because of sol-gel layer have been formed on the surface of fibre providing the antimicrobial effect and using organic-inorganic binder iSys MTX.

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