COMPARISON OF QUANTITATIVE METHODS FOR DETERMINING THE ANTIBACTERIAL EFFECTIVENESS OF NON-WOVEN TEXTILES

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ABSTRACT

This contribution is aimed at comparing two quantitative methods for determining the antibacterial effectiveness of non-woven textiles and assessment of permanence of the antimicrobial finish of the non-woven textile materials prepared from polypropylene fibers. Experience and results obtained by the quantitative test methods specified in AATCC TM 100 and STN EN ISO 20743 intended to evaluate the effectiveness of the antibacterial finish are published in the contribution. Emphasis is placed on comparability of the selected test methods, on the test microorganism used in the study as well as on evaluation of the results of antibacterial effectiveness. The non-woven fabrics, that were the subject of the evaluation, were pre-treated by surface activation with low-temperature plasma at atmospheric pressure and subsequently finished using antimicrobial (AMB) nanosol solution with a concentration of 15 ppm Ag+, 30 ppm Ag+, 60 ppm Ag+ and 120 ppm Ag+. Antibacterial effectiveness before washing and after 5 washing cycles is demonstrated on the specific examples obtained from practice.

KEYWORDS

Antibacterial effectiveness; Antimicrobial nanosol; Antibacterial textiles; Non–woven fabrics.

INTRODUCTION

Recently, awareness of antimicrobial textiles has come to the fore during the COVID 19 pandemic as consumers looked for ways to improve overall hygiene and well-being. Microorganisms naturally belong to human life. They are useful for a man, but some of them are dangerous as well. It has long been known that microorganisms, especially bacteria, can thrive on textile materials. Antibacterial fabrics are designed to provide protection against bacteria, mold and viruses [1].

As consumers are increasingly aware of the personal hygiene and health risks associated with certain microorganisms, the demand for antimicrobial textiles experienced a large increase in recent years. In addition to being effective against microorganisms, the antimicrobial finish of textiles must also meet various requirements, namely, it must be suitable for textile processing, durable in washing, dry cleaning, it must present a favorable safety and environmental profile, and should not damage quality or appearance of the textile material [2,3].

The growth of microorganisms on textiles causes a number of undesirable effects not only on the textiles as such, but it has also an adverse effect on the user. These effects include odor-causing, reduction of mechanical strength, discoloration and increased possibility of user contamination [4].

It is known that a large surface area of textiles and their ability to retain water provide favorable conditions for the growth of microorganisms such as bacteria and molds, which are found basically everywhere and are able to multiply very quickly depending on humidity, nutrients and temperature [5].

Due to growing public awareness of pathogenic health effects, intensive research and development has been encouraged in recent years to minimize or even eliminate bacterial growth on the textiles. Therefore, the researchers develop new means for antibacterial finish of the textiles [6].

As part of the research, we drew motivation from sources where the subject was a modified fabric providing protection of the human body against bacteria and viruses, ensuring protection of the human skin and face [7]. Subsequently, subject of the research was a barrier incorporating the modified fabric, preventing penetration of bacteria and other infectious microorganisms. The developed textile barrier can be used in the households, laboratories and in medical facilities (e.g. gown, drape, blanket...) [8].

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Microorganisms are known to cause major problems related to the transmission of diseases and infections through clothing, bedding, etc. It should be noted that bacteria are usually active at pH 7,0-8,0. Mold growth on textile materials is faster at relative humidity above 80%. At that time, microorganisms are found on the textile material in large quantities, they spread diseases and infections and also damage the fibers under normal conditions of use and storage [9]. MRSA bacterial infection caused by staphylococcus (methicillin-resistant Staphylococcus aureus) can be spread by direct contact with an infected person, as well as after contact with an object or surface touched by an infected person. It is transmitted by contact with sleepwear, bed linen and/or bed sheets. Therefore, there is an urgent need to develop textile materials effective against various microorganisms characterized by sterilizing and antimicrobial effects [10].

The goal was to prepare not only hydrophobic, but also breathable fabric, whose surface is finished with an antimicrobial agent. The fabrics according to this invention show excellent durability even in washing. This means that the fabric can be used even after repeated washing, it is not intended for one use only [11,12].

Plasma treatments are gaining popularity in the textile industry due to many advantages over traditional wet processing technologies. Equally interesting was a polypropylene non-woven fabric, made by spunbond technology and treated with hydrogen fluoride using plasma. It was found that the fabric treated in this way shows 99,04% bacterial reduction, which represents an effective barrier against the penetration of microorganisms [13].

EXPERIMENTAL PART

The experimental part describes the procedures, methods and results related to the evaluation of the antibacterial efficiency of modified non-woven fabrics. If bactericidal activity is required and/or assumed, then the quantitative assessment is necessary. Quantitative evaluation provides also a clearer picture of possible applications of the finished textile materials. One of the possibilities is also a fabric modified by surface activation with plasma and subsequent antimicrobial finish using nanosol containing an antibacterially active substance. Verification of its antibacterial effectiveness according to the appropriate standards is the subject of this article.

Methods for evaluating antibacterial effectiveness of the modified textiles

Two quantitative test methods were chosen to verify the antibacterial effectiveness of non-woven fabrics: AATCC TM 100 - 2019 [14], STN EN ISO 20743 – 2021 [15]. Both methods involve counting microbes and the results are reported as a percentage or logarithmic reduction of the contamination level.

The test microorganism Staphylococcus aureus CCM 4516 was used for testing and determination of the antibacterial effectiveness. The microorganism Staphylococcus aureus is a gram-positive coccus with dimensions of 0.5-1.5 μm in diameter. The cocci are arranged either individually, in squares, short chains, but most often in irregular grape-shaped clusters. Liquid inoculated (bacterial) solutions prepared from this microorganism were applied on the textile test samples in accordance with the test procedures.

Test method AATCC TM 100 - 2019

The test method for antibacterial finishes on textile materials AATCC TM 100 – 2019 (absorption method) is used for quantitative determination of effectiveness of antibacterial finishes applied on the textile materials. Textiles with antibacterial finishes offer the users protection from harmful bacteria and at the same time they reduce risk of disease transmission. The test method includes evaluation of the bactericidal (killing of bacteria) and bacteriostatic (inhibiting the growth of bacteria) effectiveness of the textile material during 24-hour contact with the tested bacteria.

The reduction factor was evaluated, which indicates the percentage by which the inoculated concentration of bacteria was reduced. For the test, (1.0 ± 0.1) ml of test inoculum per sample was used (i.e. in the range from 1x105 to 3x105 colonies/milliliter (CFU/ml)). After inoculation (0 contact time), a neutralizing solution was added to the sample to suppress the bactericidal effect and to maintain the correct pH balance. Serial dilutions were plated on nutrient agar medium and incubated at (37 ± 2) °C for 24 h. Evaluation of the inoculated samples took place at zero time and after 24 hours, in both cases the colony forming units were counted. The antibacterial efficiency was expressed by ratio of the number of bacteria on the antibacterially finished nonwoven fabric immediately after inoculation compared to a sample of the antibacterially finished nonwoven fabric incubated for a contact period of 24 hours. The amount of bacteria is given as the number of bacteria per sample (samples in the vessel), not as the number of bacteria per ml of neutralization solution (CFU/sample) and then the reduction R is calculated and expressed as a percentage (Tab. 3, Tab. 5):

$$100\,(C - A) / C = R \qquad (1)$$

where:

- R is reduction of bacteria as a percentage;
- C is number of bacteria regenerated from the inoculated finished test samples in a vessel, immediately after inoculation (at "0" contact time);
- A is number of bacteria regenerated from the inoculated finished test samples in a vessel, incubated for 24-hour contact time;

In this method, the microbial concentrations are standardized and the bacteria are supplied with nutrients during the entire incubation period. If the textiles tested do not have strong antibacterial potential, then this will allow bacteria to flourish and grow.

Test method STN EN ISO 20743 - 2021

The test method STN EN ISO 20743 - 2021 Determination of the antibacterial activity of textile products is a quantitative (absorption) test method to determine the antibacterial activity of the antibacterial textile products. This test method can be applied to all textile products including woven fabrics, waddings, clothing, bedspreads, household goods and textiles, yarn and material for various products, regardless of the type of antibacterial agents used.

In this method, similar to AATCC TM 100 - 2019, the test bacterial suspension was inoculated directly onto samples of the non-woven fabrics (exactly 0,2 ml of inoculum adjusted to a concentration of 1x105 - 3x105 CFU/ml is pipetted onto each sample). The concentration of bacteria (CFU) was counted at time zero (immediately after inoculation of the bacterial suspension) and after 24 hours of incubation of the bacteria on the non-woven fabric sample. The method required to perform the test on a sample of nonwoven fabric with antibacterial finish as well as on a reference sample of the nonwoven fabric. Result of the test was the antibacterial effect value, which was calculated from the CFUs:

$$A = (lgC_t - lgC_0) - (lgT_t - lgT_0) = F - G \qquad (2)$$

where:

- A is the resulting antibacterial effectiveness value;
- F is the growth value of the nonwoven fabric control sample $(F = lgC_t - lgC_0)$;
- G is the growth value of the nonwoven fabric sample with antibacterial finish $(G = lgT_t - lgT_0)$;
- lgC_t is the average decimal logarithm of the bacterial number determined from 3 test control samples of the non-woven fabric after 24-hour incubation;
- lgC_0 is the average decimal logarithm of the bacterial number determined from 3 test control samples of the nonwoven fabric immediately after inoculation;
- lgT_t is the average decimal logarithm of the bacterial number determined from 3 test samples of the non-woven fabric with antibacterial finish immediately after 24-hour incubation;
- lgT_0 is the average decimal logarithm of the bacterial number determined from 3 test samples of the nonwoven fabric with antibacterial finish immediately after inoculation.

If $C_0 > T_0$, C_0 is replaced by T_0 in the calculations.
Results of the testing will be assessed according to the achieved value of antibacterial efficiency A as shown in Tab. 1.

Table 1. Assessment of antibacterial properties according to the STN EN ISO 20743 - 2021 method

Effectiveness of antibacterial properties	Antibacterial value *(A)*
low	$A < 2$
significant	$2 \leq A < 3$ (2,3)
strong	$A \geq 3$

Materials used

For the purposes of verifying the antibacterial effectiveness using the above-mentioned methods, a sample of non-woven fabric was prepared from 100% PP using spunbond technology with mass per unit area of 40 g/m^2 and a thickness of 0,38 *mm*. The prepared sample of non-woven fabric was pre-treated with low-temperature plasma and then finished by application of antimicrobial (AMB) nanosol solutions with a concentration of 15 *ppm* Ag+, 30 *ppm* Ag+, 60 *ppm* Ag+ and 120 *ppm* Ag+ (Tab. 2).

Samples of the non-woven fabrics were subjected to five cycles of washing and drying in accordance with STN EN ISO 6330: 2012 using washing procedure 4N at a water temperature of (40±3) °*C* and a commercial detergent. Drying was carried out by procedure C, i.e. drying in a horizontal position in a spread state and then antibacterial effectiveness of the samples was evaluated (Tab. 2).

RESULTS AND DISCUSSION

Antibacterial effectiveness was quantitatively determined on samples of non-woven fabrics on which the AMB nanosol was applied under specified conditions. After incubation the bacteria are leached from the samples, their number is determined and the reduction of the number on the textile sample is calculated as a percentage or the strength of the antibacterial effect of the finished non-woven fabric is assessed. The results of testing by the absorption method according to the above-mentioned procedures are shown in Tab. 3-6.

Table 2. Identification of non-woven fabrics for verification of the antibacterial effectiveness.

Description of samples of non-woven fabrics	Marking of samples of non-woven fabrics before washing	Marking of samples of non-woven fabrics after 5 washing and drying cycles
standard PP fabric without finish	PP	
non-woven PP fabric finished by application of AMB nanosol solution with a concentration of 15 *ppm* Ag^+	PP1/15	PP2/15
non-woven PP fabric finished by application of AMB nanosol solution with a concentration of 30 *ppm* Ag^+	PP1/30	PP2/30
non-woven PP fabric finished by application of AMB nanosol solution with a concentration of 60 *ppm* Ag^+	PP1/60	PP2/60
non-woven PP fabric finished by application of AMB nanosol solution with a concentration of 120 *ppm* Ag^+	PP1/120	PP2/120

Table 3. Evaluation of antibacterial effectiveness (*R*) of non-woven fabrics **before washing** according to AATCC TM 100 – 2019.

Sample of finished non-woven fabric	PP1/15	PP1/30	PP1/60	PP1/120
Number of bacteria from inoculated test samples *(C) [CFU/sample]*	1,53 x 10^5	1,36 x 10^5	1,25 x 10^5	1,20 x 10^5
Reduction in number of bacteria (*R*) [%]	57,52	70,59	>99,92	>99,92

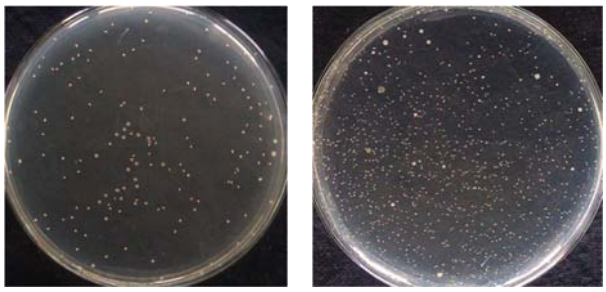
Table 4. Evaluation of the antibacterial effect (*A*) of the fabrics **before washing** according to **STN EN ISO 20743 -2021.**

Sample of finished non-woven fabric	PP1/15	PP1/30	PP1/60	PP1/120
Growth value *F* ($F = lg\ C_t - lg\ C_0$)	+ 2,70	+2,63	+2,53	+2,51
Growth value *G* ($G = lg\ T_t - lg\ T_0$)	-1,10	- 3,20	-4,65	-4,75
Antibacterial activity value *(A = F-G)*	3,80	5,83	7,18	7,26
Assessment of antibacterial properties from Tab.1	strong A ≥ 3			

Assessment of antibacterial effectiveness of the fabrics before washing

This work consists of two parts. In the first part, we focused on the evaluation of antibacterial effectiveness on selected fabrics before washing.

Figure 1 shows the growth of bacteria on agar after the contact time on PP non-woven fabric without antibacterial finish.



contact time: 0 hour contact time: 24 hours

Figure 1. Comparison of bacterial growth on agar: **100% PP non-woven fabric without antibacterial finish.**

To determine antibacterial effectiveness of the textile samples quantitatively, reduction in the number of bacteria *R* (Equation 1) was calculated according to the standard method AATCC TM 100 - 2019 (Tab. 3). The amount of bacteria is expressed as a number of bacteria per sample; according to the requirements of the standard, when diluted to 10^0, the value "less than 100" is indicated. The amount of inoculum per sample (1.0±0.1) *ml* of the appropriate solution of 18 *h* culture of the test organism is applied so that the amount of 1-3 x 10^5 organisms is reached on the textile test samples in "0" contact time.

The results listed in Tab.3 show, that antibacterial finish of the test samples for the microorganism *Staphylococccus aureus* CCM 4516 led to a reduction of number of bacteria at the level of **58%** on the finished PP1/15 test sample and almost **100%** on PP1/60 and PP1/ 120 samples, prepared with a higher concentration of AMB nanosol. A strong bactericidal effect was achieved on the non-woven fabrics finished by application of AMB nanosol solution before washing and drying.

Our goal was to verify reproducibility and compare the results obtained by both above-mentioned methods (Tab. 3 and Tab. 4). Table 4 shows results of determining the antibacterial effectiveness before washing and drying using another absorption method according to STN EN ISO 20743 - 2021. The test is considered effective if the test inoculum is between 1x10^5 and 3x10^5 *CFU/ml*.

Based on the results from the evaluation of the antibacterial effectiveness of the tested samples listed in Tab. 4 it can be concluded, that the finished test samples evaluated according to STN EN ISO 20743 - 2021 method show a strong antibacterial effectiveness, which is consistent compared to the AATCC TM 100 - 2019 method (Tab. 3). Comparison of the methods by evaluating the antibacterial effectiveness on non-woven fabrics before washing shows that the both test absorption methods confirmed a high antibacterial result.

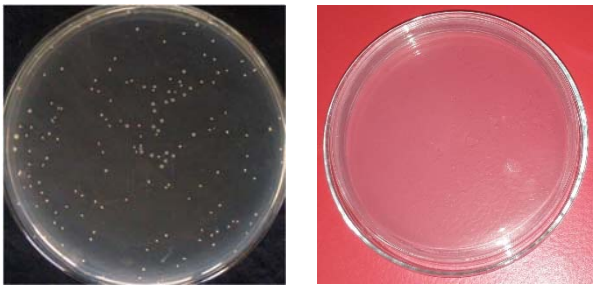
Comparison of growth of bacteria on agar after contact time (0 hour and 24 hours) is shown in Fig. 2 and Fig. 3. The following section shows selected images of growth of bacteria on agar after a contact time of 0 hour and after a contact time of 24 hours, reproducibility of which was repeatedly confirmed by both test methods before washing.

Table 5. Evaluation of the antibacterial effectiveness (R) on the finished nonwoven fabric samples **after washing** according to **AATCC TM 100 – 2019.**

Sample of finished non-woven fabric after washing	PP2/15	PP2/30	PP2/60	PP2/120
Number of bacteria from inoculated test samples *(C) [CFU/sample]*	1,41 x 10^5	1,20 x 10^5	1,18 x 10^5	1,10 x 10^5
Reduction in number of bacteria (*R*) [%]	41,84	60,00	98,83	99,78

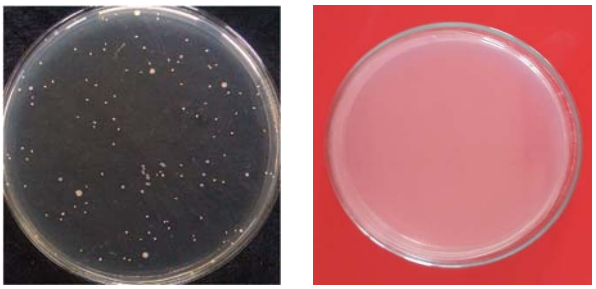
Table 6. Evaluation of the antibacterial effect **A** of the fabrics **after washing** according to **STN EN ISO 20743 – 2021.**

Sample of finished non-woven fabric after washing	PP2/15	PP2/30	PP2/60	PP2/120
Growth value *F* ($F = lg\ C_t - lg\ C_0$)	+ 2,51	+2,48	+2,40	+2,37
Growth value *G* ($G = lg\ T_t - lg\ T_0$)	- 1,00	- 2,82	- 4,68	- 4,79
Value of antibacterial activity *(A = F-G)*	3,51	5,30	7,03	7,16
Assessment of antibacterial properties from Tab.1	**strong A ≥ 3**			



contact time: 0 hour contact time: 24 hours

Figure 2. Sample PP1/60 before washing – comparison of growth of bacteria on agar by the **AATCC TM 100 method.**



contact time: 0 hour contact time: 24 hours

Figure 3. Sample PP1/60 before washing - comparison of growth of bacteria on agar by the **STN EN ISO 20743 method.**

Assessment of antibacterial effectiveness of the fabrics after washing

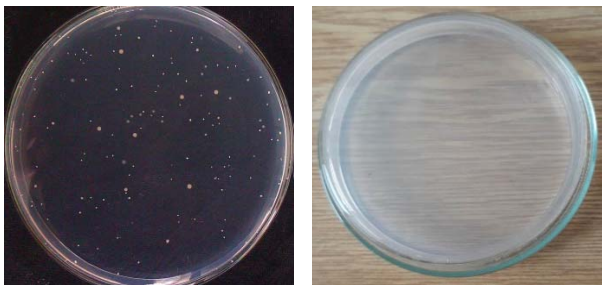
The second part of this research was devoted to the evaluation of the permanence of the antibacterial finish on the samples of non-woven textiles subjected to five washing cycles. Antibacterial effectiveness was evaluated after 5 washing cycles according to the above-mentioned methods (Tab. 5, Tab. 6). The antibacterial efficiency was expressed by the ratio of the number of bacteria on the antibacterially finished nonwoven fabric immediately after inoculation compared to the sample of the antibacterially finished nonwoven fabric incubated for a contact period of 24 hours.

Results presented in Tab. 5 show, that washing did not have a significantly negative effect especially on the non-woven fabric samples PP2/60 and PP2/120 regarding reduction of the antibacterial effectiveness compared to the non-woven fabric samples before washing (Tab. 3). The highest antibacterial efficiency after washing was achieved on the sample of PP non-woven fabric finished by application of the antimicrobial nanosol solution containing 120 *ppm* Ag^+, where reduction of number of bacteria of the test microorganism *Staphylococccus aureus* CCM 4516 was approximately 99,80% after 5 washing cycles. A sample containing 60 *ppm* Ag^+, PP2/60 approx. 98,80 % achieved the same high antibacterial effectiveness after washing. The PP2/15 sample containing the AMB nanosol with concentration of 15 *ppm* Ag^+ achieved a reduction of number of bacteria over 40 %, which is a decrease by about 27 % compared to the non-woven fabric sample (PP1/15) before washing. The PP2/30 sample with nanosol concentration of 30 *ppm* Ag^+ achieved about 60 % reduction of number of bacteria, which was a decrease by 15 % compared to the non-woven fabric sample (PP1/30) before washing (Tab. 3 and Tab. 5).

Table 6 shows the results of determining the antibacterial effectiveness of nonwoven fabrics after washing using the absorption method according to STN EN ISO 20743 - 2021.

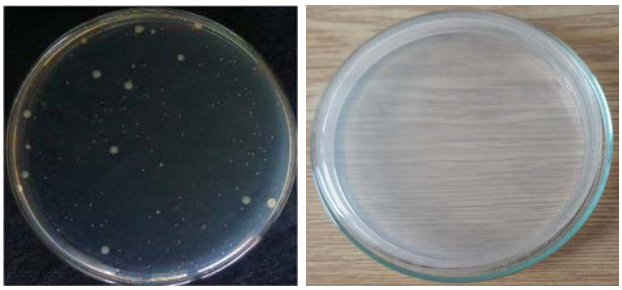
Results of the evaluation of the antibacterial activity of non-woven fabrics after washing given in Tab. 5 and Table 6 show, that the antibacterial activity is almost on the same bactericidal level for samples **PP 2/60** and **PP2/120** (*A* ≥ 3).

Selected images of bacterial growth on agar after a contact time of 0 h and after a contact time of 24 h are presented in the next part. Their reproducibility was repeatedly confirmed by both test methods **after washing** (Fig.4 and Fig.5).



contact time: 0 hour contact time: 24 hours

Figure 4. Sample PP1/60 after washing – comparison of growth of bacteria on agar by the **AATCC TM 100 method.**



contact time: 0 hour contact time: 24 hours

Figure 5. Sample PP1/60 after washing - comparison of growth of bacteria on agar by the **STN EN ISO 20743 method.**

Reproducibility of both above-mentioned methods was verified for each sample by parallel measurements, from which the average values, necessary for the calculations to determine the antibacterial effectiveness, were obtained. Colonies on the agar plates were counted according to the AATCCTM 100-2019 method (at zero time and after 24 hours) and also according to the STN EN ISO 20743-2021 method. After counting the colonies on the agar plates, the values, according to the AATCC TM 100 method, were substituted into the equation $100\ (C\text{-}A)/C = R$, from which the result of antibacterial effectiveness (reduction) in *%* can be seen.

In accordance with the STN EN ISO 20743, colonies on agar plates were counted as well. The average values of the number of bacteria were converted to a decimal logarithm according to the specified procedure. The value of the antibacterial effect *(A)* was calculated according to the equation given in the standard: $A = (lgC_t - lgC_0) - (lg\ T_t - T_0)$. Antibacterial properties of the non-woven fabric are assessed on the basis of the calculated *A* value. This standard defines the antibacterial effectiveness as strong ($A \geq 3$) - shown in Tab.1.

Figure 6 clearly shows the number of bacteria recovered from inoculated finished test samples in a vessel, incubated for 24 hours. Figure 7 clearly shows the average logarithmic values (lgT_t) of the number of bacteria obtained from three antibacterially finished non-woven test samples after 24 hours of incubation.

No viable bacteria were detected on the antibacterially finished nonwoven fabrics (PP1/60, PP1/120) on which the *Staphylococcus aureus* bacterium was applied (incubated for 24 hours in a microbiological incubator at (37±2) °C) or a significant reduction in the number of viable bacteria (PP1/15, PP1/30) has been found. After 24-hour cultivation, the number of colonies on agar plates was determined and counted (*CFUs*), and then the antibacterial effectiveness was calculated according to the AATCC TM 100 (Fig. 6) and STN EN ISO 20743 standard (Fig. 7).

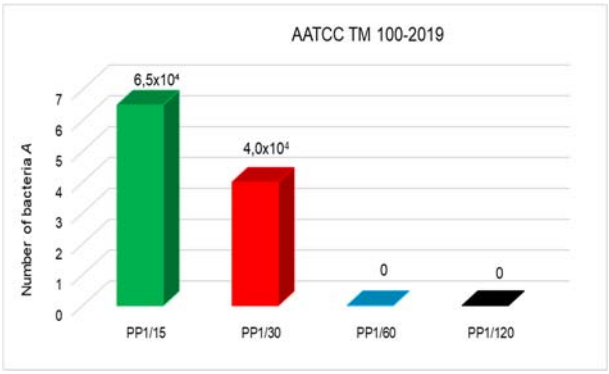


Figure 6. Number of viable *Staphylococcus aureus* bacteria on antibacterially finished textiles before washing according to the AATCC TM 100 method: ***A*** – average number of bacteria recovered from inoculated finished test samples incubated for 24 hours.

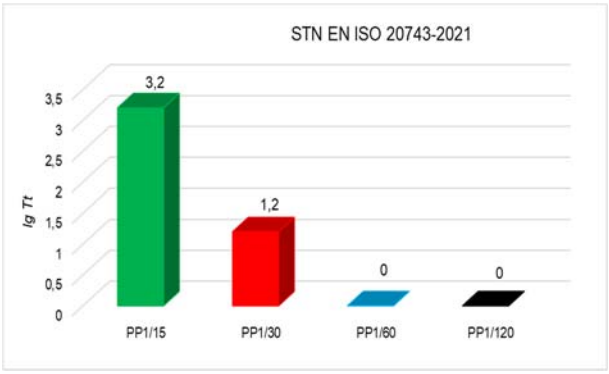


Figure 7. Number of viable *Staphylococcus aureus* bacteria on antibacterially finished textiles before washing according to the STN EN ISO 20743 method: ***lgT$_t$*** – decimal logarithm of the arithmetic mean of the number of bacteria per non-woven fabric after 24 hour incubation

Based on comparison of the antibacterial effectiveness results on 100 *%* PP non-woven fabric, it can be concluded that bactericidal effectiveness with a high degree of bacterial reduction was achieved according to the AATCC TM 100 - 2019 method and strong antibacterial effectiveness according to the STN EN ISO 20743 -2021 method (PP1/60, PP1/120), PP2/60, PP2/120). Values with less low reductions and/or significant value of antibacterial effectiveness, obtained by the methods, mentioned in the text above, could be caused by lower stability of the antimicrobial finish on PP nonwoven fabrics (PP1/15, PP2/15, PP1/30, PP2/30). Suitability of the selected test methods, together with the selection and finish of the non-woven fabric and laboratory verification of the test methods for the assessment of antibacterial activity showed us that after verifying reproducibility of the results by both absorption methods, it is possible to consider the test methods STN EN ISO 20743 - 2021 and AATCC TM 100 - 2019 sufficiently sensitive and equally reliable from the experimental viewpoint.

CONCLUSION

The antimicrobial finish protects textiles from odors and ensures their freshness, as well as protection against degradation caused by bacteria and mold. However, differences in test results between specific laboratories and failure to meet effectiveness expectations due to the use of inappropriate test methods often lead to uncertainty on the market of the antimicrobial products. Information allowing comparison of the effectiveness of antimicrobial finishes is often misleading due to differences in methodologies, as a result of inappropriate tests as well as different level of laboratory experience with their evaluation. The only way how to ensure comparability of the results is to perform side-by-side tests in the same laboratory using the same test methods.

It is possible to conclude that the assessment of antibacterial effectiveness according to the quantitative methods AATCC TM 100 - 2019 and STN EN ISO 20743 - 2021 is based on the same principle with slight deviations, while the result is expressed in a different way. Each methodology has its own expression of results, and by comparing the methods it was possible to find a correlation between the results. All samples of the non-woven fabrics had a strong antibacterial effect. Washing did not show any negative effect on reduction of the antibacterial effectiveness in comparison with the samples of nonwoven fabrics before washing. In order to determine significant level of antibacterial effect and low level of antibacterial effect, it would be necessary to test materials with AMB nanosol concentration of less than 15 *ppm* Ag^+ and number of bacteria less than 40%. The effect of low-temperature plasma on increased adhesion of AMB nanosol to the surface of PP non-woven fabric was demonstrated.

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REFERENCES

1. Antimicrobial textiles: promoting hygiene during the COVID-19 pandemic and beyond, Performance Apparel Markets, 71, 2021.
2. Gao Y., Cranston R.: Recent advances in antimicrobial treatments of textiles, Test. Res. J., 2008, 78(1), pp. 60-72. https://doi.org/10.1177/00405175070823
3. Windler L., Height M., Nowack B.: Comparative evaluation of antimicrobials for textile applications., Environ. Int., 53, 2013, pp. 62 -73. https://doi.org/10.1016/j.envint.2012.12.010
4. Venugopala K. N., Rashmi V., Odhav B.: Review on natural coumarin lead compounds for their pharmacological activity. BioMed Res. Int., 2013, pp. 563-568. https://doi.org/10.1155/2013/963248
5. Zanoaga M.,Tanasa F.: Antimicrobial reagents as funcional finishing for textiles intended for biomedical applications. I. Synthetic organic compounds. Chem. J. Mold., 9(1), 2014 pp.14-32. https://doi.org/10.19261/CJM.2014.09(1).02
6. Morais S., D., Guedes R., M., Lopes M., A.: Antimicrobial Approaches for Textiles: From Research Market, Materials, 9, 2016, pp. 1 – 21. https://doi.org/10.3390/ma9060498
7. Fan Y.: Composite medical protective clothing, CN2669636Y, 2003.
8. Woodcock A.: Infection barrier, EP0398611A1, 1989.
9. Rajendran S.: Infection control and barrier materials: An overview, Medical Textiles and Biomaterials for Healthcare, 2006, pp. 131-135. https://doi.org/10.1533/9781845694104.3.131
10. Virus inactivation sheet, KR101759363B1, 2010.
11. Nano Motion Technology Co Ltd.: Protective clothing system for preventing respiratory system infectious disease, and the clothing, CN100506096C, 2003.
12. Sieren Co. Ltd.: Virus barrier laminated fabric excellent in washing durability, JP2015013391A.
13. Parthasarathi V., Thilagavathi G.: Development of plasma enhanced antiviral surgical gown for healthcare workers, Fashion and Textiles 2, 2015, 4. https://doi.org/10.1186/s40691-015-0028-7
14. AATCC TM 100-2019. Test Method for Antibacterial Finishes on Textile Materials. Assessment of.
15. STN EN ISO 20743-2021. Textiles – Determination of antibacterial activity of textile products.