BIOACTIVE NONWOVENS WITH SUPERABSORBING POLYMERS FOR FILTERING FACEPIECE RESPIRATORS USED IN HEAVY-DUTY APPLICATIONS AT HIGH TEMPERATURES AND HUMIDITY

Majchrzycka K[1], Okrasa M[1], Brochocka A[1], Jachowicz A[2], Gutarowska B[2]
[1] *Department of Personal Protective Equipment, Central Institute for Labour Protection – National Research Institute, Łódź, Poland*
[2] *Institute of Fermentation Technology and Microbiology, Lodz University of Technology, Łódź, Poland*
kamaj@ciop.lodz.pl

Within the present study the efficiency of filtering nonwovens with bioactive and sorption properties have been investigated. Two types of nonwovens with bioactive agents and superabsorbing polymers were manufactured using melt-blown technology from polypropylene along with pristine nonwoven serving as a control sample. The influence of additives on basic filtration properties (paraffin oil mist, sodium chloride penetration, pressure drop) were assessed. Moreover, their antimicrobial properties as well as water sorption capacity were determined to confirm their applicability as a multifunctional layer in the construction of filtering facepiece respirators.

Key Words: filtering facepiece respirators, antimicrobial additives, superabsorbing additives

1. INTRODUCTION

Filtering facepiece respirators FFRs are one of the most common respiratory protective devices that are used throughout industry for the protection against dusts, fumes, mists and smokes. Long-term use of such devices in a heavy working conditions (high dust concentration, temperature and humidity) may lead to the formation of aggregates of particles that can detach from the filtering surface and be transferred to the respiratory system [1]. On the other hand the heat and moisture accumulated under the facepiece is usually perceived as uncomfortable and what is more can form favorable conditions for the growth of microorganisms on the filtering materials [2]. To resolve this issue, works aiming at development of a new w type of filtering nonwoven with bioactive and sorption properties have been carried out. Within the presented study two types of nonwovens with bioactive agents (bioperlite and magnesium monoperphthalate) and superabsorbing polymers (sodium polyacrylate) were manufactured using melt-blown technology from polypropylene. The additives were introduced into the nonwoven structure simultaneously during the production process. In this paper the influence of additives on basic filtration and utility properties (paraffin oil mist penetration and air flow resistance) of the prepared filtering nonwovens were discussed. Moreover their antimicrobial properties against selected bacteria and fungi (*Escherichia coli*, *Staphylococcus aureus*, *Bacillus subtilis*, *Candida albicans*, *Aspergillus niger*) and water sorption capacity were experimentally assessed.

2. MATERIALS AND METHODS

2.1 Bioactive Filtering Nonwovens

Two types of polypropylene nonwoven composites manufactured using the melt-blown technique were tested. The main difference between the variants of the nonwoven was the use of two different types of biocide. In the first one (WSB1) bioperlite, previously patented by the authors [3], was used, while in the second one (WSB2) pure magnesium monoperoxyphthalate was added. In both variants commercial superabsorbing polymer (SAP) was added to increase water sorption of the material. A pristine polypropylene nonwoven (W0) manufactured at the same technological conditions but without any of the additives constituted a control variant. Thickness of the nonwovens was in the range 1.6-2.4 mm and the mass per unit area in the range of 76-105 g/m^2.

2.2 Filtration and Utility Properties
Penetration of paraffin oil mist and sodium chloride aerosol, defined as a ratio of an aerosol concentration downstream of the sample to an aerosol concentration upstream of the sample, were determined according to the EN 13274-7:2008 standard [4]. Pressure drop measurements were carried out alongside the measurements of paraffin oil mist penetration using digital micromanometer CMR-10A.

2.3 Water sorption capacity
The water sorption capacity of nonwovens was determined using the gravimetric method with distilled water as the test liquid. Prior to testing round samples of 80 mm diameter were completely dried, placed in beakers and soaked with 200 ml of distilled water for 20 min. Then the swollen samples were placed on paper filter to drain the excess water and weighted. The water sorption capacity was calculated from the equation:

$$P_{H_2O} = \frac{w_2 - w_1}{w_1} \quad (1)$$

where w_1 and w_2 denote the masses of the polymer before and after swelling.

2.4 Microorganisms survivability
The microorganisms obtained from American Type Culture Collection (ATCC) and National Collection of Agricultural and Industrial Microorganisms (NCAIM) and stored in the Pure Culture Collection LOCK 105. They were belonging to various taxonomic groups (bacteria, yeasts, moulds) and diverse growth physiology were used to study survival on selected nonwovens: *E. coli (*ATCC 10536), *S.aureus* (ATCC 6538), *B. subtilis* (NCAIM 01644), *C. albicans* (ATCC 10231), *A. niger* (ATCC 16404). Inocula of 2.2×10^7 - 7.0×10^9 CFU/ml density were obtained according to methodology described in [5]. Then, 25 µl of the inocula were placed on UV-disinfected nonwoven swatches of 4 cm^2 surface area. The swatches were then placed in sterile Petri dishes and incubated in Binder-720 climatic chamber at 30±2°C and relative humidity of 80%. Quantitative static AATCC 100-2004 method was used to determine microorganism survival on the nonwovens [6]. Test samples were taken immediately after inoculum application at 0h and after 24h of incubation. The tests were performed according to methodology described in [5]. Microorganism survivability was calculated as a ratio of the number of microorganisms after incubation to the initial number of microorganisms.

3. EXPERIMENTAL RESULTS AND DISCUSSION
3.1 Filtration and Utility Properties
The results of filtration and utility properties of tested nonwovens are shown in table 1.

Table 1. Filtration and utility parameters of filtering nonwovens with bioactive and sorption properties

Vatiant of nonwoven	Paraffin oil mist penetration, %	Sodium chloride aerosol penetration, %	Pressure drop, Pa
W0	$7.33^{a}\pm1.91$	$6.21^{a}\pm1.92$	$199.6^{a}\pm31.2$
WSB1	$11.99^{b}\pm3.34$	$7.99^{a}\pm3.04$	$185.4^{ab}\pm28.2$
WSB2	$9.03^{a}\pm1.51$	$7.94^{a}\pm1.52$	$173.5^{b}\pm13.4$

a, b – statistically significany differences are marked with different letters (Anova, α=0.05; Fisher test, α=0.05)

The lowest values of paraffin oil mist penetration for the same processing parameters were obtained for control variant W0. In case of sodium chloride aerosol no statisticaly significant diffrences were observed between filtering nonwovens with bioactive and sorption properties and control sample. At the same time the pressure drop for WSB1 and WSB2 was slightly lower than for the control variant W0. The obtained results indicate that the applied modifiers have no significant effect on filtration and utility properties of filtering nonwovens with bioactive and sorption properties.

3.2 Water sorption capacity

The influence of modifiers on the water sorption capacity is illustrated in figure 1.

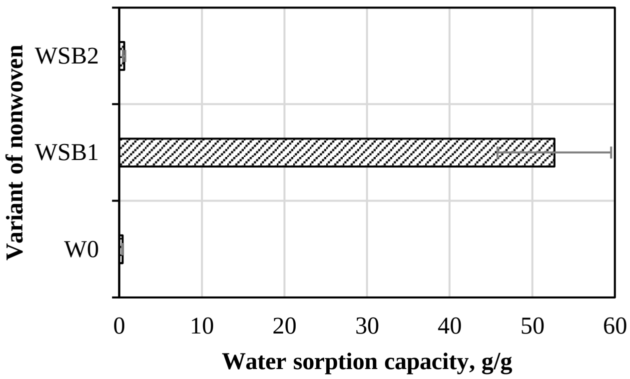

Figure 1. Swelling capacity of filtering nonwovens.

The water sorption capacity for W0 and WSB2 was at the negligible level of 0.41 and 0.59 g/g, respectively. In case of WSB2 it was significantly higher (52.7 g/g). The results show that magnesium monoperoxyphthalate (WSB2) greatly affects the properties of superabsorbing polymer (the capacity of raw SAP is approx. equal to 300 g/g), which excludes its use in the targeted area of application.

3.3 Microorganisms survivability

The number of microorganisms on filtering nonwovens at time t = 0 and after 24 h of incubation and their survivability are presented in Table 2.

Table 2. Number of microorganisms and their survivability on filtering nonwovens

Microorganism	Variant of nonwoven	Number of microorganisms, CFU/sample		Survivability, %
		at 0h	after 24h	
E. coli	W0	$3.6\times10^8 \pm 9.6\times10^7$	$2.6\times10^8 \pm 1.7\times10^8$	71
	WSB1	$9.3\times10^7 \pm 6.7\times10^7$	$6.5\times10^7 \pm 6.2\times10^7$	70
	WSB2	$2.9\times10^7 \pm 3.5\times10^6$	$2.1\times10^7 \pm 8.5\times10^6$	72
S. aureus	W0	$9.4\times10^7 \pm 4.3\times10^7$	$3.8\times10^7 \pm 2.9\times10^7$	41
	WSB1	$2.3\times10^7 \pm 9.9\times10^6$	$1.3\times10^7 \pm 9.3\times10^6$	59
	WSB2	$6.0\times10^7 \pm 3.3\times10^7$	$3.1\times10^7 \pm 2.7\times10^7$	52
B. subtilis	W0	$1.4\times10^7 \pm 1.0\times10^7$	$5.7\times10^6 \pm 5.1\times10^6$	41
	WSB1	$1.7\times10^7 \pm 4.8\times10^6$	$9.0\times10^6 \pm 5.2\times10^6$	54
	WSB2	$6.0\times10^7 \pm 4.5\times10^7$	$3.5\times10^7 \pm 7.8\times10^6$	59
C. albicans	W0	$4.2\times10^6 \pm 1.8\times10^6$	$2.3\times10^6 \pm 1.0\times10^6$	56
	WSB1	$2.7\times10^6 \pm 7.8\times10^5$	$2.2\times10^6 \pm 7.8\times10^5$	82
	WSB2	$1.9\times10^6 \pm 4.7\times10^5$	$1.6\times10^6 \pm 2.0\times10^5$	86
A. niger	W0	$3.4\times10^5 \pm 7.8\times10^4$	$1.9\times10^4 \pm 8.0\times10^3$	6
	WSB1	$4.3\times10^5 \pm 6.1\times10^4$	$2.5\times10^4 \pm 1.2\times10^4$	6
	WSB2	$3.6\times10^5 \pm 7.5\times10^4$	$2.0\times10^4 \pm 9.5\times10^3$	6

It was found that the survivability of microorganisms depends primarily on their type. It was the largest for *C. albicans* yests (56-86%) and the lowest for *A. niger* moulds (6%, regardles of the nonwoven type). In case of *S. aureus*, *B. subtilis* bacteria and *C. albicans* yeast, a slight increase in survivability of microorganisms for modifies nonwoven variants WSB1 and WSB2 was observed in relation to the control sample W0, while for *E. coli* and *A. niger* no effect of biocide on survivability was observed. This might indicate that the amount of the biocidal agent was and its biocidal activity was insufficient for the intended application in FFRs. At the same time beter results were observed for the nonwoven modified with bioperilite (WSB1) than for the one modified with magnesium monoperoxyphthalate (WSB2).

4. CONCLUSION

In this paper the results of preliminary works aiming at development of a new w type of filtering nonwoven with bioactive and sorption properties have been presented. The results are promising and they indicate that the additives did not have any adverse effect on the filtration and utility properties of the nonwovens. The water sorption capacity was significantly affected by the addition of magnesium monoperoxyphthalate. The biocidal activity was low, which indicated that greater concentration of biocide should be used for the targeted area of application.

5. REFERENCES

1. Majchrzycka K, Okrasa M, Jachowicz A, Szulc J, Gutarowska B. Microbial Growth on Dust-Loaded Filtering Materials Used for the Protection of Respiratory Tract as a Factor Affecting Filtration Efficiency. *Int J Environ Res Public Health*, 2018, Vol.15, 1902.
2. Majchrzycka K, Okrasa M, Skóra J, Gutarowska B. Evaluation of the Survivability of Microorganisms Deposited on Filtering Respiratory Protective Devices under Varying Conditions of Humidity. *Int J Environ Res Public Health*, 2016, Vol.13, No.1, 98.
3. Brycki B., Gutarowska B. Majchrzycka K., Brochocka A., Orlikowski W.,Krucińska I, Gliścińska E., Krzyżanowski J., Łysiak I, Biocide for the production of filtering nonwovens and a method for obtaining a biocide for the production of filtering nonwovens, *Patent PL 211878 B1*, 2012.
4. EN 13274-7:2008 Respiratory protective devices. Methods of test. Determination of particle filter penetration.
5. Majchrzycka, K.; Okrasa, M.; Szulc, J.; Jachowicz, A.; Gutarowska, B. Survival of Microorganisms on Nonwovens Used for the Construction of Filtering Facepiece Respirators. *Int. J. Environ. Res. Public Health*, 2019, Vol. 16, 1154.
6. AATCC Test Method 100-2004 Antibacterial Finishes on Textile Materials: Assessment of Antibacterial Finishes on Textile Materials, *Technical Manual/2010*, 2004.

The paper is based on the results TechKom project: 'Technology for the production of multifunctional composites for human protection in heavy working conditions' funded in the years 2015-2018 by National Centre for Research and Development (project consortium: CIOP-PIB, PŁ, MASKPOL).