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New Filtering Antimicrobial Nonwovens With Various Carriers for Biocides as Respiratory Protective Materials Against Bioaerosol

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This study evaluated the bioactivity of polypropylene melt-blown filtering nonwovens used in respiratory protective devices (RPD) with a biocidal agent (alkylammonium microbiocides) on 2 mineral carriers. Two types of carriers were tested: a bentonite, with an aluminosilicate base, and a perlite, volcanic glass. High biostatic and biocidal effects of modified nonwovens with biocides were tested against Escherichia coli *(*E. coli*) and* Staphylococcus aureus *(*S. aureus*) bacteria. Nonwovens modified with a biocide on a bentonite carrier showed an opposite reaction to a biocide on a perlite. The research also showed that 10% concentration of a biocidal agent on a perlite carrier was sufficient to inhibit the growth of bacteria (100% reduction) placed in the structure of a filtering material during normal use of RPD. A comparison of the biological activity of 2 filtering materials, each containing 10% of a perlite and produced in a laboratory and industrial conditions, showed no statistically significant differences.*

melt-blown filtering material bioactive fibres alkylammonium microbiocide
perlite bentonite

1. INTRODUCTION

Bioactive fibres are necessary in filters and half-masks protecting workers against risks caused by pathogenic bioaerosols. Antimicrobial properties of such fibres could reduce or eliminate epidemic diseases and infections. The outbreak of severe acute respiratory syndrome (SARS), the continuing threat of avian flu and the recent outbreak of the H1N1 (influenza A) virus have also raised public awareness of the need to protect workers against natural bioaerosols [1, 2]. High efficiency of physical capture of bioarosols particles and the ability to inhibit the growth of micro-organisms

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already placed in the structure of a filtering material should ensure high performance of respiratory protecting devices (RPD).

Nowadays, fibre production technologies are dynamically developing, especially in the field of biotextiles. The term *biotextiles* in this case means biologically active textile materials, usually of a complex structure, with a biologically active agent (biocide) introduced and bonded to a material, either chemically or physically. There are recent studies on using bioactive textiles in medicine for wound dressings, in bed linen and in protective clothing [3, 4, 5, 6, 7, 8]. Except for this research, there are no studies describing applications of bioactive filters in personal protective equipment protecting against harmful bioaerosols.

The specificity of bioactive textiles requires appropriate proportions between the effectiveness in blocking bioaerosol particles (at a minimum level of 98%) and air flow resistance (at a minimum level of 200 Pa). A potential user can reject the material because of too high breathing resistance. Therefore, a biocidal agent should be implemented permanently into the structure of polymer fibres with a diameter under 1.5 μm. The melt-blown technology with its technical possibilities can help to achieve this requirement. Polypropylene is used in this technology because of its good thermoplastic and recycling properties. Bioactive polypropylene fibres are modified with antibiotics (e.g., tetracycline hydrochloride), glycidyl methacrylate, cyclodextrin, quaternary ammonium salts and others substances with biocides [9, 10, 11, 12, 13, 14]. The results of tests for half-masks with bioactive fibres indicated that the final material obtained with the melt-blown technology had an acceptable filtering effect of over 97% [15].

However, while applying the melt-blown technology, it is necessary to ensure that the biocidal agent is durable, resistant to humidity and temperature, and nontoxic for the user. In this study, chemical substances like dialkylodimethylamine chloride, alkylodimethylbenzoylamine chloride, alkylotriamine and phosphonianes were used according to Directive 2012/16/EU [16], and Poland's acts on biocidal products [17] and on categories and groups of biocidal products [18]. Quaternary ammonium microbiocides, according to their properties, are recommended as agents inhibiting the growth of micro-organisms in textile materials [19].

The first study on bioactive filtering nonwovens with quaternary ammonium microbiocides designed for constructing RPD revealed bacteriostatic and fungistatic effects for numerous microorganisms [20]. A bioperlite, a mineral carrier for a biocidal compound, was used in this research. Thus, the polymer material changed its properties from hydrophobic to hydrophilic gaining high antimicrobial activity. Akin-Öktem, Tanrisinibilir and Tincer [21] and Akin-Öktem and Tincer [22] discussed changes in the physical properties of a polymer after adding a perlite. They stated that adding a perlite increased durability and flexibility of polymers and enabled polymers to bond with various chemical agents.

The present study evaluated biostatic and biocidal effectiveness of filtering nonwovens, obtained with the melt-blown technology with a biocidal agent alkylammonium microbiocide, on two nonorganic carriers, a perlite and a bentonite (in concentrations of 10, 15 and 20%). Moreover, experiments were carried out to compare antimicrobial properties of melt-blown filtering materials with a biocide precipitated on a perlite carrier (10%) produced in a laboratory and industrial conditions. The filtration efficiency of the manufactured bioactive material was checked in the presence of bacteria and standard nonbiological aerosols (sodium chloride aerosol and paraffin oil mist) used for estimating the penetration protection level of RPD according to European standards [23, 24].

2. EXPERIMENTAL

2.1. Biocides on Carriers

Bioperlite, an alkylammonium microbiocide on a perlite carrier, was prepared by precise spraying a perlite ($Ø_{max} < 30$ μm) with an isopropanol solution of biocides, humectants and sequestering agents. The product was dried under vacuum (6.5×10^2 Pa, 293 K, 48 h) and analysed with Fourier transform infrared spectroscopy (FTIR), two-phase titration and elemental analysis. Infrared

spectra were recorded in KBr pellets with an FTIR Bruker IFS 113v spectrometer (Bruker Optik, Germany), which were evacuated to avoid water absorption. Elemental analyses were done with a Vario EL III instrument (Elementar Analysensysteme, Germany). In the final product, the total percentage of active substances; i.e., N,N-didecyl-N,N-dimethylammonium chloride (Aldrich, Germany), N-benzyl-N-dodecyl-N,N-dimethylammonium chloride (Aldrich, Germany), N,N-bis(3-aminopropyl)-N-dodecyloamine (Lonza, Switzerland), 1,2,3-trihydroxypropane (Aldrich, Germany) and the sodium salt of 2-phosphonobutane-1,2,4-tricarboxylic acid (Lakeland, UK); was 5.0%. Quaternary alkylammonium salts and alkyltriamine constituted 92.7% of all active substances.

Biobentonite, alkylammonium microbiocides on a bentonite carrier, was obtained in the same way as a bioperlite.

2.2. Tested Bioactive Nonwoven

A bioactive nonwoven was obtained by introducing a bioperlite and a biobentonite in the form of powder into the mass of developed polypropylene fibres (type Moplen HP 540 J, Basell Orlen Polyolefins, Poland). A device constructed at the Central Institute for Labour Protection – National Research Institute (CIOP-PIB), Poland, was used to produce a bioactive filtering nonwoven with the melt-blown technology [25]. The fibre-forming head enabled introducing a biocidal agent into the polymer stream and ensured its even placing in the structure of the nonwoven. Brochocka and Majchrzycka described the newly developed fibre-forming head structure [25]. A biocidal agent (bioperlite or biobentonite) is dosed to the head in a controlled way and then centrally and symmetrically transferred to the fibre forming zone. Feeding the agent in this way enables proper mixing of fibres with the biocidal agent, which is sucked into the stream of fibres, produced and deposited on the formed fleece surface, resulting in a smaller loss of the biocidal agent. The scanning electron micrograph (SEM) technology confirmed this fact (Figure 1). The method of modifying a melt-blown nonwoven was based on the fact that there was only one carrier connected to the surface of polypropylene fibres, whereas active substances on the carrier

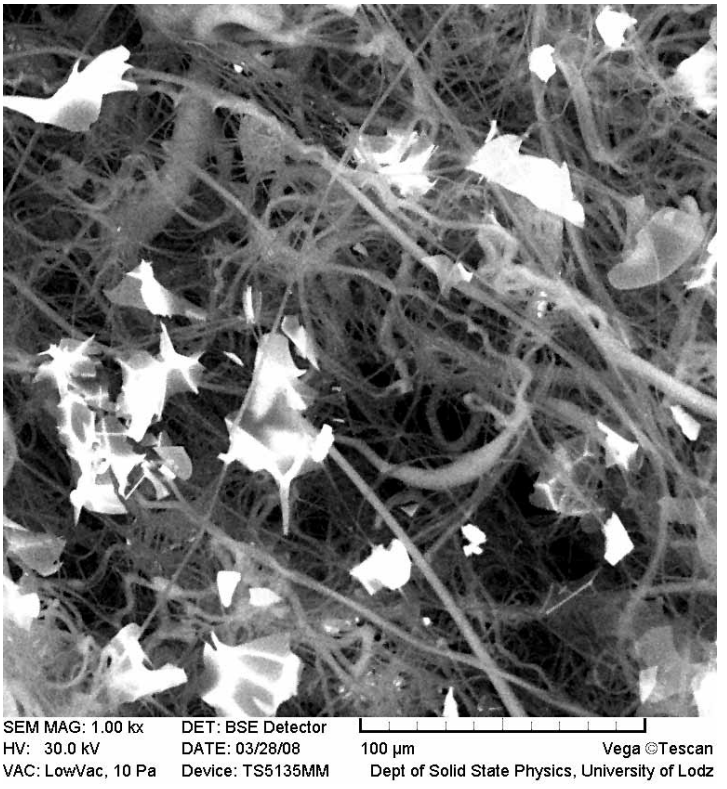

Figure 1. Nonwoven fabric with 10% concentration of bioperlite (scanning electron micrograph).

remained "free" and capable of microbial activities. The active substance carrier was connected to the surface as a result of a physical interaction. The size of selected powder particles (bioperlite or biobentonite) allowed only their partial immersion in the polypropylene fibre material [26]. Active substances, alkylammonium salts (charged positively) and polyamines, reacted electrostatically with a perlite (aluminosilicates are charged negatively on the surface), thus creating a solid system.

The nonwovens had a 10, 15 and 20% concentration of a bioperlite and a biobentonite, with a respective 0.46, 0.69 and 0.93% concentration of the biocide. A sample without a bioperlite was used as the control nonwoven. Furthermore, control tests were carried out on the nonwoven with a perlite but without biologically active compounds. At the same time, a similar filtrating material containing 10% bioperlite (0.46% of the active substance) was produced under industrial conditions (Filter Service, Poland).

The amount of microbiocides adsorbed on the surface, which can undergo desorption, was determined with ultraviolet (UV) spectrophotometry. The sample (20 g) of melt-blown nonwovens with a biocidal agent was weighed (with precision of 0.0001 g) and extracted in 750 cm^3 of demineralized water with the conductivity under 10 μS at 35 ± 20 °C for 24 h. The extract solution was transferred into a measuring flask and filled with water up to 1000 cm^3. The absorbance with methyl orange was measured in UV light and, based on the established analytical curve, the concentration of microbiocides in the extract was described. In the performed extraction, 46% of the microbiocides present in the polypropylene nonwoven with a biocidal agent (bioperlite) underwent desorption. On the basis of this analysis, it can be stated that 54% of microbiocides were permanently bound to fibres, whereas the rest of them were desorpted.

The formed bioactive melt-blown nonwovens were activated with a positive electric charge of 25 kV. The basic filtration parameters were

- penetration with paraffin oil mist: 2.13% [23];
- air flow resistance: 106.90 Pa;
- surface mass: 90 g/m^2;
- average fibre diameter: 2.43 μm (minimum value: 0.30 μm; maximum value: 10.00 μm);
- filter thickness: 1.66 mm;
- pore size: 1.60 μm.

2.3. Micro-Organisms and Microbiological Media

Micro-organisms *Escherichia coli (E. coli*, ATCC 8739) and *Staphylococcus aureus* (*S. aureus*, ATCC 6538) were used in this study. They were activated on 150 ml of TSB (tryptic soy bullion) medium in 250-ml Erlenmayer flasks at 37 °C for 48 h. After incubation, the inoculum suspension of micro-organisms was prepared. Bacteria cells were separated from the liquid medium with centrifugation (at g = 910 for 10 min) followed by suspension in a saline solution (0.85% sodium chloride, volume 150 ml). Cell density in the inoculum suspensions was determined with a microscope (Thom chamber) and breeding by seeding on TSA (tryptic soy agar) medium. The density of bacterial suspensions was in the 10^8–10^9 colony forming units per ml (CFU/ml) range.

Two culture media were used: TSB to activate bacteria prior to preparing the inoculum suspension and TSA to culture bacteria in Petri dishes after their contact with fabrics.

3. TEST METHODS

3.1. Evaluation of Antimicrobial Activity of Nonwovens

Bioactive filtering materials were inoculated with 0.1 ml of a suspension of micro-organisms and incubated at 37 °C in a sterile Petri dish. The samples were taken at 0 and after 6 h from material inoculation. The samples of materials were subsequently transferred into 100 ml of a saline solution to wash out the micro-organisms from the fabric. Later, they were shaken for 15 min in a water bath. The samples were diluted in a sterile saline solution and seeded in a sterile Petri dish. Subsequently, they were poured over with a half-liquid TSA medium, mixed and left to cool. Next, the samples were incubated at 37 °C for 48 h. After that time, all grown colonies were counted.

On the basis of the results, a mean value for each micro-organism was calculated for each filtering material (the tests were repeated three times).

3.2. Filtration Efficiency

The developed variants of nonwovens were evaluated, including penetrating stable sodium chloride and liquid paraffin oil mist aerosols, according to the methodology in Standard No. EN 143:2000/A1:2006 [24]. The average diameter of sodium chloride aerosol particles was 0.6 μm, measured and recorded with a Grimm (Germany) optical particle counter and Moores (Germany) recorder, respectively. The concentration of paraffin oil mist aerosol was measured with a laser photometer (Lorenz, Germany). The number of aerosol particles that passed through a filtering material, in relation to the total number of particles, was expressed as percentage penetration. The efficiency of filtration was calculated as

$$E = 100\% - P, \tag{1}$$

where E—filtration efficiency (%), P—penetration (%).

Bioaerosol filtration efficiency was evaluated with a device constructed at CIOP-PIB (Figure 2) [27, 28]. Tests were based on creating a bacterial aerosol (*E. coli*, *S. aureus*) suspended in 0.85% sodium chloride solution with an atomizer, mix-

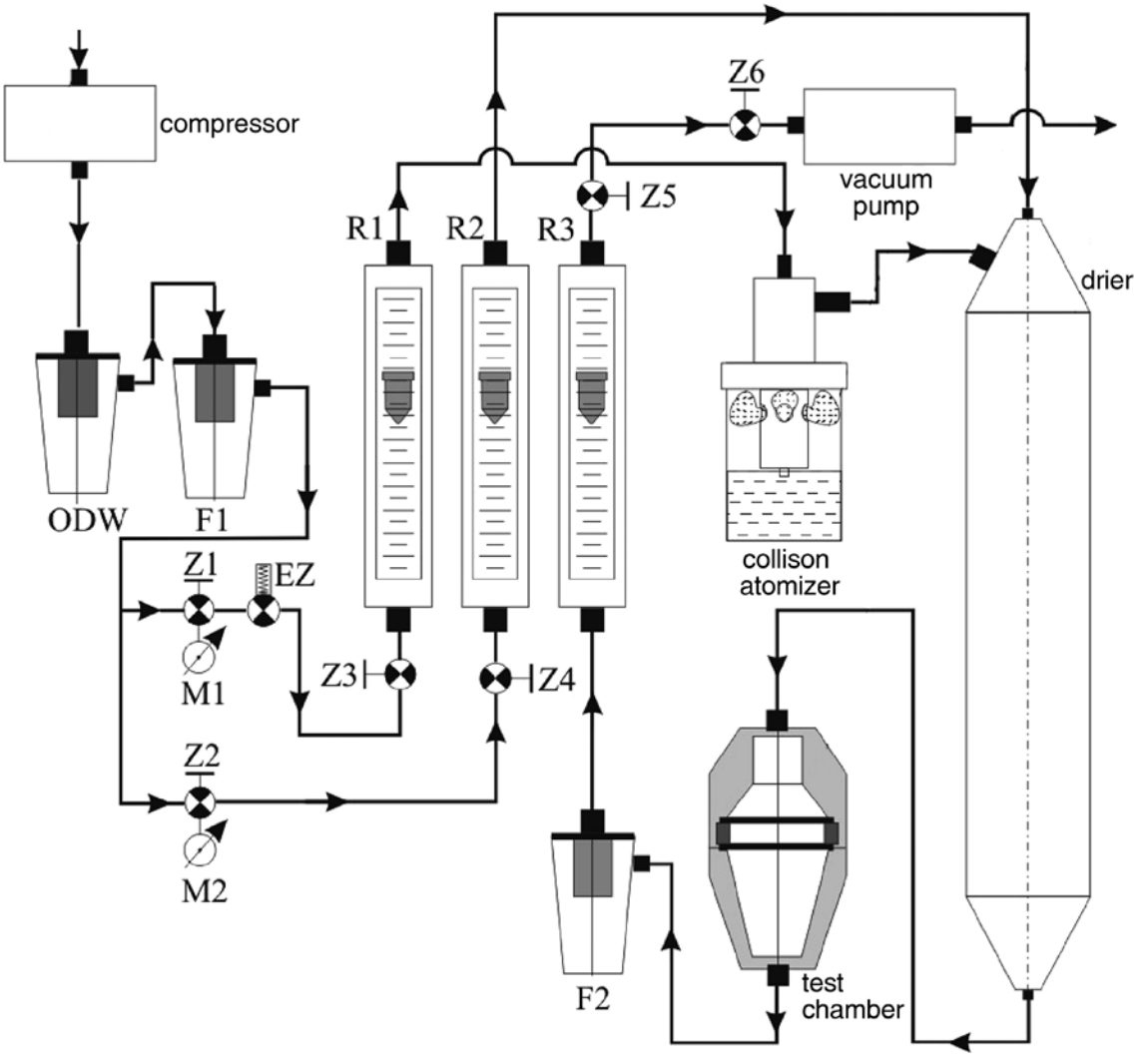

Figure 2. An assembly for determining the efficiency of filtration in conditions ensuring an uninterrupted flow of a bioaerosol through the test filter. *Notes.* ODW—cyclone separator; F1—air filter type AHF 04/0.01 μm; Z1, Z2—pressure reduction valves; M1, M2—manometers; EZ—electrovalve; R1, R2, R3—rotameters; Z3, Z4—airflow fine adjustment valves; Z5—air suction fine adjustment valve; Z6—air suction preliminary adjustment valve; F2—output filter ACF 04/0.003 ppm.

ing it with dry air and directing the bioaerosol into the measuring chamber. The flow rate of the mixture was maintained at 30 L/min to achieve a face velocity at the filter media of 0.5 m/s. The pump used for generating the aerosol and diluting the air maintained the experimental rig under positive pressure to prevent micro-organisms from entering the system. Two filters were installed for each test in the measuring chamber: a filter made of tested bioactive filter materials and a microbiological filter (e.g., a gelatin filter with 0.3-μm pores; Sartorius, Germany). The bioaerosol was sprayed on nonwoven samples for 20 min (600 L of the bioaerosol were plotted on the sample). Later, each sample was placed on TSA medium incubated at 37 °C for 24 h. The number of bacteria was measured with the colony counting method.

Filtration efficiency (%) was calculated by comparing the number of bacteria stopped on the microbiological filter (in front of which the nonwoven was placed) and the total number of micro-organisms (stopped on the microbiological filter without the nonwoven):

$$E = (N_t - N_f)/N_t \times 100\%, \quad (2)$$

where E—filtration efficiency (%), N_t—total number of micro-organisms on the microbiological filter without the nonwoven, N_f—number of micro-organisms on the microbiological filter after passing through the nonwoven.

4. METHODS OF CALCULATIONS

4.1. Biostatic and Biocidal Activity

Antimicrobial activity was calculated from the results presented as the number of colony-forming units per test (CFU/test) for a given duration of exposure. Two parameters described the antimicrobial activity: (a) the biostatic effect, i.e., the inhibition of microorganism growth and (b) the biocidal effect. Standards No. EN 1276:2009 [29] and EN 1650:2008 [30] provided criteria for the activity of the nonwovens in this study. In short, activity under 0.5 was regarded as low and meant a threefold decrease in the number of micro-organisms; whereas the activity of 3 or more for fungi and bacteria was regarded as high and meant a thousandfold decrease in the number of micro-organisms. Biostatic (inhibiting) activity was calculated with Equation 3:

$$\textit{biostatic activity} = \log A/B, \quad (3)$$

where A—number of micro-organisms per test after exposure time t with the control nonwoven, B—number of micro-organisms per test after exposure time t with the bioactive nonwoven.

Biocidal activity was calculated with Equation 4:

$$\textit{biocidal activity} = \log C/B, \quad \text{b} \quad (4)$$

where C—number of micro-organisms per test after time $t = 0$ with the control nonwoven, B—number of micro-organisms per test after exposure time t with the bioactive nonwoven.

4.2. Micro-Organisms Survival Index

Because the textile materials were not analysed at the same time and because the micro-organisms themselves have their specific growth physiology, to compare the obtained data, the survival index N_t for micro-organisms was calculated with Equation 5:

$$N_t = \frac{N}{N_0}, \quad (5)$$

where N_0—number of micro-organisms on the sample of the textile material for time $t = 0$, N—number of micro-organisms on the sample of the textile material for time t_n.

4.3. Statistical Methods

Statistical calculations were done with arithmetic mean (M), standard deviation (SD) and t test. They showed significant differences between the analysed groups of data (two groups of nonwovens with the addition of an active substance and one sample without a biocide were compared). Statistica 6.0 (Poland) was used.

5. RESULTS

Tables 1 presents the results of survival indexes N_t for *E. coli* and *S. aureus* during their exposure on filtering nonwovens.

Statistical analyses showed significant differences in survivability of both kinds of bacteria on the nonwovens with 10 and 20% concentration of a bioperlite. However, there were no differences in survivability of tested bacteria for the control nonwovens with a biobentonite. There was no clear activity of this carrier. A comparative statistical analysis (*t* test) of survivability of bacteria on the nonwovens with 10, 15 and 20% of a bioperlite did not show any significant differences between the nonwovens with 15 and 20% and between sets of the nonwovens with 10 and 15% or 10 and 20%. This proved that survivability of bacteria on the nonwovens with over 15% did not change after 6 h of incubation. Therefore, 10% concentration of a bioperlite is sufficient to obtain bacterial growth inhibition, and 15% concentration is biocidal, thus reducing tested bacteria entirely. The results of the biostatic and biocidal activity against *E. coli* and *S. aureus* confirmed data (Table 2).

The study revealed that the bacteriostatic activity of the nonwovens with a biocidal agent on a bentonite carrier, both towards *E. coli* and *S. aureus*, was very low. The growth of bacteria was observed after 6 h of incubation, which proved no activity on this nonwoven. The nonwoven with a biobentonite did not inhibit the growth of tested micro-organisms. High biostatic and biocidal influences on the micro-organisms were observed on the nonwovens with a biocidal agent on a perlite carrier. The biological activity of the nonwovens increased, when the concentration of a bioperlite with the active substance increased after 6 h of incubation. High activity of the nonwovens and 10% concentration of a bioperlite produced the biological effect.

The highest bacteriostatic and bacteriocidal effects of the nonwovens with 15 and 20% of a bioperlite were maximal for *S. aureus* (100% reduction in micro-organisms) after 6 h of incubation. It was found for *S. aureus* (like for *E. coli*)

TABLE 1. Survival Indexes N_t for *E. coli* and *S. aureus* on Bioactive Nonwovens With Bioperlite and Biobentonite After 0 and 6 h of Incubation

	N_t for *E. coli*				N_t for *S. aureus*			
	0 h		6 h		0 h		6 h	
Nonwoven	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Perlite without a biocide (control)	1.000	0.579	0.026	0.025	1.000	1.475	0.338	0.547
Bioperlite (10%)[1]	1.000	1.566	0.000	0.000	1.000	0.866	0.000	0.000
Bioperlite (15%)	1.000	1.214	0.000	0.000	1.000	1.700	0.000	0.000
Bioperlite (20%)	1.000	0.000	0.000	0.000	1.000	1.466	0.000	0.000
Bentonite without a biocide (control)	1.000	0.407	0.134	0.066	1.000	0.201	0.217	0.171
Biobentonite (10%)	1.000	1.555	0.886	0.020	1.000	0.477	0.809	0.257
Biobentonite (15%)	1.000	0.113	0.711	0.102	1.000	0.347	0.345	0.207
Biobentonite (20%)	1.000	0.382	0.922	0.171	1.000	0.263	0.591	0.348

Notes. 1—in parentheses, concentration of bioactive carriers.

TABLE 2. Biostatic and Biocidal Activity of Filter Nonwovens Against *E. coli* and *S. aureus* Bacteria During 6 h of Exposure

	Bacteriostatic Activity		Biocidal Activity	
Nonwoven	***E. coli***	***S . aureus***	***E. coli***	***S. aureus***
Bioperlite (10%)[1]	2.960	1.807	3.832	2.470
Bioperlite (15%)	3.273	7.828	4.145	8.491
Bioperlite (20%)	3.641	7.828	4.513	8.491
Biobentonite (10%)	–0.948	–0.562	–0.075	0.101
Biobentonite (15%)	–0.832	–0.200	0.041	0.463
Biobentonite (20%)	–0.884	–0.536	–0.012	0.127

Notes. 1—in parentheses, concentration of bioactive carriers; ■—high activity, □—low activity.

that the presence of a bioperlite in the nonwoven with a 10% concentration gave satisfactory results for the biological activity of the material.

Survivability of bacteria on the melt-blown nonwovens with 10% concentration of a bioperlite produced in a laboratory and industrial conditions was also compared. The main difference consisted in the method of inserting a biocide agent during the production of the melt-blown nonwovens [25]. Table 3 presents survival indexes N_t for *E. coli* and *S. aureus* on laboratory and industrial bioactive nonwovens with a 10% bioperlite after 0 and 6 h of incubation, and the differences between laboratory and industrial nonwovens.

There were no significant differences between antimicrobial interactions of the nonwovens containing 10% concentration of bioperlite produced in a laboratory and industrial conditions.

Table 4 presents filtration efficiency of nonwovens with a bioperlite and a biobentonite in the presence of solid particles (sodium chloride), liquid aerosols (oil mist) and micro-organisms (*E. coli* and *S. aureus*).

The aim of this study was to examine whether filtering nonwovens with a bioperlite and a biobentonite could be used in RPD. Such equipment was evaluated according to Standard No. EN 143:2000 [23] and Standard No. EN 143:2000/A1:2006 [24]. It was revealed that using a biocidal agent during forming melt-blown nonwovens did not decrease the filtering efficiency for nonbiological solid (sodium chloride) and liquid (paraffin oil mist) aerosols. Filtration efficiency was, on average, 97.5–97.7% in the presence of paraffin oil mist (average particle size 0.3 μm) and 98.7–99.7% in the presence of sodium chloride particles (average particle diameter 0.6 μm).

Additional efficiency tests, which are not obligatory according to EU standards, of filtering materials designed for constructing RPD were carried out for the nonwovens with a perlite, because nonwovens with a bentonite have no antimicrobial activity. Filtration efficiency of the nonwovens with a perlite for *E. coli* was 95–96.8% and was higher than for *S. aureus* (65.5–74.1%; the aerodynamic diameters were 0.87 μm for *E. coli* and 0.93 μm for *S. aureus*) [31]. Because biological and nonbiological aerosol particles that penetrate through a filtering material are detected in a different way, these val-

TABLE 3. Survival Indexes N_t for *E. coli* and *S. aureus* on Laboratory and Industrial Bioactive Nonwovens With 10% Concentration of Bioperlite After 0 and 6 h of Incubation

	N_t for *E. coli*				N_t for *S. aureus*			
	0 h		6 h		0 h		6 h	
Nonwoven	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Laboratory (with 10% bioperlite)	1.000	1.566	1.38E-6	0.000	1.000	0.866	1.89E-7	0.000
Industrial[1] (with 10% bioperlite)	1.000	1.656	8.05E-8	0.000	1.000	1.525	2.07E-7	0.000

Notes. 1—industrial nonwoven produced by Filter Service, Poland.

TABLE 4. Filtration Efficiency of Melt-Blown Nonwovens With Bioperlite and Biobentonite

	Filtration Efficiency[1]					
	Bioperlite[2]			Biobentonite[3]		
Aerosol	**10 (0.46)**	**15 (0.69)**	**20 (0.93)**	**10 (0.46)**	**15 (0.69)**	**20 (0.93)**
Paraffin oil mist	97.5	97.6	97.6	97.5	97.6	97.7
Sodium chloride	98.9	98.7	98.8	98.8	98.8	99.7
E. coli	95.0	96.8	96.4	nt	nt	nt
S. aureus	65.5	74.1	73.2	nt	nt	nt

Notes. 1—percentage of stopped particles; 2—concentration of bioperlite, concentration of a biocide in nonwoven in parentheses (%); 3—concentration of biobentonite, concentration of a biocide in nonwoven in parentheses (%); nonvowens with nominal surface mass of 90 g/m^2; nt—not tested (nonwovens without microbial activity).

ues cannot be compared with standard methods with nonbiological aerosols. The results of these tests can be used in selecting a recommended efficiency of RPD as opposed to measuring actual exposure to harmful bioaerosols at a specific workstation.

To confirm permanent deposition of a biocidal agent (bioperlite) in the structure of a melt-blown nonwoven, several tests were carried out to check the content of microbiocides in the material and the durability of its bond. Microbiocide content in polypropylene fibres modified with 10% concentration of a bioperlite was analysed with the elemental analysis and the spectrophotometric analysis in UV. Microbiocides deposited on a bioperlite, after introduction into polypropylene fibres, could be bound permanently into the fibre or they could be absorbed on the surface (Figure 1). A biocidal substance absorbed on the surface showed higher activity than the substance bounded to the fibre (e.g., partially immersed); even though it could undergo desorption under the influence of physical and chemical factors.

The elemental analysis described the total number of microbiocides introduced into polypropylene fibres through a bioactive perlite. Four samples of bioactive melt-blown nonwovens with 10% concentration of a bioperlite were analysed. It was found that the average content of microbiocides in the samples reached 0.86 wt% as calculated for active substances. This value was the total number of microbiocides permanently bound to fibres and adsorbed on the surface. The test was based on the amount of a nitrogen present in polypropylene fibres with and without a biocidal agent.

5.1. Conclusion

The study on the biocidal activity showed that a polypropylene modified with a biocidal agent deposited on a perlite is bioactive. Its bioactivity and biocidal efficiency stays at a level which guarantees safety of RPD used for an extended time in the presence of a bioaerosol.

The results obtained for a polypropylene modified with a biocidal agent deposited on a bentonite were not satisfactory (aluminosilicate material). Higher bulk density, in comparison with a perlite, may be the cause of a worse distribution of a bentonite on a polypropylene. Moreover, in biobentonite modifier, sodium cations in a bentonite change into cations of quarternary alkylammonium salts. This means that in addition to some typical features of a carrier, a bentonite is also a material that can undergo ion exchange. This is the result of a significant decrease in the amount of active substances acting as biocides, whereas a perlite is only a carrier of active substances. Microbiocides of an active substance are tied to the surface of a carrier only with electrostatic forces and this allows the modifier to retain all its biocidal activity. Introducing a bioactive modifier structure into the technology of filtering nonwovens based on thermoplastic polymers can be recommended. Better biocidal properties may be obtained in a bioactive substance-carrier structure when electrostatic affinity forces dominate without any chemical bonds.

The use of melt-blown nonwovens modified with a biocidal agent plotted on a fine-grained carrier, perlit, is recommended for constructing bioprotection of a respiratory system.

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