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Biofunctionalization of Textile Materials.1. Biofunctionalization of Poly(Propylene) (PP) Nonwovens Fabrics by Alafosfalin

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Abstract: This paper presents the method of obtaining poly(propylene) (PP) nonwoven fabrics with antimicrobial properties, using Alafosfalin as the nonwoven modifying agent. Alafosfalin, namely L-alanyl-L-1-aminoethylphosphonic acid, presents representative P-terminal phosphonodipeptide, which possesses a strong, broad spectrum of antimicrobial properties. The analysis of these biofunctionalized nonwoven fabrics processed by the melt-blown technique, included: scanning electron microscopy (SEM), UV/Vis transmittance, FTIR spectrometry, and air permeability. The nonwovens were subjected to microbial activity tests against colonies of Gram-positive (*Staphylococcus aureus*) and Gram-negative (*Escherichia coli*) bacteria. Results indicate that the described nonwovens can be successfully used as an antibacterial material.

Keywords: poly(propylene); nonwoven fabric; Alafosfalin; antibacterial activity; polymer functionalization; polyolefins

1. Introduction

Poly(propylene) nonwoven (PP nonwoven) fabric is a thermoplastic, small density material with excellent comprehensive performance, mildew resistant, with a great development potential as medical materials [1]. Thus, PP nonwoven fabrics are applied as containers, suture material and surgical meshes, oxygenator membranes [2], or wound dressings [3,4]. In order to expand the functions of PP nonwoven fabrics to medical requirements, it is necessary to modify and process it. In this regard, biocompatible hybrids carrying and releasing bioactive drugs in a controlled and sustained manner may significantly improve the efficacy of wound therapies compared with current treatments. Antibacterial polypropylene nonwoven is often used as a hybrid material combining the PP nonwoven with other antibacterial components.

The recent, more representative examples of antibacterial PP nonwoven are listed in Table 1.

Table 1. Antibacterial polypropylene nonwoven.

Abbrev.	Action/Application	Tested Bacteria	Ref.
PP-NIPAAm-Cg-Cs PP-g-AA-Cg-Cs	Membrane-wound healing enhancement	<i>S. aureus</i>	[5]
PP-g-AA-Cs-Cg PP-g-AA-Cs-Cg-Hi	Various concentrations of heparin	<i>S. aureus</i>	[6]
PP-AAg-Cg-Cs PP-g-AA-PG-Cs	Anti-bacterial property and the effect on accelerating wound healing strong	<i>S. aureus</i>	[7,8]

Table 1. Cont.

Abbrev.	Action/Application	Tested Bacteria	Ref.
PP-g-PGMA PP-g-PHMG PP-g-PNVP-PGMA PP-g-PNVP-PHMG	Antimicrobial activity; platelet and red blood cell adhesion	<i>E. coli</i> ; <i>S. aureus</i>	[9]
PP-g-NIPAAm PP-g-NIPAAm-Cs	Wound dressing applications; good biocompatibility to fibroblast cells	<i>E. coli</i> ; <i>S. aureus</i>	[10]
(PP)-viscose-Cs-Gc(2%–2.5%)	Good biocompatibility; the correlation between efficiency in vitro and in vivo results, qualifies these antimicrobial biomaterials for clinical use	<i>E. coli</i> ; <i>S. aureus</i> ; <i>Klebsiella aeruginosa</i> ; <i>Candida albicans</i>	[11]
PP-g-AA-Cg PP-g-AA-Cg-PNIPAAm	Wound healing tests	Tests on rats	[12]
PP/PNIPAAm/Gelatin-hyaluronan-chondroitin-6-sulfate	Tri-layer membrane as the artificial skin for extensive burn injury	The wound dressing did not induce the tissue inflammatory or immune response.	[13]
PP-g-AA-NIPAAm PP-g-AA-NIPAAm-Cs	Potential wound dressing	<i>Pseudomonas aeruginosa</i> ; <i>S. aureus</i>	[14]
PP-g-AA-Cs	Potential wound dressing substitute for second-degree burns	Bioactivity assessments by aPTT; TT and fibrinogen concentration	[15]
PP-g-PLLA-Oct-HSA	Active dressings for the treatment of wounds	<i>E. coli</i> ; <i>S. aureus</i>	[16]
PP-g-PLLA-Oct	Medical dressings specific to infected wounds	<i>E. coli</i> ; <i>S. aureus</i>	[17]

AA—acrylic acid; Cg—collagen; Cs—chitosan; GMA—glycidyl methacrylate (GMA); HMG—Hexamethylenediamine guanidine hydrochloride; Gc—gentamycin chloride; g—grafted; H—heparin NIPAAm-*N*-isopropyl acrylamide; NVP—*N*-Vinyl-2-pyrrolidone; Oct—octenidine; PLLA—poly(L-lactide); PP—polypropylene nonwoven; aPTT—activated partial thromboplastin time.

Bioactivity assessments on the chitosan-immobilized surfaces were anticipated by activated partial thromboplastin time (aPTT), thrombin time (TT), and fibrinogen concentration.

Aminophosphonic acids—phosphonic analogs of naturally occurring amino acids (Figure 1) present a power biological activity, being inhibitors of native amino acid enzymes. The significance of aminophosphonates is illustrated by the multidirectionality of the studies conducted on them: methods of synthesis of aminophosphonic acids (AA^{PH}), aminophosphonic acids (AA^P) and phosphonopeptides (P-terminal (AA^C-AA^P) and N-terminal (AA^P-AA^C)), occurrence in living matter (e.g., β -Ala^P), biological, pharmacological, industrial and agrochemical properties/applications [18–27].

Figure 1. Structures of 1-amino carboxylic acids (AA), 1-aminophosphonic acids (AA^{PH}), 1-aminophosphonic acids (AA^P), phosphonopeptides: P-terminal (AA^C-AA^P) and N-terminal (AA^P-AA^C) (applied names are in accordance with the general rules elaborated by Kudzin et al. [27,28]).

Aminophosphonate compounds of special biological importance are presented in Table 2.

Table 2. Aminophosphonate compounds of special biological importance.

Abbrev. (Name)	Structure	Action/Application	Ref.
Gly ^P (phosphoglycine)		Primary degradation product of glyphosate, inhibitor of prostate cancer cell growth in vitro, phytotoxin	[18,29–33]

Table 2. Cont.

Abbrev. (Name)	Structure	Action/Application	Ref.
β -Ala ^P (β -phosphono-alanine, 2-AEP, ciliate)		The most widespread, first AA ^P isolated in natural sources	[18,34–36]
Glu ^{γP(Me)} (phosphinothricin, PPT)		A naturally occurring broad-spectrum systemic herbicide produced by several species of <i>Streptomyces</i> ; inhibiting glutamine synthetase	[18,37]
PMG (PhosphonoMethyl-Glycine; Glyphosate)		A broad spectrum, non-selective systemic herbicide, inhibiting the activity of 5-enolpyruvyl-shikimic acid-3-phosphate synthase	[18,38,39]
Ala-Ala ^P (alaphosphin; alafosfalin)		Ala-Ala ^P selectively inhibited peptidoglycan biosynthesis in both Gram-negative and Gram-positive bacteria. The mechanism of action of Ala-Ala ^P involve three stages: (i) active transport by peptide permeases; (ii) intracellular peptidase cleavage; and (iii) action of Ala-Ala ^P on alanine racemase (EC 5.1.1.1)	[18,40–49]

Applied names are in accordance with the general rules elaborated by Kudzin et al. [24,25].

Alafosfalin((S)-Alanyl-(R)-1-aminoethylphosphonic acid) the representative of phosphonopeptides, is a bioactive compound with high antibacterial properties [40–49]. Thus, presented for a wide spectrum of Gram-positive and Gram-negative bacteria. Thus minimum inhibitory concentrations (MIC) in vitro of Alafosfalin against representative bacteria, (*Enterobacter species* 1398; *Enterococcus faecalis* O-G FS 5; *E. coli* NCBI 33; *Haemophilus influenzae* NCTC 4560; *Klebsiella aerogenes* O-G KA1 *Serratia marcescens* ATCC 14756; and *Salmonella typhimurium*) were determined by Atherton et al. [42].

Alafosfalin was selected from a range of related peptides on the basis of its activity, low toxicity in mammals, pharmacokinetic properties and stability to peptidases [40,44–47]. Alaphosphin proved active against majority of *Serratiamarcescens* strains [48], and also in vitro potentiation of cephalosporins against urinary tract bacteria [49] possessing potential usefulness in human medicine for the treatment of urinary tract of bacterial infections.

Despite the large range of applications of aminophosphonate compounds, there is only a Blanchard and Graves paper on their usage as cellulose hybrids [50].

As a part of our research program directed on the synthesis of biologically active functionalized phosphonates [26,27,51–53] and their grafting on polymer matrix [54] we present the preparation and biological exploration of a polymer hybrid, based on polypropylene (PP) nonwoven fabric modified on surface by representative P-terminal phosphonopeptide–Alafosfalin (Alaphosphin).

2. Materials and Methods

2.1. Materials

2.1.1. Polymers

Polypropylene (PP) produced by Borealis (Vienna, Austria) type HL612 FB, MFR = 1200 g/10 min, in the form of granulates was used for fabrication of nonwoven samples.

2.1.2. Chemical Agents

Alafosfalin (L-Alanyl-L-1-aminoethylphosphonic acid), Synonym: (S)-Alanyl-(R)-1-aminoethylphosphonic acid; Alaphosphin; L-Ala-Ala^P, CAS Number: 60668-24-8, ≥98.0%) from Sigma-Aldrich (Saint Louis, MO, USA) was used for surface modification of polymer nonwovens.

2.1.3. Finishing Agents

Revacryl 247-styrene-acrylic ester copolymer dispersion of low viscosity (Synthomer, Essex, UK); Lutexal Thickener HC–polyacrylate, ammonia salt (BASF, Ludwigshafen, Germany) as thickening agent; Pluriol 600-poly(ethylene glycol) of molar mass 600 g/mol (BASF) as wetting agent.

2.1.4. Bacterial Strains

E. coli (ATCC 25922) and *S. aureus* (ATCC 6538) were purchased from Microbiologics (St. Cloud, MN, USA).

2.2. Methods

2.2.1. Nonwoven Fabrics

Nonwovens were fabricated by the melt-blown technique using a one-screw laboratory extruder (Axon, Nyvang, Sweden) with a head with 30 holes of 0.35 mm diameter each, compressed air heater and collecting drum. Processing parameters for fabrication of PP nonwoven are presented in Table 3.

Table 3. Processing parameters applied for preparation of poly(propylene) (PP) composite nonwovens by melt-blown technique.

Processing Parameters	
Temperature of the extruder in zone 1	240 °C
Temperature of the extruder in zone 2	285 °C
Temperature of the extruder in zone 3	290 °C
Head temperature	240 °C
Air heater temperature	270 °C
Air flow rate	7–8 m ³ /h
Polymer yields	4 g/min
Mass per unit area of nonwovens	80 g/m ²

2.2.2. Dip-Coating of Nonwoven Fabric and Modification of Phosphonodipeptide

The coating pastes of homogeneous dispersion and appropriate viscosity (about 60–70 dPas) were prepared based on styrene-acrylic resin, wetting agent as well as thickening agent and water.

Thickening agent ensures viscosity and appropriate grip of product, wetting agent prevents the formation of agglomerates in coating paste and uniformity in coating dispersion, and styrene-acrylic resin combines all ingredients of coating paste with nonwoven fabric. The applied ratio of component composition has main influence on the mechanical properties of the textile material.

Alafosfalin powder was added into the paste in 5 variants of concentrations: 0.005%, 0.01%, 0.05%, 0.1%, and 0.15% and then mixed for 10 min. The nonwoven samples were impregnated with the paste, squeezed and dried for 3 h at 50 °C (to constant weight). The increase of sample dry mass after modification was 5%. Component composition of used pastes is listed in Table 4.

Table 4. Component composition of used pastes (%).

Styrene-Acrylic Resin	Wetting Agent	Thickening Agent	Water
5 g	5 g	1 g	89 g
5%	5%	1%	89%

2.2.3. Scanning Electron Microscopy

The microscope analysis (SEM) was performed on a TESCAN VEGA 3 scanning electron microscope (Brno, Czech Republic). The SEM microscopic examination of the surface topography was carried out in a high vacuum using the energy of the probe beam 20 keV. The surface of each preparation was

sprayed with a conductive substance (gold), using a Quorum Technologies Ltd. (Lewes, UK) vacuum dust extractor. Magnification 5000× and 10,000×.

2.2.4. ATR-FTIR

Changes of the chemical structure of polypropylene surface products were assessed using ATR-FTIR spectroscopy. The study was performed in the range of 400–4000 cm^{-1} using a spectrometer Jasco 4200 series with ATR attachment (Pike Gladi ATR, Fitchburg, WI, USA).

2.2.5. UV-Vis Analysis

Changes of the physical properties as transmittance (%T) of nonwoven polypropylene fabric before and after phosphonodipeptide incorporation were assessed using a double beam Jasco V-550 UV/Vis spectrophotometer (Tokyo, Japan) with integrating sphere attachment in the range: 200–800 nm.

2.2.6. Filtration Parameters

Air permeability was determined for one layer of nonwoven sample and the test based on EN ISO 9237:1998 standard [55]. An FX 3300 TEXTTEST AG permeability tester (Schwerzenbach, Switzerland) was used. Air at a pressure of 100 and 200 Pa was passed through a fabric area of 20 cm^2 diameter for testing. An average of 10 values was taken to be the final value of the sample.

2.2.7. Tensile Testing

Tensile testing of nonwoven fabrics was carried out in accordance with the EN ISO 10319:2015-08 standard [56]. A Tinius Olsen H50KS tester (Horsham, PA, USA) was used. Stretching speed was 20 mm/min.

2.2.8. Antimicrobial Activity

The antibacterial activity of the resulting nonwoven fabrics was tested according to PN-EN ISO 20645:2006 [57] (textile fabrics—determination of antibacterial activity—agar diffusion plate test).

Gram-negative bacteria *E. coli* (ATCC 25922) and Gram-positive bacteria *S. aureus* (ATCC 6538) were used as model bacteria in this study.

Antibacterial activity of PP/Ala-AlaP hybrids was tested by the agar diffusion method using Muller Hinton medium agar. The test was initiated by pouring each agar onto sterilized Petri dishes and allowing it to solidify. The surface of the growth media was inoculated by overnight broth cultures of bacteria (0.4×10^8 CFU mL^{-1}). Samples of sterile PP discs (10 mm) were charged with coating pastes with various amounts of Ala-Ala^P (Table 5) and then discs with hybrids Ala-Ala^P/PP were placed onto the inoculated agar and incubated at 37 °C for 24 h. The diameter of the clear zone around the sample was measured as an indication of growth inhibition. All tests were carried out in duplicate. Simultaneously, the same tests were carried out as control samples with samples of unmodified polypropylene nonwoven.

3. Results and Discussion

The analysis of the biofunctionalized nonwoven fabrics covered: scanning electron microscopy (SEM), UV/Vis transmittance, ATR-FTIR spectrometry, and also technical parameters, including filtration parameters and tensile properties (durability for stretching and relative elongation). For samples with the highest charge with Ala-Ala^P, an antimicrobial activity against representative Gram-positive and Gram-negative bacteria was determined.

3.1. Scanning Electron Microscopy

Scanning electron microscopy SEM spectra of polypropylene nonwoven (PP) and polypropylene nonwoven charged with phosphonodipeptide modifier (alafosfalin paste concentrations 0.15%) are

presented in Figure 2. SEM spectra of polypropylene nonwoven present smooth surface of unmodified polymer fibers. The modification of PP by a surface deposition of Ala-Ala^P lead to a rough surface of the textile, covered with dots/smudges of the modifier on PP fibers, accompanied by formation of more loose texture of the modified nonwoven.

Figure 2. SEM spectra of polypropylene nonwoven (PP) (a,b) and polypropylene nonwoven with phosphonodipeptide modifier (c,d), taken at magnifications 5.00 kx (5×10^4) (left) and 10.0 kx (10×10^4) (right), respectively.

3.2. ATR-FTIR Spectra

Comparison of ATR-FTIR spectra of Ala-Ala^P, polypropylene nonwoven (PP), and polypropylene nonwoven charged with Ala-Ala^P (Ala-Ala^P/PP) is presented on Figure 3.

Characteristic FTIR signals of Ala-Ala^P, polypropylene (PP) and Ala-Ala^P-polypropylene nonwoven hybrid (PP/Ala-Ala^P) are summarized in Table 5.

Thus, the IR spectrum of Ala-Ala^P/PP hybrid (Ala-Ala^P paste concentrations 0.15%) reveals the bands derived from representative bands of Ala-Ala^P, namely bands at 3273 cm^{-1} ($\nu(\text{N-H})$), 1664 cm^{-1} (characteristic for $\nu(\text{C=O})$, $\nu(\text{C-N})_{\text{Ala}}$, $\delta(\text{CC}_{\text{Ala}}(\text{=O}) \text{N}_{\text{Ala}})$), 1081 cm^{-1} ($\nu(\text{C-N})$, $\nu(\text{C-C})_{\text{Ala}}$, $\delta(\text{CCH}_3)_{\text{Ala}}$, $\rho_{\text{b}}(\text{C-N}^+\text{H}_3)$), 930 cm^{-1} ($\delta(\text{C-C})_{\text{Ala}}$, $\nu(\text{C-N}^+\text{H}_3)$); 700 cm^{-1} ($\nu(\text{C}_5\text{-P})$, $\nu(\text{C-C}_{\text{Ala}})$) and 558 cm^{-1} ($\delta(\text{N}_{\text{Ala}}\text{C}_5(\text{P})\text{C})$ $\delta(\text{N}_{\text{Ala}}\text{C}_5(\text{P})\text{C})$), respectively.

Figure 3. ATR-FTIR spectra of Ala-Ala^P, polypropylene nonwoven (PP), and nonwoven sample charged with Ala-Ala^P (0.15%) (PP/Ala-Ala^P).

Table 5. Characteristic FTIR bands determined for Ala-Ala^P, polypropylene (PP), and Ala-Ala^P-polypropylene nonwoven hybrid (PP/Ala-Ala^P).

Polypropylene-IR according to Urbaniak-Domagala, 2012 [58]

Vibrations									
Wave number (cm ⁻¹)	2916	2959	2881	2841	1460	1376	1357	1170, 1153	975, 899
Vibration type (group)	ν(CH ₂)	ν(CH ₃)	ν(CH ₃)	ν(CH ₂)	δ(CH ₃)	δ(CH ₃)	γ(CH ₂ -CH)	γ(CH ₃), δ(CH ₂), δ(CH)	γ(CH ₃), ν(CH ₂), ν(CH)
Ala-Ala ^P -IR according to Podstawka et al., 2008 [59]

Vibrations									
Wave number, (cm ⁻¹)	3273	3100	2982	2940, 2885	1664	1081	930	700	558
Vibration type (group)	ν(N-H)	ν(C-H)	ν(C-S-H)	ν(C-H)CH ₃	ν(C=O), ν(C-N) _{Ala} , Δ(CC _A (=O)N _A)	ν(C-N), ν(C-C) _{Ala} , δ(CCH ₃) _{Ala} , ρ _b (C-N ⁺ H ₃)	δ(C-C) _{Ala} , ν(C-N ⁺ H ₃)	ν(C-S-P), ν(C-C _A)	Δ(N _A C _S (P)C) δ(N _A C _S (P)C)
Ala-Ala ^P /PP									
Wave number, (cm ⁻¹)	3273	—	—	—	1664	1081	930	700	558
Vibration type (group)	ν(N-H)	—	—	—	ν(C=O), ν(C-N) _{Ala} , Δ(CC _A (=O)N _A)	ν(C-N), ν(C-C) _{Ala} , δ(CCH ₃), ρ _b (C-N ⁺ H ₃)	δ(C-C) _{Ala} , ν(C-N ⁺ H ₃)	ν(C-S-P), ν(C-C _A)	Δ(N _A C _S (P)C) δ(N _A C _S (P)C)

Legend: ν—stretching vibration, δ—deformation, ρ_b—bending deformation, γ—twisting vibrations, CA—the carbon atom of the amide bond, NA—the nitrogen atom of the amide bond, CS—the carbon atom of the spacer group between alanine and phosphonate group, CCH₃—the carbon atom of the methyl group, CCOOH—the carbon atom of the carboxyl group, Ala—part of N-terminal alanine, and S—shoulder.

3.3. UV/Vis Transmittance Spectra

Comparison of transmittance spectra (%T) in the range $\lambda = 200\text{--}800\text{ nm}$ of polypropylene nonwoven samples without (PP) and with L-Ala-Ala^P modifier (PP-MOD-Ala-Ala^P paste concentrations 0.15%) is given in Figure 4. Recorded UV/Vis transmittance spectra (%T) of samples after phosphonodipeptide modification revealed changes in macrostructure of nonwoven after modification expressed by the depress of transmittance ability in the range $\lambda = 200\text{--}800\text{ nm}$. All polypropylene modified nonwoven samples with different L-Ala-Ala^P contents had the similar spectral characteristics and transmittance.

Figure 4. Comparison of transmittance spectra (%T) in the range $\lambda = 200\text{--}800\text{ nm}$ of polypropylene nonwoven samples without (PP) and with L-Ala-Ala^P modifier (PP-MOD).

3.4. Technical Parameters

Filtration parameters expressed by the air permeability were detected for clean polypropylene nonwoven and nonwovens with addition of Alafosfalin. All these results indicated that phosphonodipeptide modification decreased filtration properties of nonwovens (Table 6). Modified nonwoven samples with different L-Ala-Ala^P contents had an approximately similar result of filtration properties. The content of coating pastes L-Ala-Ala^P applied on the polypropylene nonwoven samples does not affect filtration properties.

Table 6. The air flow resistance of polypropylene (PP) nonwovens without and with L-Ala-Ala^P modifier according to: PN-EN ISO 9237:1998 [55].

Parameter		PP	PP-Ala-Ala ^P (%Ala-Ala ^P Paste Concentrations)					
			0	0.5	1	5	10	15
Average air permeability	100 Pa	250	196	198	185	196	193	191
(mm/s), pressure decrease:	200 Pa	482	369	355	322	351	360	355

The results of tensile strength testing, including durability for stretching (kN/m) and relative elongation at maximum load (%) of PP nonwoven fabrics and PP/Ala-Ala^P hybrids are listed in Table 7.

Table 7. Results of tensile strength test.

Parameter	PP	PP-Ala-Ala ^P (%Ala-Ala ^P Paste Concentrations)					
		0	0.5	1	5	10	15
Tensile strength (kN/m)	0.32	0.40	0.41	0.39	0.38	0.37	0.37
Relative elongation at maximum load (%)	35.0	38.7	38.1	38.2	37.5	37.3	37.2

The results revealed an increase of these parameters for PP loaded with the paste in comparison with PP, namely distinct in tensile strength (0.32 to 0.40 (kN/m)) and slow in relative elongations (35.0% to 38.7%), respectively.

3.5. Antimicrobial Activity

The nonwovens prepared were subjected to antimicrobial activity tests against *E. coli* (ATCC 25922) and *S. aureus* (ATCC 6538) [60,61] (Table 8). Results of these studies gave new Ala-Ala^P biofunctionalized materials which provide antimicrobial protection against different bacterial microorganisms (Gram-negative and Gram-positive).

Table 8. Results of tests on the antibacterial activity of L-Ala-Ala^P modified nonwovens.

Sample No.	Ala-Ala ^P on Polypropylene Nonwovens [Ala-Ala ^P /PP]	Average Inhibition Zone (Zoi) of Bacterial Growth for Bacteria (mm)	
	Ala-Ala ^P Coating Pastes Concentrations (%)	<i>E. coli</i>	<i>S. aureus</i>
1	0	0	0
2	0.005	0	0
3	0.01	12	0
4	0.05	12	12
5	0.1	14	14
6	0.15	14	14

Surface of applied disks with 1 cm diameter equals 0.785 cm²
 Concentration of inoculum (bacterial suspension) amount of live bacteria CFU/mL = 0.4×10^8

Amounts of 0.01% Ala-Ala^P coating paste concentration supplied on polypropylene nonwovens provide antimicrobial properties for *E. coli* and no less than 0.05% phosphonodipeptide modification of PP nonwoven showed antibacterial activity against *S. aureus* (Table 8). At the same time, applied surface modification of the nonwovens with phosphonopeptide had no effect on mechanical properties of the modified textile.

4. Conclusions

The development of new products is closely related to progress in many areas of science, especially in chemistry and biochemistry. The interdisciplinary study focused on functionalization of textile polymers by an insertion (or coating) of bioactive compounds into/onto the surface of their fibers which can be an interesting direction of the textile product engineering development.

These new, described nonwovens can be successfully used as an antibacterial material. An important attribute of the presented solution is the simple process of implementation, low production costs and good efficiency of antimicrobial properties.

Apart from the antibacterial activity, such products also show acceptable air filtration ability and tensile strength, independently from the amounts of applied phosphonodipeptide surface concentrations.

The introduction of bioactive aminophosphonateclass (PCN compounds) into the structure of textiles is a novelty in the scientific literature, both in the modification of textiles and in the title compounds itself. Alafosfalin and other phosphonodipeptides compounds are characterized by uncomplicated synthesis and safety of use, for the above reasons there are large possibilities for wider use in the material and textile manufacturing industry.

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