Properties of textiles from PP fibres modified with multifunctional additives

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Goal of the research is preparation of multifunctional concentrates offering properties of: flammability reduction (FR), enhancement of UV resistance (UV) and antimicrobial finish (AMB). Basic characteristics of the prepared multifunctional concentrates used for treatment of polypropylene fibres are presented.and their effectiveness against flame, UV radiation and microbes were tested. Obtained results of change of selected performance characteristics of the textiles in relation to their construction and possibilities of practical application are compared in discussion. The achieved results revealed positive effect of the developed concentrate (28/1676 type) containing FR component on reduction of time of spontaneous flame burning of the knitted fabrics by 20 seconds in comparison with the standard. Besides, reduction of strength of the modified knitted fabric by the influence of UV radiation only by 5 % in comparison with 95 % after exposition on a standard knitted fabric was achieved. Tests for antibacterial activity confirmed high degree of bacterial reduction (> 90 %) on knitted fabrics from the modified PP fibre. This way high efficiency of the multifunctional concentrate (FR and UV and AMB) 28/1676 type was confirmed.
Key words: *multifunctional concentrates, multifunctional PP fibres, reduced flammability, UV resistance, antimicrobial finish.*

1. Introduction

At present development in manufacture of PP fibres is among other things oriented mainly to preparation of technical and special types with advanced functional and performance properties, whereby enlargement of the assortment for textile and technical applications is carried out mainly by the way of physical and chemical modification [1]. Modifications of PP fibres required mostly by textile industry include: reduced flammability, high UV stability, antimicrobility, antistatic properties and improved moisture management in relation to perspiration. The requirement for tex-

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tiles with multifunctional performance is increased nowadays. However, these materials are not available at today's world market in sufficient quantities. Combination of reduced flammability (FR), high UV stability (UV) and antimicrobial modification (AMB) in one product for the field of textiles designed for automobile and furniture industry is involved mostly. Another requirement for multifunctionality of the modified fibres and textiles is combination of modification for improvement of moisture management (MM) together with antimicrobial and antistatic (ANT) modification required mainly for sportswear and workwear. The most important world manufacturers of the modification concentrates have „monofunctional" concentrates on PP carrier in their offer only [2-4]. Schulman offers monoconcentrates for AMB modification (Polybatch Abact and Polybatch Amic), for UV modification (Polybatch FFP UVRI and Polybatch UV 381) and FR modification (Polyflam line) for PP sheets and tapes. Clariant offers monoconcentrates for AMB modification (CESA Antimikro, Mevopur and Sanitized) and FR modification (CESA Flam) for PP sheets, tapes and fibres. Ciba (BASF) offers monoconcentrates for AMB modification (Irgaguard), for UV modification (Irgastab) and ANT modification (Irgasurf and Irgastat) for PP sheets, tapes and fibres. Gabriel Chemie offers monoconcentrates for UV modification (HP 794160UV, HP 793680UV and HP 793680UVAO), FR modification (HP 72521FR, HP 791460UVFR) and ANT modification (PP 791310AS and PP 78680AS20) for PP sheets and tapes. However, none of the world manufacturers offers multifunctional concentrates of modification additives with PP polymer carrier.

It is problematic to prepare multifunctional fibres from the available monofunctional concentrates. Addition of several „monofunctional" additive concentrates into the polymer system of PP fibre increases proportion of polymer carriers and foreign non-polymer components in the fibre, changes rheology of the melt and therefore the polymer mixture becomes non-spinnable. Original detailed research focused on study of synergic effects of the used and available additives and knowledge of the particular patterns in the process of fibre preparation will enable to prepare PP fibre with required multifunctional properties. Worldwide originality of the above-mentioned research, in the part of preparation of multifunctional fibres, consists in detailed study of compatibility of the multicomponent concentrate with PP polymer system in the spinning process as well as study of influence on microfibre morphology and structure up to evaluation of the performance characteristics. At present no PP fibres showing more than two permanent modifications are available at the world market. Three-functional modification of polypropylene mass-dyed microfibre is an absolute world novelty and process of its preparation with application of one multifunctional concentrate of modification additives is highly innovative one.

Performance textiles are a new paradigma for textile industry and they represent a strong basic sector for the above-mentioned industrial branch. Performance textiles are textiles with higher added value which increases possibilities of their application both in the frame of clothing products (mainly for sport, leisure, increased comfort and wearing hygiene) and in the assortment of technical textiles (automobile industry, civil engineering, furniture industry, healthcare etc.). The present world trends are oriented to performance enhancement by means of:

– surface chemical treatments in textile finishing in the frame of which it is possible to ensure the „added value" by influencing one, maximally two functional properties;
– application of special, additived fibre types by means of which it is possible to increase the „added value" of the textiles by their multifunctionality i.e. by imparting synergic effect by means of influencing at least 2-3 performance characteristics of the textiles;
– application of blended yarns containing individual components of special fibres which enable to achieve multifunctionality of the textile material.

Present trends in the world are oriented also on following ways and processes for influencing performance of the textiles [5]:

Nanotechnologies – application of nanoparticles on chemical basis improves performance characteristics e.g. antimicrobial properties, UV stability, antistatic properties, soil resistance, improvement of crease resistance;

Antimicrobial finish – the finish is performed mostly by additivation in fibre mass for suppression of grow (and/or destruction) of the micro-organisms, elimination of unpleasant odour of the textiles (clothing textiles for sportswear and leisurewear) and/or hygiene improvement e.g. in footwear, home textiles, textiles for occupant compartment of vehicles or in healthcare. Carriers containing nanoparticles are used mostly for additivation. As an example we can mention following well-known textile products: Odor-Easter (footwear), Sole Fresh TM and Foot Smart (socks), AegisMicrobe Shield (clothing).

Moisture management – moisture management is one of the crucial performance criteria mainly for clothing textiles. Ability of the clothing to transport moisture influences wearing comfort significantly. This ability is achieved by using microfibres or by application of silicones on molecular level in fibre mass with the aim to increase hydrophilic properties of the textile material. Examples of well-known products showing improved moisture management include

textiles Coolmax (sportswear), Coolplus (socks, underwear).

Flammability reduction – in general, two ways of flammability reduction are used at present: additivation of the fibre with a concentrate containing flame retardant and surface finish performed by impregnation. Both the ways are followed strictly from environmental viewpoint because agents based on phosphorus-containing compounds or halogen organic compounds are used. The most expensive way of flammability reduction of the textiles is application of e.g. aramide fibres with permanent non-flammability (e.g. Kermel or Nomex fibre).

The other literature quotations [6, 7] confirm high demand for multifunctionality of the textiles as well. The requirements are solved mostly by combination of modified fibres used in textiles as well as by surface textile finishing [8].

2. Experimental

2.1. Characteristics of the prepared multifunctional concentrates

Selected PP polymers with processing properties suitable for research of PP concentrates (Moplen HF501N, Tatren HG1007) and for spinning tests of the multifunctional PP fibres (Tatren HT2511) were procured and evaluated in the frame of the research.

On the base of study stage of our research halogen-free FR modifiers Melapur MC25 (designation FR) and Flamestab NOR116 (FRUV), stabilizers Irgafos 168, Chimasorb 944 FDL and Tinuvin 770 DF (UV) as well as AMB additives Irgaguard B7000 (AMB1) and Biostat B (AMB2) were selected and procured for research of multifunctional concentrates. Their suitability for preparation of the multifunctional concentrates was confirmed by thermal analyses.

Material output of our research of the multifunctional PP concentrate were 3 types of PP concentrates in combination of FR, UV and AMB with designation 28/1673; 28/1674; 28/1676. Technological reliability of the process with optimized parameters of their preparation was satisfactory, comparable with reliability of a process of preparation of standard monofunctional concentrates. The processing and rheological properties of the prepared model samples of the multifunctional concentrates were on required level for additivation of PP fibres (Tab.1 and 2) [9].

The above-mentioned tests confirmed positive results obtained in the stage of laboratory research of PP concentrates with FR+AMB+UV modification effect. Subsequently spinning tests of the prepared multifunctional concentrates (laboratory spinning line TŠ-32 with draw-off up to 2500 m/min) were performed with favourable results.

Tab.1 Composition of the prepared multifunctional concentrates (FR + AMB + UV)

Concentrate designation	PP (%)	FR (%)	FR+UV (%)	AMB (%)	Dispersant (%)	UV stabilizers (%)
28/1673	49.4	25.0	-	10.0	5.6	10.0
28/1674	41.4	33.0	-	10.0	5.6	10.0
28/1676	49.7	25.0	3.0	10.0	4.8	7.5

Note: Technological stability of the concentrate preparation was trouble-free in all technological nodes.

Tab.2 Rheological constants of PP polymer and model samples of the multifunctional PP concentrates

Sample	K (Pa s)	n	B
PP Tatren HT 2511	2104.8	0.5364	0.9985
28/1673	2280.8	0.5051	0.9992
28/1674	2786.0	0.4851	0.9990
28/1676	2503.6	0.4910	0.9995

Note: Evaluation according to the Square model $\tau = K.Dn$.
K- Coefficient of consistency;
n – Pseudoplastic deviation;
B – Coefficient of certainity

2.2. Characteristics of the prepared PP multifunctional fibres

Laboratory tests of 11 different types of mono and multifunctional concentrates and additives were performed. Modified PP fibres with higher linear density of 5 dtex in smooth version and in friction textured version in grey state with various additive concentration were prepared. A model spinning and drawing line allowing to work at reduced spinning temperature was used. There are only several manufacturing devices allowing to work with spinning temperatures under 250 °C. Smooth types of PP fibres were prepared directly on the spinning and drawing line. The friction textured PP fibres were textured on AFK machine from Barmag and the doubled types of PP fibres on TG 20 machine. In general, workability of

Tab.3 Evaluation of coloristic properties of the modified PP fibres with FR+UV+AMB finish containing multifunctional concentrate 3 wt.% (D 65 light type)

Sample	dL	da	db	dC	dH	dE
36/2014/4 (standard)	0.44	0.03	-0.05	0.05	0.03	0.44
36/2014/7	1.59	-0.21	0.75	-0.72	-0.29	1.77
36/2014/10	1.9	-0.11	0.42	-0.42	-0.12	1.19
36/2014/13	-2.21	-2.33	17.28	14.6	-9.53	17.57

Note: dL, da, db, dC, dH, dE – designation of coloristic deviation by CIELab.

Tab.4 Physico-mechanical properties and LOI of the multifunctional textured PP 84/16 x 4 FT, colour P-001 containing multifunctional concentrate 3 wt.%

Sample of PP fibre	Type of additives concentrate	Content in polymer (wt. %)	Linear density of PP fibre (dtex)	Fibre strength (cN/dtex)	Elongation (%)	LOI (vol.% O_2)
36/2014/4 (standard)	-	-	368.9±0.1	3.51±0.1	96±12	26 ± 0.5
36/2014/7	28/1673	3	372.7±0.4	2.29±0.1	111.5±5.8	32 ± 0.5
36/2014/10	28/1674	3	372.6±0.7	2.33±0.1	113.5±7.9	31 ± 0.5
36/2014/13	28/1676	3	373.9±0.3	2.3±0.1	112±16	31.5 ± 0.5

the evaluated multifunctional concentrates was good, however degradation of some additives due to long-term thermal stress was observed. It caused yellowing of the fibre. Influence of the additive on colour change is evaluated in Tab.3. Physico-mechanical properties of the final fibre are given in Tab.4. The prepared samples of multifunctional fibres meet the values of mechanical properties specified by a standard. LOI determination was performed, using EN ISO 4589-2 Plastics. Determination of flammability using method of oxygen number, to evaluate flammability reduction and the results are given in Tab.4. Significant increase of LOI by 6 % in comparison with a non-modified sample was achieved already with 2 % content of additives concentrate 28/1674 type, which is a remarkable one. The best results of our laboratory research in the group of PP modified with FR+UV+AMB finish were achieved with the multifunctional concentrate of 28/1674 type used also in the frame of our pilot plant research [9].

Sample of PP fibre 36/2014/13 was prepared experimentally with the aim to investigate technological conditions directly on a manufacturing line. Concentrate 28/0045 V was used; however unsuitable values of coloristic deviation (dE = 17,57) were achieved in comparison with samples of PP fibre 36/2014/7 where different concentrate was used.

3. Results and discussion

3.1. Evaluation of influence of the multifunctional PP fibres on performance characteristics of selected textile types

Basic group of modified PP fibre Prolen VEL FTS 167/36x2 P 001 additived with FR+UV+AMB concentrate in 3 wt.% ratio was prepared in order to evaluate textile processability in various textile constructions. The processability and subsequent properties of textiles prepared from samples of PP fibres with designation: sample No. 36/2014/4 (standard), sample No. 36/2014/7 (additives concentrate No. 28/1673), sample No. 36/2014/10 (additives concentrate No. 28/1674), sample No. 36/2014/13 (additives concentrate No. 28/1676) were evaluated. The modified PP fibre was processed on flat knitting machines CMS 330 Tc type with 12 E gauge into jersey fabrics (knitted fabrics for clothing applications) and simultanously on rapier loom CCI Evergreen 2014 type into woven fabrics with plain and twill (3/1 type) weave. Subsequently physico-mechanical properties, functional properties and performance characteristics of the prepared textiles were evaluated [17].

Description and identification of the prepared textile samples made of Prolen VEL FTS 167/36 x 2 dtex P001 fibre additived with the FR+UV+AMB multifunctional concentrate (3 wt.% ratio):

A) KNITTED FABRIC
standard: (without additive)
sample No. 1:
(concentrate No. 28/1673)
sample No. 2:
(concentrate No. 28/1674)
sample No. 3:
(concentrate No. 28/1676)

B) WOVEN FABRIC, plain weave
standard: (without additive)
sample No. 1:
(concentrate No. 28/1673)
sample No. 2:
(concentrate No. 28/1674)
sample No. 3:
(concentrate No. 28/1676)

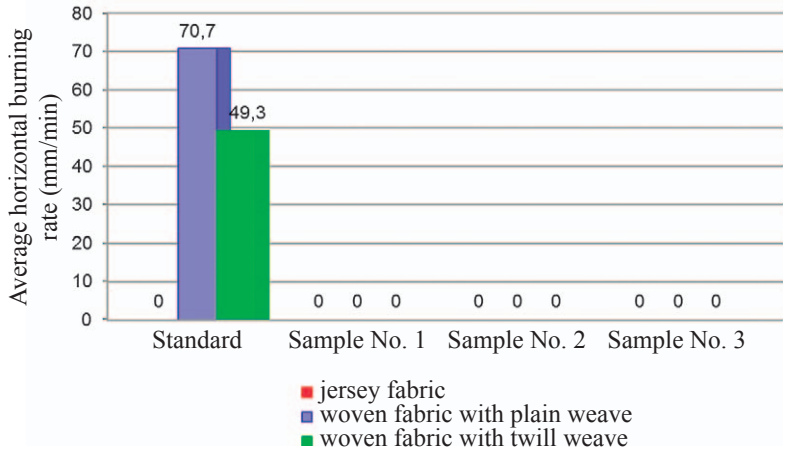

Fig.1 Average horizontal burning rate of horizontally placed fabrics (knitted and woven fabrics) determined according to ISO 3795: 1995

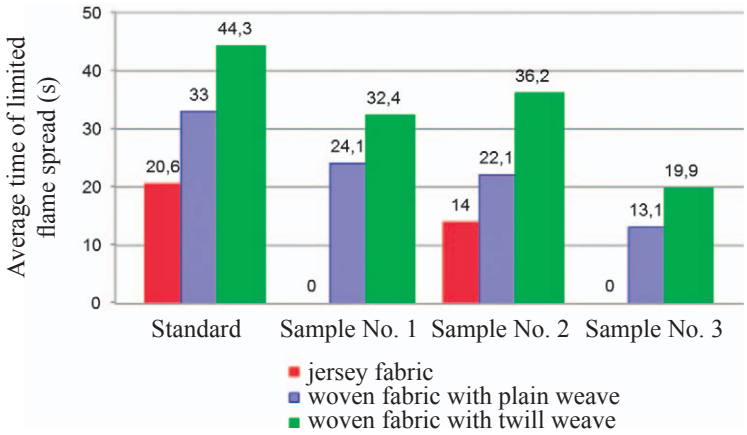

Fig.2 Average time of limited flame spread of vertically placed fabrics (knitted woven fabrics) determined according to EN ISO 15025: 2003.

C) WOVEN FABRIC, twill weave
standard: (without additive)
sample No. 1:
(concentrate No. 28/1673)
sample No. 2:
(concentrate No. 28/1674)
sample No. 3:
(concentrate No. 28/1676)

3.2. Evaluation of influence of flammability reduction of the fabrics

Fig.1 and 2 show results from evaluation of flammability of the knitted and woven fabrics (plain and twill weave) in horizontal and vertical direction determined according to specific test standards. It flows from results given in Figure 1 that all tested textiles from the multifunctional FR+AMB+UV PP fibres have horizontal burning rate on a level of 0 seconds regardless of the applied multifunctional concentrate in PP fibre, construction of the textile material (knitted fabric, woven fabric) and weave of the woven fabric (plain, twill weave) what is a significantly positive result of flammability reduction. According to the results given in Fig.2 (limited flame spread in vertical direction) the best results were achieved with textiles prepared from the modified PP fibre containing multifunctional concentrate No. 28/1676 (sample No. 3) where the average time of spontaneous flame burning was on a level of max. 0-19,9 seconds in dependence on textile construction, this time of the other multifunctional textiles ranged from 14 to 44 seconds.

It is possible to state on the base of the achieved results that the best results from a viewpoint of flammability were achieved regardless of textile construction (knitted fabric, woven fabric, weave) with PP fibre modified with the multifunctional concentrate No. 28/1676. Based on comparison of efficiency of the concentrate with other concentrate types, from a viewpoint of flammability reduction and in comparison with ratio of individual components (FR+UV+AMB) the given combination of components proved to be the most suitable.

3.3. Evaluation of influence of increasing UV stability of the multifunctional PP fibres

Fig.3 shows results from evaluation of influence of UV radiation on phy-

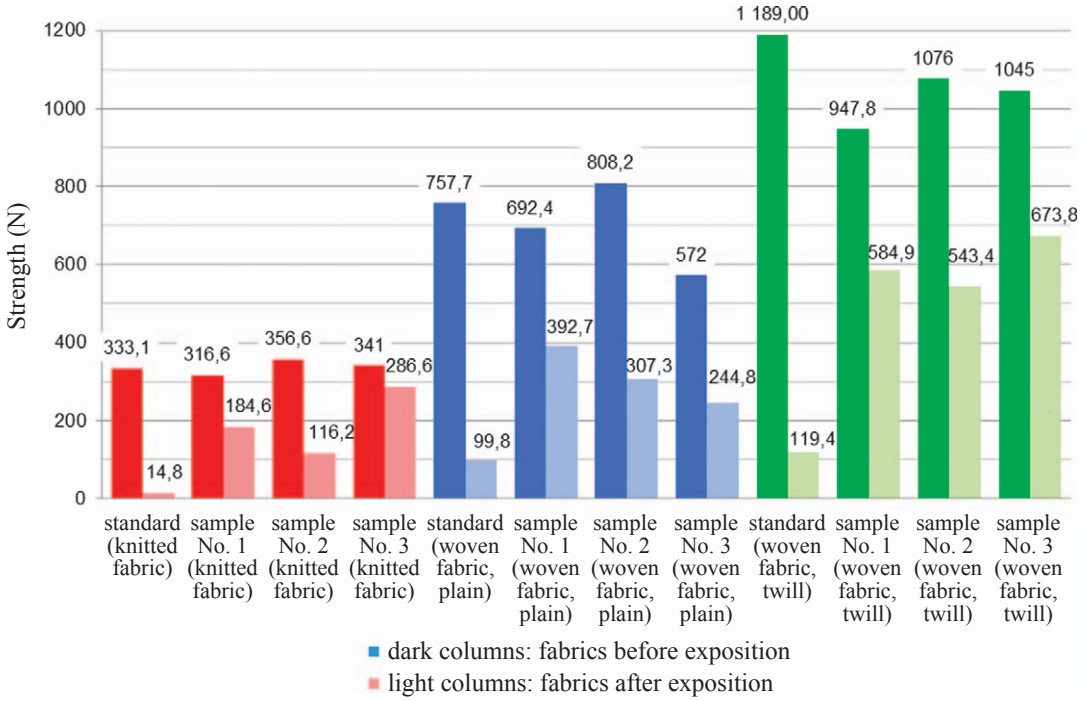

Fig.3 Comparison of strength values on knitted and woven fabrics (plain and twill weave) from the modified PP fibres before and after UV exposition for a period of 741 hours.

sico-mechanical parameters of a standard and multifunctional knitted and woven fabric (plain and twill weave) prepared from the above-mentioned PP fibres modified with the concentrate containing FR+UV+AMB1 additives.

Method of comparison of physico-mechanical properties (strength, elongation) of tubular knitted fabrics and woven fabrics before and after UV lamp exposition was selected. Exposition time was calculated with radiation intensity of 60 +/- 2 ($W.m^{-2}$), wavelength 300 – 400 nm, for a period of 741 hours (1 year equivalent of UV radiation for temperate zone), determined according to the standard STN EN 12 608: 2005 and Xenotest Alpha apparatus used in the experiments. While on a knitted fabric made from standard PP fibre the determined strength reduction after 741 hours was nearly by 95 %, on a knitted fabric from PP fibres finished using additive 28/1676 type this reduction was by 15 % only. According to the achieved results it is possible to establish significant positive result of application of UV additive, mainly in the multifunctional concentrate 28/1676 type, on the woven fabrics as well. It ensured strength reduction after 741 hours of exposition on twill fabric by about 35 % only, while reduction on woven fabric from standard (non-modified) PP fibres was as much as by 90 %. The mentioned differences in strength were not so significant on the woven fabric with plain weave.

In connection with evaluation of colour change after UV radiation exposition the highest grade 4 was determined always on sample No. 3 (multifunctional concentrate 28/1676), lower grade 3-4 was determined on the other samples, whereby the sample No. 1 (plain weave) with concentrate 28/1673 showed grade 2-3 only. The mentioned difference in the found values in favour of concentrate 28/1676 type can be again assigned to the most suitably selected ratio of the FR+UV+AMB components.

3.4. Evaluation of influence of antimicrobial efficiency of the prepared fabrics.

Results from evaluation of antimicrobial activity on knitted and woven fabrics prepared from the multifunctionally modified types of PP fibres are given in Tab.5-7. High antibacterial activity (over 99 % reduction) on bacteria *Staphylococcus aureus* was confirmed on all samples of knitted fabrics made from the modified PP fibres. On evaluation with bacteria

Tab.5 Results from evaluation of antimicrobial efficiency on PP knitted fabrics bacteria *Staphylococcus aureus* and *Klebsiella pneumoniae* using AATCC 100: 2012 method

Bacteria	*Staphylococcus aureus* (CFU/ sample)				*Klebsiella pneumoniae* (CFU/ sample)			
Contact time	standard	Sample No. 1	Sample No. 2	Sample No. 3	standard	Sample No. 1	Sample No. 2	Sample No. 3
0 h	$174x10^3$	$51x10^3$	$92x10^3$	$101x10^3$	$132.6x10^3$	$109x10^3$	$125x10^3$	$136x10^3$
24 h	$101x10^4$	<100	<100	$253x10^1$	$116.3x10^5$	$121x10^4$	$282.3x10^3$	$58x10^2$
Reduction [%]	no	>99.80	>99.89	>97.50	no	no	no	99.2

Tab.6 Results from evaluation of antimicrobial efficiency on PP woven fabrics with weave with bacteria *Staphylococcus aureus* and *Klebsiella pneumoniae* AATCC 100: 2012 method

Bacteria	*Staphylococcus aureus* (CFU/ sample)				*Klebsiella pneumoniae* (CFU/ sample)			
Contact time	standard	Sample No. 1	Sample No. 2	Sample No. 3	standard	Sample No. 1	Sample No. 2	Sample No. 3
0 h	$42x10^4$	$100x10^3$	$52x10^2$	$136x10^1$	$150x10^3$	$179x10^3$	$110.3x10^3$	$114.6x10^3$
24 h	$93x10^5$	< 100	$246x10^0$	< 100	$82x10^5$	$264.3x10^{4*}$	$79.6x10^3$	$105x10^1$
Reduction [%]	no	≥98.82	99.17	≥ 99.51	no	no	27.83	99.08

Tab.7 Results from evaluation of antimicrobial efficiency on PP woven fabrics with weave with bacteria *Staphylococcus aureus* and *Klebsiella pneumoniae* AATCC 100: 2012 method

Bacteria	*Staphylococcus aureus* (CFU/ sample)				*Klebsiella pneumoniae* (CFU/ sample)			
Contact time	standard	Sample No. 1	Sample No. 2	Sample No. 3	standard	Sample No. 1	Sample No. 2	Sample No. 3
0 h	$129x10^3$	$43x10^2$	$53x10^2$	$73x10^2$	$150.6x10^3$	$88x10^3$	$111.6x10^3$	$51.3x10^3$
24 h	$69x10^4$	$51x10^1$	75	43	$111.3x10^5$	$111x10^2$	$32x10^1$	164
Reduction [%]	no	88.14	98.58	99.4	no	87.39	99.71	99.68

Klebsiella pneumoniae high reduction achieved the knitted fabric with concentrate No. 28/1676 (sample No. 3) only, no reduction was established on the other PP fibres.

High antibacterial activity on evaluation to bacteria *Staphylococcus aureus* (over 88 % reduction) was confirmed on all samples of woven fabrics with plain weave as well with twill weave (3/1) prepared from the multifunctionally modified PP fibres. When bacteria *Klebsiella pneumoniae* (which is much more resistant) was used, high reduction (over 99 %) was established on the woven fabric with plain weave prepared from PP fibre containing the concentrate No. 28/1676 (sample No. 3), the other samples showed no reduction. On the contrary, all samples of woven fabric with twill weave made of the modified PP fibre showed high reduction (over 87 %). Different results achieved with the above-mentioned bacteria are probably are connected with surface structure of the woven fabric in relation to wetting of the surface with an inoculum.

It results from the comprehensive evaluation of antimicrobial activity that application of AMB addivites in combination with FR and UV additives does not reduce their efficiency and does not cause any accompanying negative effects. The multifunctional FR+AMB+UV concentrate with designation No. 28/1676 can be considered the most suitable one according to the achieved results.

4. Conclusion

Goal of the research work was preparation of multifunctional (FR+UV+AMB) concentrate with carrier on polypropylene polymer, designed for modification of polypropylene (PP) fibres. Subsequent evaluation of selected performance characteristics of the textile materials (knitted and woven fabrics) prepared from the modified fibres confirmed high multifunctional efficiency of the concentrate (designation No. 28/1676) with composition as follows: 25 % halogen-free FR modifier (Melapur MC25) + 3 wt. % FR UV modifier (Flamstab NOR 116) + 10 wt. % antimicrobial additive AMB 2/Biostat B/ + 4,8 wt. % dispersant and 7,5 wt. % UV stabilizer (Irgafos 168, Chimasorb 944 FDL, Tiamin 770 DV). Suitable technological workability of the multifunctional concentrate for additivation of PP fibres without negative accompanying rheological and/or coloristic influences was established. Subsequently, after application of 3 wt. % portion of the above-mentioned concentrate type to the modified PP fibres following positive changes of performance characteristics were established in the textile materials (knitted and woven fabrics) in comparison with fabrics made from standard PP fibres:

– reduction of average time of limited flame spread of vertically placed knitted fabrics by 20 seconds (reduction by 100 % compared to the standard) and of horizontally placed woven fabrics also by 20 seconds (reduction by 80 % compared to the standard);
– strength of the knitted fabrics decreased by 5 % only after UV lamp exposition with conditions determined for temperate zone compared to 95 % strength reduction after exposition of a standard knitted fabric. The woven fabrics (twill weave) showed strength reduction by 35 % only, while strength reduction of the standard fabric was as much as by 90 %.
– tests performed in the frame of evaluation of antibacterial activity to bacteria *Staphylococcus aureus* and *Klebsiella pneumoniae* confirmed high degree of reduction (> 90 %) on knitted fabrics from the modified PP fibre. The above-mentioned type of multifunctional concentrate (28/11676) ensured high AMB activity (> 80 % reduction) to both types of bacteria also in the woven fabrics with plain and twill weave.

The achieved results of change of selected performance characteristics of the knitted and woven fabrics have confirmed real possibilities of application of the multifunctional concentrate 28/1676 type for efficient modification of PP fibre which can be used with advantage e.g. for special protective clothing or technical textiles (e.g. car seat covers).

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