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POLYMERIC BLENDS DESIGNED FOR SURFACE DECONTAMINATION

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This paper proposes a novel approach towards obtaining biodegradable polymeric nanocomposites for the removal of contaminants. The present work describes the preparation and characterization of a set of polymeric blends suitable for surface decontamination. These solutions have been engineered to entrap the contaminant into the nanocomposite matrix and to form peelable films that can be easily removed. Thus, the contaminant is sealed into the polymeric film and can be safely removed and disposed. The purpose of this study consisted in the investigation of the relationship between the composition of the polymeric blends and their properties. Nanocomposite films were prepared by casting from aqueous solutions. Viscosity and evaporation rate measurements were performed for the optimization of the decontamination solution composition and the compatibility among components was investigated through FT-IR technique and thermal analyse. The decontamination efficiency was evaluated through antimicrobial tests.

Keywords: surface decontamination; polymer; nanocomposite; peelable films; antimicrobial

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1. Introduction

Nowadays, more than ever, the chemical, biological, radiological and nuclear (CBRN) threats prove us that they can become pandemic and can endanger the global population. Decontamination plays an essential role in the defence against CBRN hazards. A decontamination process is undertaken towards the removal or neutralization of the contaminant. For military purposes, decontamination actions are crucial because they allow us to restore the combat effectiveness of equipment and personnel. [1]

Most of the existing decontamination methods are not considered environmentally safe because they require excessive amounts of reactants, solvents or water and they are corrosive and/or toxic [1-3]. Chemical decontamination is the most common technique involved in the removal of the contaminants and it can be performed by applying the active ingredients in a variety of forms: solutions, steam, foams, gels, powders, chemical fog, aerosols etc. [3-7]. After the 1950s, decontamination systems like DS2 (Decontamination Solution 2) or PDK (Personal decontamination kit) were extensively used [4] for decontamination. This type of solutions cannot be considered environmentally safe due to their composition which consists in mixtures of corrosive or toxic reactants like: sodium hydroxide, diethylene triamine, phenol, ammonia, peroxides or detergents. The decontamination systems that require large amounts of water do not represent a feasible solution because water can be often difficult to find on the battlefield and the disposal of this contaminated water will further represent an important issue [1]. In this context, recent studies focus on developing decontamination solutions that would overpass these problems [8-11]. Contemporary decontamination systems should be based on biodegradable components while, at the same time, should ensure an efficient removal of the contaminant. Multiple attempts of developing this type of materials can be found in literature, but each method has its own limitations (solvents, toxicity of components, decontamination efficiency) [4, 6].

Polymeric peelable films represent a modern and versatile method for surface decontamination [12]. Various polymers can be listed as film-forming polymers: acrylates [13], silicones [13], vinyl polymers [3, 5, 13], polyurea [14], cellulose derivates [13], alginate derivates [15], gelatine derivates [16]. Film forming polymeric solutions are extensively used in obtaining polymeric films with decorative, protective or functional purposes [5, 17, 18] for ordinary applications like cosmetics industry, food industry, or special purposes like drug delivery, ballistic protection or decontamination.

According to literature, poly(vinyl alcohol) (PVA) is one of the few biodegradable synthetic polymers which is also water-soluble, non-toxic and has the ability to form peelable films [19, 20]. Since complete biodegradability of PVA can be achieved only in the presence of appropriately acclimated microorganisms [20], we decided to improve our decontamination solutions recipe by partially replacing PVA with a natural polymer - sodium alginate (SA), due to its faster biodegradability [21]. Sodium alginate is a natural hydrophilic polysaccharide obtained from marine brown algae [22], which possesses high hydrophilicity, fast biodegradability, and antibacterial activity [21]. Hence, the decontamination peelable films benefit from the advantages of both polymeric components: PVA ensures film forming, mechanical resistance while SA enhances their biological features. The composition of these polymeric blends can be customised depending on the targeted CBRN agent.

In this context, the aim of this study consisted in the optimisation of the composition of an eco-friendly decontamination solution. The polymeric blends were especially designed to be biodegradable, non-toxic, easy to apply, easy to remove while ensuring a high decontamination efficiency. Therefore, we report here a novel approach for obtaining improved polymeric blends employed in surface decontamination, which aims to reveal the influence of the biodegradable components on the final properties of these nanocomposite materials. This work also comprises the investigations performed for the evaluation of the decontamination efficiency through antimicrobial tests.

2. Experimental

2.1. Materials

Polymeric matrix: Poly(vinyl alcohol) (with 98–99% hydrolysis degree, DP ≈ 1700-1800, Mw ≈ 115000 Da, Loba Chemie, **PVA**), sodium alginate (SpecialIngredients®, **SA**); *Nanoclays:* hydrophilic bentonite (nanoclay, Sigma–Aldrich, **BT**), saponite (clay nanoparticles, Nanoshel®, **SP**); *Complexing agents:* ethylenediaminetetraacetic acid (tetrasodium salt dihydrate, Sigma–Aldrich, **EDTA**), iminodisuccinic acid (Tetrasodium Iminodisuccinate, BAYPURE® CX 100 solid G, Lanxess, **IDS**); *Plasticiser:* anhydrous glycerol (Sigma–Aldrich, **GLY**); *Commercial disinfectants:* Keradet-aktiv (Kiehl, **KRD**), IsoRapid® (Oro Clean Chemie AG, **IRPD**).

2.2. Methods

The composition of each decontamination solution is illustrated in Table 1. All the polymeric blends were prepared, according to the concentrations indicated in Table 1 in conjunction with the specific recipe described below.

Table 1

Composition of the decontamination solutions

Sample	PVA [%]	SA [%]	BT [%]	SP [%]	EDTA [%]	IDS [%]	IRPD [%]	KRD [%]	GLY [%]
PB0	5	0	1	0	0	0.1	0	0	2.5
PB1	5	0.5	1	0	0	0.1	0	0	2.5
PB2	5	1	1	0	0	0.1	0	0	2.5
PB3	5	1.5	1	0	0	0.1	0	0	2.5
PB4	5	2	1	0	0	0.1	0	0	2.5
PB5	10	0	1	0	0.1	0	0	0	5
PB6	10	0	0	1	0.1	0	0	0	5
PB7	10	0	1	0	0.1	0	1	0	5
PB8	10	0	1	0	0.1	0	0	0.03	5

PB9	10	0	0	1	0.1	0	1	0	5
PB10	10	0	0	1	0.1	0	0	0.03	5
DS1	0	0	0	0	0	0	1	0	0
DS2	0	0	0	0	0	0	0	0.03	0

2.2.1 Preparation of the neat decontamination solutions

The first step in obtaining the neat decontamination solutions (PB0, PB5 and PB6) consisted in the solubilisation of the chelating agent (EDTA or IDS) in distilled water. After the complete solubilisation of the chelating agent, the nanosized clay (bentonite or saponite) was dispersed by ultrasonication. The next step consisted in the addition of PVA, under vigorous stirring at 90-95℃, until complete dissolution of the polymer. The last step was the addition of glycerol.

2.2.2 Preparation of the polymeric blends with sodium alginate

Polymeric blends containing SA (PB1, PB2, PB3, PB4) were prepared for the investigation of the influence of sodium alginate on the final properties of the decontamination solutions and peelable films, respectively. For this purpose, sodium alginate water solution (which was previously prepared separately using the appropriate amount of distilled water) was added to neat decontamination solutions (after bentonite dispersion and prior to PVA dissolution).

2.2.3 Film casting

Polymeric nanocomposite peelable films of about 0.2 mm (±0.05 mm) were obtained via solvent casting technique, in less than 24 h (depending on the composition). For this purpose, 15 mL of each decontamination solution was transferred in polystyrene Petri-dishes (of 90 mm diameter) and allowed to dry at 25 ℃ and 50–55% relative humidity.

2.2.4 Preparation of the antimicrobial decontamination solutions

As mentioned in the *Introduction* section, the composition of these polymeric blends can be customised depending on the targeted CBRN agent. For this purpose, two commercial disinfectant solutions (IsoRapid® and Keradet-Aktiv) were added to the recipe of our decontamination solutions (the neat decontamination solutions PB5 and PB6, utilised as reference samples in the present study, were developed and optimised in our previous studies [2, 12]), in order to evaluate the antimicrobial activity of this new decontamination systems (PB7, PB8, PB9, PB10). Standard disinfectant solutions, DS1 and DS2 were prepared according to the specifications of IsoRapid® and Keradet-Aktiv producers, in order to compare their efficiency with the one of our decontamination solutions.

2.2.5 Antimicrobial testing

For the determination of the antimicrobial activity, the agar disk-diffusion method was used. According to this well-known procedure, agar plates were inoculated with a standardized inoculum of the test microorganism. Then, filter paper discs (about 6 mm in diameter) were placed on the agar surface. These paper discs were inoculated with active substances. The Petri dishes were incubated under suitable conditions. Generally, antimicrobial agent diffuses into the agar and inhibits germination and growth of the test microorganism, therefore we measured the diameters of inhibition growth zones.

2.2.6 Bacteria Strains Preparation

The antimicrobial activity of polymeric solutions was tested against *Staphylococcus aureus*, ATCC 6538 (as a model of Gram-positive non-sporing bacteria), *Bacillus subtilis* (as a model of Gram-positive bacteria spore-forming), ATCC 6633, *Escherichia coli*, ATCC 8739 and *Pseudomonas aeruginosa*, ATCC 9027 (as a model for Gram-negative bacteria). Being considered standard microorganisms for testing the antimicrobial properties [23], these bacteria (listed above) were chosen for the evaluation of the antimicrobial activity of the polymeric blends. The bacterial strains were harvested in mid-log phase, after cultivation on tryptic soy agar (TSA) (Merck) and kept overnight at 36 °C. Portions of suspension were harvested by centrifugation and resuspended in deionized water. The suspensions were adjusted to approximately 10^5 CFU / mL. The concentration of suspension was verified by decimal dilution and cultivation on Tryptic soy agar.

2.2.7 Disk diffusion test

The bacteria strains were spread on the Mueller-Hinton agar (MHA) (Merck) using sterile cotton swab. The disks were placed on agar surface and loaded with 10 μL of test solutions. The Petri dishes were incubated at 36 °C. The inhibition zone was observed after 24 h of incubation. Sterile blank (BK) antimicrobial disk was used in the test.

2.3. Characterization

Rheological behavior of polymeric blend solutions was studied on Rheotest 2.1 (Germany) device with coaxial cylinders at room temperature 25 °C, being the most adequate working temperature [24-26]. The dependency of dynamic viscosity of the polymeric solutions upon the shear gradient was investigated in both the presence and the absence of sodium alginate, to establish a model flow profile of solutions with the most filmogen characteristics. For the investigation of the solvent casting process, ATS 120 Axis Thermobalance was used to measure the evaporation rate of the solvent (ammount of water evaporated in time, from each decontamination solution). For this test, 4 grams of solution was transferred in a Petri dish with a diameter of 55 mm, and the evaporation rate was recorded at 25 °C, 30 °C and 35 °C. The termobalance is equipped with Promas software which calculates the evaporation rate by weighting the sample at every 150 s for 2 h. The FT-IR spectra were collected at 4 cm^{-1} resolution, from 550 to 4000 cm^{-1}, using a Perkin Elmer Spectrum Two with a Pike MiracleTM ATR modulus. The thermal properties of the polymeric blends were investigated with a DTA OZM 551 Ex Differential Thermal Analysis System equipped with Meavy dedicated software. The measurements were performed on samples weighing approximately 25–30 mg which were heated from 30 °C to 450 °C with a constant heating rate of 5 °C/min.

3. Results and discussions

The first step of this work consisted in obtaining different types of decontamination solutions by employing four different concentrations of sodium alginate, to establish the influence of this component on the final properties of the material. The composition of these polymeric blends can be customised depending on the targeted CBRN agent. Therefore, the next step consisted in the incorporation of two commercial disinfectants into the previously developed decontamination solutions to evaluate their antimicrobial activity.

The polymeric decontamination solutions can be applied on various types of surfaces (metal, glass, plastic, wood, ceramics, concrete) by pouring, brushing, rolling, or spraying technique. Once applied on the targeted surface, the active ingredients from the decontamination solution will begin to interact with the contaminants, entrapping them into the polymeric nanocomposite matrix. The curing process of the aqueous polymeric film occurs as the solvent evaporates. When this process ends, the nanocomposite film containing the contaminant agent can be easily and safely removed by exfoliation, thus the surface will be decontaminated. All the steps described above are illustrated in Fig.1.

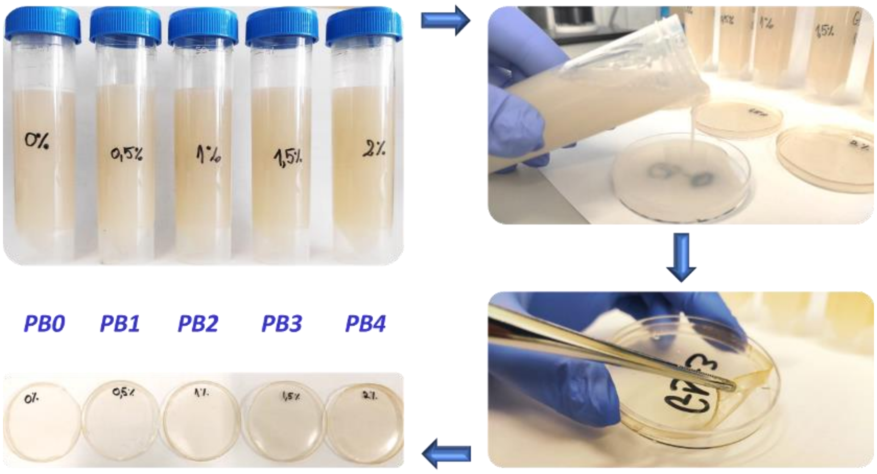

Fig. 1. Curing process of the aqueous polymeric blends

Since the aim of this study was the optimisation of the composition of the polymeric blends designed for decontamination, we investigated the most relevant specific characteristics of the decontamination solutions (rheological properties, evaporation rate) and peelable films (interactions between components via FT-IR spectroscopy, thermal properties via DTA analysis) obtained from them, respectively.

Studying the rheology of the decontamination solution it is very important when choosing the optimal match between the application technique and the type of surface targeted for decontamination. The rheologic profiles of all decontamination polymeric blend (noted hereafter PB) solutions are given in Fig. 2 which depicts the rheological behaviour of PB0, PB1, PB2, PB3 and PB4 at 25°C, in the absence or presence of sodium alginate. It can be observed that the solutions are characterized by a pseudo-plastic flow (described by a decrease of viscosity with the shear rate) and that the pseudo- plastic behaviour is less obvious at higher extents of sodium alginate. Hence, the blank solution PB 0 showed the lowest dynamic viscosity, while in the case of PB1, PB2, PB3 and PB4 the dynamic viscosity increased gradually, due to the higher content of sodium alginate. The pseudo-plastic behaviour of the polymeric blends has a clear tendency of shifting towards Newtonian (quasi-Newtonian) behaviour at higher shear rates. Upon sodium alginate addition, it was noticed a similar pattern of the flow behaviour as in the case of the blank solution PB0. It is also worth mentioning that the most filmogen polymeric solution should present a Newtonian or quasi-Newtonian flow profile in order to generate thin high-quality films suitable for surface decontamination.

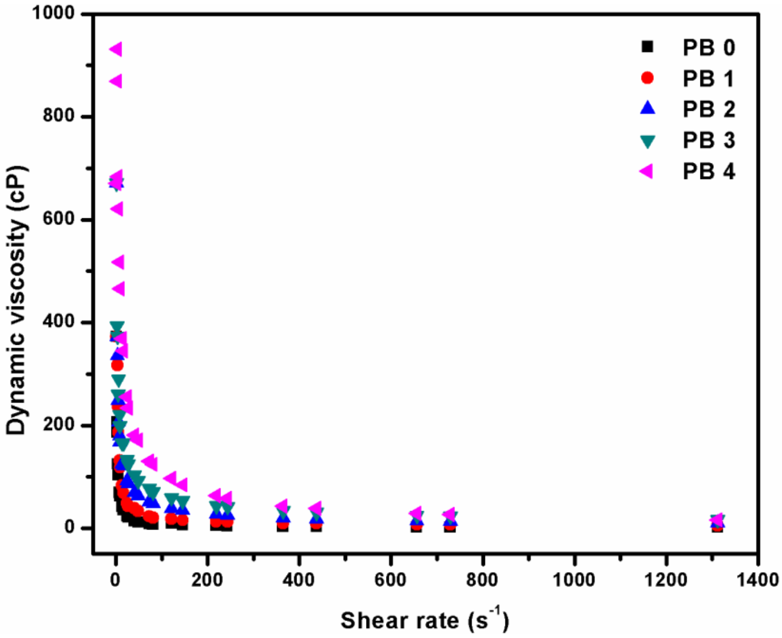

Fig. 2. Rheological behavior of the polymeric blends solutions at 25 °C

The evaporation rate of the polymeric blends represents an important characteristic for the decontamination process because it influences the duration of the interaction between the active ingredients and the contaminants and also conditions the time elapsed until the exfoliation of the strippable film is possible. Table 2 summarises the evaporation rates obtained for each polymeric blend. Unsurprisingly, evaporation rate increases with temperature. The evaporation rate of the polymeric blends containing SA, decreased with the addition of SA, probably due to the following considerations: the polymeric blends containing higher concentrations of SA possess a higher viscosity which slows down the evaporation process; the hydrophilicity of SA together with the supplementary intermolecular hydrogen bonds established by SA lead to a longer retention of the water molecules into the polymeric system, thus delaying the evaporation.

The mechanism of film formation from the polymeric dispersions also depends on the composition of the polymeric blends and, at the same time, on the interactions established among the components. Thus, FT-IR analysis was performed in order to investigate the interactions established between the components of the polymeric blends. FT-IR spectra of the peelable films are displayed in Fig. 3. The broad band at 3275 cm^{-1} assigned to hydrogen bonded O–H stretching vibrations was shifted towards 3285 cm^{-1} with the addition of SA, indicating the formation of new hydrogen bonds between the components of the polymeric blends. The C–H stretching at 2930 cm^{-1} was shifted to 2940 cm^{-1}. The two peaks from 1620 cm^{-1} and 1582 cm^{-1} turned into one sharp peak at 1605 cm^{-1} associated with carboxylate O–C–O asymmetric stretching vibrations, while its intensity increased with SA concentration. The absorption bands at 996 cm^{-1} and 1030 cm^{-1} can be assigned to the Si–O stretching vibration from the clay which are slightly shifted due to the Si-OH interactions with SA additive.

Table 2

Evaporation rates of the decontamination solutions

Sample	**Evaporation rate at 25°C [mg/min]**	**Evaporation rate at 30°C [mg/min]**	**Evaporation rate at 35°C [mg/min]**
PB0	2.58±0.5	5.16±0.8	10.16±0.9
PB1	3.10±0.8	6.41±0.6	10.66±0.5
PB2	3.00±0.9	6.25±0.4	10.08±0.9
PB3	2.91±0.7	6.08±0.6	9.92±0.5
PB4	2.69±0.9	5.91±0.5	9.66±0.7

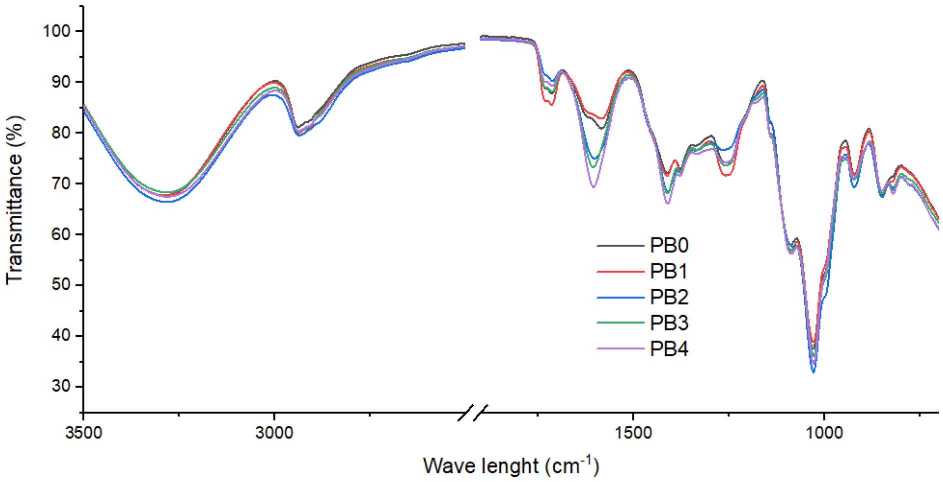

Fig. 3. FT-IR spectra of the polymeric blends peelable films

The thermograms (Fig.4.) of the strippable polymeric films contain two visible sharp endothermic peaks (between 100-150°C and 250-300°C) and one broad endothermic peak (between 170-220°C). The first sharp endothermic peak can be associated with the rearrangement of the crystalline segments of the polymeric chains during the heating process but also to the dehydration of the material. The addition of SA shifted this peak to lower values; therefore, we can say that the mobility of the polymeric chains inside these blends increased with the augmentation of SA content. The broad peak situated between 170-220°C can be assigned to the melting temperature of the crystalline domains of polyvinyl alcohol. The second sharp peak can be attributed to the decomposition process of the polymeric blends, which started earlier for the polymeric blends containing SA.

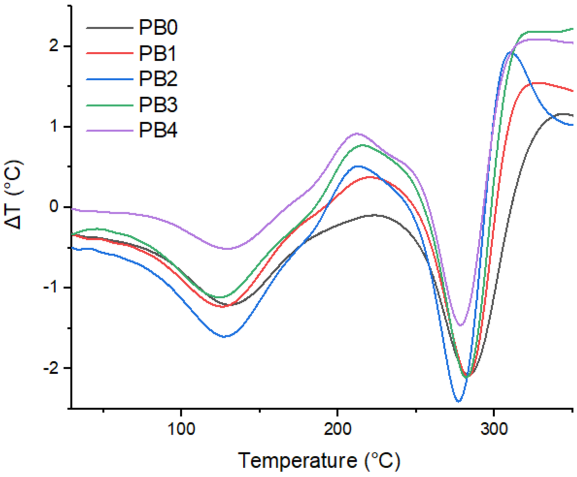

Fig. 4. DTA thermogram of the polymeric blends peelable films

The antimicrobial activity of polymeric solutions was tested against bacteria, as listed in Fig. 5., according to the procedure described in *Methods Section*. The diameters of zone inhibition (including the diameter of the 6 mm discs) measured after 24 h are presented in Table 3. The presence of a clear zone around the disks containing the samples PB7, PB9 and DS1 suggests that these solutions possess antibacterial activity which is able to inhibit the growth of the Gram-negative and Gram-positive bacteria. This visible clear zone produced by bentonite and saponite decontamination solutions containing IsoRapid® disinfectant can be observed in Fig.5. The polymeric solutions PB5 and PB6 did not inhibit the microbial growth evaluated by this method.

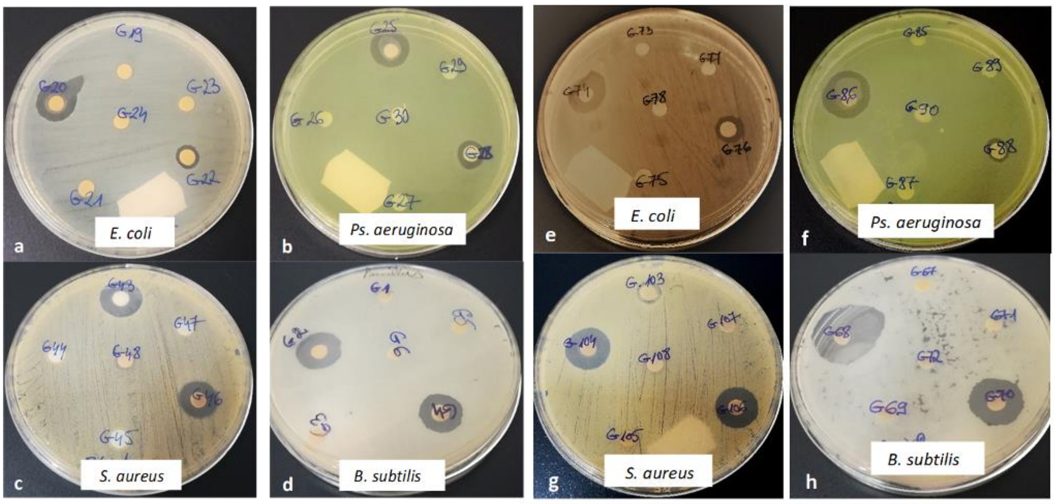

Fig. 5. Antimicrobial activity test by disc diffusion method of decontamination solutions based on bentonite (a↔d) and saponite (e↔h) against bacteria: *E. coli (a,e)*; *Ps. aeruginosa (b,f); S. aureus (c,g)*; *B. subtilis (d,h)*

The solutions (PB8 and PB10) containing Keradet-Aktiv disinfectant solution (DS2) did not show antimicrobial activity at all, even if DS2 was prepared according to the specifications of their manufacturer. On the other hand, IsoRapid® disinfectant (DS1) exhibited antimicrobial activity. It is very important to mention that the antimicrobial activity of IsoRapid® disinfectant is augmented by our polymeric decontamination solutions, the inhibition zone being larger for PB7 and PB9 solutions in comparison with the inhibition zone of neat disinfectant solution DS1. A further evaluation in determining the antibacterial activity of polymeric solutions, using MIC value, is required to establish the lowest concentration of decontamination solution necessary for the inhibition of the growth of bacteria.

Table 3

Antimicrobial activity of the decontamination solutions

Microorganism test	***Tested solutions***	***Diameter of inhibition zone (mm)***	***Microorganism test***	***Tested solutions***	***Diameter of inhibition zone (mm)***
E. coli	PB5	0	***E. coli***	PB6	0
	PB7	14.3		PB9	13.4
	PB8	0		PB10	0
	DS1	8.6		DS1	10.4
	DS2	0		DS2	0
	BK	0		BK	0
Ps. aeruginosa	PB5	0	***Ps. Aeruginosa***	PB6	0
	PB7	14.5		PB9	17.6
	PB8	0		PB10	0
	DS1	10		DS1	8.5
	DS2	0		DS2	0
	BK	0		BK	0
Bacillus subtilis	PB5	0	***Bacillus subtilis***	PB6	0
	PB7	15.8		PB9	24
	PB8	0		PB10	0
	DS1	13.7		DS1	16.3
	DS2	0		DS2	0
	BK	0		BK	0
S. aureus	PB5	0	***S. aureus***	PB6	0
	PB7	16.2		PB9	16
	PB8	0		PB10	0
	DS1	14		DS1	15
	DS2	0		DS2	0
	BK	0		BK	0

4. Conclusions

The results of this study showed that our eco-friendly polymeric nanocomposite strippable films can be successfully employed for surface decontamination. Various decontamination solutions were prepared and characterised in order to obtain an optimal combination between the components, while ensuring a high decontamination efficiency. The introduction of sodium alginate into the polymeric blends ensures a faster biodegradability of these materials while keeping the same performances of the strippable coatings. The incorporation of disinfectants into the polymeric dispersions targeted the biological contaminants. Disk diffusion method showed that the efficacy of the commercial disinfectant solutions was improved by our polymeric blends. These peelable polymeric films can be successfully used on microbial contaminated surfaces, reducing the risk of spreading bio-contaminants by entrapping the contaminants into the nanocomposite matrix.

This work represents a promising start for future research that can be conducted towards designing and optimising new recipes for all the types of CBRN contaminants.

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REFERENCES

[1] G. Toader, P.-O. Stănescu, T. Zecheru, T. Rotariu, A. El-Ghayoury and M. Teodorescu,, "Water-based strippable coatings containing bentonite clay for heavy metal surface decontamination," Arabian Journal of Chemistry, vol. 12, no. 8, pp. 4026-4034, 2019.

[2] L. A. Felton, "Mechanisms of polymeric film formation," International Journal of Pharmaceutics, vol. 457, no. 2, pp. 423-427, 2013.

[3] K. Frederiksen, R.H. Guy, K. Petersson, "The potential of polymeric film-forming systems as sustained delivery platforms for topical drugs", Expert Opinion on Drug Delivery, vol. 13, no. 3, pp. 349-360, 2015.

[4] G. Toader, T. Rotariu, E. Rusen, J. Tartiere, S. Eșanu, T. Zecheru, I. C. Stancu, A. Serafim and B. Pulpea, "New solvent-free polyurea binder for plastic pyrotechnic compositions," Materiale Plastice, vol. 54, no. 1, pp. 22-28, 2017.

[5] C. Dragolici and F. Dragolici, "Introduction in means and methods used in chemical, biological, radiological, and nuclear decontamination," Rom. Journ. Phys., vol. 59, no. 9-10, p. 920–929, 2014.

[6] D. Pulpea, T. Rotariu, G. Toader, G. B. Pulpea, V. Neculae and M. Teodorescu, "Decontamination of radioactive hazardous materials by using novel biodegradable strippable coatings and new generation complexing agents," Chemosphere, vol. 258, Article 127227, 2020.

[7] M.A. Ebadian, Assessment of strippable coatings for decontamination and decommissioning, Topical Report, U.S. Department of Energy, 1998.

[8] R. Manjumeena, D. Duraibabu, J. Sudha and P. T. Kalaichelvan, "Biogenic nanosilver incorporated reverse osmosis membrane for antibacterial and antifungal activities against selected pathogenic strains: An enhanced eco-friendly water disinfection approach," Journal of Environmental Science and Health, Part A, vol. 49, no. 10, pp. 1125-1133, 2014.

[9] D. Li-Zhen, S. M. Arun, P. Zhongli, K. V. Sriram, X. Jinwen, Z. Magdalena and X. Hong-Wei, "Emerging chemical and physical disinfection technologies of fruits and vegetables: a comprehensive review," Critical Reviews in Food Science and Nutrition, vol. 60, no. 15, pp. 2481-2508, 2020.

[10] Z. S. Ines, F. Patrick, F. S. Ulrich and L. Claus-Michael, "Development and characterization of film forming polymeric solutions for skin drug delivery," European Journal of Pharmaceutics and Biopharmaceutics, vol. 65, no. 1, pp. 111-121, 2007.

[11] H-Y. He, Z. He, Q. Shen, "Eco-friendly synthesis and characterizations of single-wall carbon nanotubes/Ag nanopaticle hybrids for environmental decontamination," Materials Research Express, vol. 6, no. 3, Article 51095445, 2018.

[12] A. F. Alim, D. A. Richard, K. J. Adam, E. O. Laurel, H. L. Charlotte and Y. W. Corrie, "Guide for the selection of biological, chemical, radiological, and nuclear decontamination equipment for emergency first responders," U.S. Department of Homeland Security, 2007.

[13] D. Pulpea, M. Bunea, T. Rotariu, R. Ginghină, G. Toader, A. Moldovan and B. Pulpea, "Review of materials and technologies used for chemical and radiological decontamination," Journal of Military Technology, vol. 2, no. 1, pp. 43-52, 2019.

[14] V. Kumar, R. Goel, R. Chawla, M. Silambarasan, R. K. Sharma, "Chemical, biological, radiological, and nuclear decontamination: Recent trends and future perspective," J Pharm Bioallied Sci., vol. 2, no. 3, pp. 220-238, 2010.

[15] M. Wartell, M. Kleinman and B. Huey, strategies to protect the health of deployed U.S. Forces: force protection and decontamination, Washington (DC): NCBI - National Academies Press (US), 1999.

[16] H. L. Xi, S. P. Zhao, W. Zhou, Advances in peroxide-based decontaminating technologies, Huan Jing Ke Xue, vol. 34, no. 5, pp. 1645-1652, 2013 (Chinese). (from Europe PMC).

[17] S. Dehghani, S.V. Hosseini, J.M. Regenstein, “Edible films and coatings in seafood preservation: A review”, Food Chemistry, vol. 240, pp. 505-513, 2018.

[18] T. S. Parreidt, K. Müller, M. Schmid, "Alginate-based edible films and coatings for food packaging applications," Foods, vol. 7, no. 10, Article 170, 2018.

[19] L. Cai, H. Shi, A. Cao, J. Jia, "Characterization of gelatin/chitosan ploymer films integrated with docosahexaenoic acids fabricated by different methods," Sci Rep, vol. 9, p. 8375, Article 8375, 2019.

[20] N. Azahari, N. Othman and H. Ismail, "biodegradation studies of polyvinyl alcohol/corn starch blend films in solid and solution media," Journal of Physical Science, vol. 22, no. 2, pp. 15-31, 2011.

[21] C. Emo, C. Andrea, D. Salvatore and S. Roberto, "Biodegradation of poly (vinyl alcohol) based materials," Progress in Polymer Science, vol. 28, no. 6, pp. 963-1014, 2003.

[22] M. Bahadoran, A. Shamloo and Y. Nokoorani, "Development of a polyvinyl alcohol/sodium alginate hydrogel-based scaffold incorporating bFGF-encapsulated microspheres for accelerated wound healing," Sci Rep, vol. 10, p. 7342, Article 7342, 2020.

[23] S. Maiti and L. Kumari, "3 - Smart nanopolysaccharides for the delivery of bioactives," in Nanoarchitectonics for Smart Delivery and Drug Targeting, William Andrew Publishing, 2016, pp. 67-94.

[24] A. Bauer, W. Kirby, W. M. Sherris and M. Turck, "Antibiotic susceptibility testing by a standardized single disk method," Am. J. Clin. Pathol, vol. 45, p. 493–496, 1966.

[25] A. M. Florea, T. Iordache, C. Branger, M. Ghiurea, S. Avramescu, G. Hubca and A. Sarbu, "An innovative approach to prepare hypericin molecularly imprinted pearls using a “phyto-template”," Talanta, vol. 148, pp. 37-45, 2016.

[26] C. Lazau, T.-V. Iordache, A.-M. Florea, C. Orha, C. Bandas, A.-L. Radu, A. Sarbu and T. Rotariu, "Towards developing an efficient sensitive element for trinitrotoluene detection: TiO2 thin films functionalized with molecularly imprinted copolymer film," Applied Surface Science, vol. 384, pp. 449-458, 2016.