Ph.D. Theses

Antibacterial activity of reactive hybrid nanocomposite surfaces

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1. Introduction and objectives

Certain semiconductor metal oxides (TiO_2, ZnO, SnO_2) shows photocatalytic properties when exposure to light, therefore can be applied by removal of pollution and pathogen microorganisms in our environment. Nowadays, the titanium dioxide is one of the most investigated photocatalyst and because of its practical applicability it can be used in many research fileds.

Semiconductor metal oxides – such as TiO_2 also– have no negative effect on microorganisms and on human cells, the antibacterial activity is exposed only under illumination.

Free radicals, which are produced during illumination of TiO_2 have sufficiently large oxidation potential to degrade the cell wall of bacteria and thus getting into the cell and they can react organelles. The process of photocatalysis blocks the metabolism and multiplication of bacterial cells, which leads to its total physical and chemical degradation. The above mentioned properties makes photocatalysts suitable to become an important part of health prevention strategy. TiO_2 can be activated only under UV light ($\lambda \leq 388$ nm), which is only 5% of natural sunlight. It is subservient in terms of applicability, that absorption of light must expressed in visible region. For this reason the optical properties of TiO_2 have to be modified. TiO_2 particles can be modified with transition metals as well as with non-metallic materials too. Electrons, which are in the conduction band (via modifying photocatalysts with transition metals) can increase photocatalytic efficiency during trapping process on deposited metals. The photocatalytic effect continue for as long as the photocatalytic layer is excited with activating light. Due to the practical applicability the catalyst particles must be immobilized on surfaces, different organic or inorganic compounds can be functioned as catalyst support material. Using this method mechanically stable reactive surfaces can be created, which can be useful in wastewater treatment or in degradation of compounds or microorganisms. The main objective of my work is to develop and characterize a mechanically stable and antibacterial surface, which is able to inactivate human pathogen bacteria on the surface.

In order to apply the developed surfaces in highly frequented places in terms of infection (health care facilities) different antibiotic resistant and biofilm producing bacteria were tested during the microbiological tests. During investigation of photocatalytic surfaces the types and concentration of photocatalyst particles were systematically varied to increase the antibacterial effectiveness. In the course of immobilization of photocatalyst particles different polymers were used and the effect of the nature of the polymers was examined on photocatalytic effect of developed surfaces. Further important objective of my work was to

optimize the microbiological characterization methods. During the tests methicillin resistant Staphylococcus aureus was used inter alia, which can also occurs often in hospital settings and also can have multi-resistance. Fluorimetric measurements and microscopic examinations were carried out with specific labelling methods to characterize the interaction between bacteria and photocatalysts.

2. Materials and Methods

2.1 Preparation of reactive hybrid nanocomposite films

During my work nanohybrid surfaces were prepared using different hydrophilic and hydrophobic polymers and TiO_2, ZnO photocatalysts. Functionalized photocatalysts were synthesized with photoreduction. Functionalization of photocatalysts with silver was carried out with silver nitrate precursor in each case. Immobilization of photocatalysts were carried out with hydrophobic Epoxi resin (Poly(Bisphenol A-co-epichlorohydrin; Sigma Aldrich, Hungary) and hydrophilic Plextol (poly(ethyl-acrylate-co-methyl-methacrylate; Pannoncolor Kft, Hungary) and hydrophilic Prolak (poly-styrol-co-acrylate; Profec Lc. Kft, Hungary).

2.2 Reagents used for characterization of the antibacterial efficiency

For fluorescence microscopic examinations of cell wall structure stability LIVE/DEAD® BacLight Bacterial Viability kit L7007 fluorescence stain kit (Life Technologies, Hungary) was used, which utilize mixtures of SYTO 9 (1,67mM) green fluorescent nucleic acid stain and the red-fluorescent nucleic acid stain, propidium iodide (1,67mM) dissolved in DMSO. For measurement of concentration of reactive radicals, which are produced during photocatalyst-light interaction and are responsible for antibacterial effect NaOH (1M) solution and luminol (5-amino-1,2,3,4-tetrahydrophtalazine-1,4-dione; Sigma-Aldrich, Hungary) was used. The effect of photocatalysts on bacterial bioluminescence was investigated on *Allovibrio fischerii* (Hach, Hungary). During the investigation decreasing metabolism of the bacteria in 2% NaCl solution was measured with luminometer (Sirius L Single Tube luminometer, Titertek Berthold, Germany).

2.3 Reagents used for microbiological measurements

During microbiological characterization modified MSZ EN ISO 27447:2009 national standard was used, tests were carried out on different bacteria which were international reference strains: *Staphylococcus aureus* ATCC 29523, methicillin resistant *Staphylococcus aureus* ATCC 43300, *Enterococcus faecalis* ATCC 29212, *Escherichia coli* ATCC 29522, , *Pseudomonas aeruginosa* ATCC 27853 and clinical isolates: *Enterococcus faecium*, *Enterobacter cloacae*, *Acinetobacter baumannii*, *Escherichia coli* DH5α. For culturing bacteria BHI-broth (Oxoid, Hampshire, UK) and Mueller-hinton agar (Bio-Rad, Budapest) was used. During microbiological tests and microscopic examinations physiological saline (0.9%) was used as medium of bacteria.

3. Experimental methods

3.1. Synthesis of reactive nanocomposites

Microbiological characterization were carried out with surfaces with ZnO and TiO_2 photocatalyst content. Functionalization of photocatalyst with nano-sized silver was carried out with photoreduction method.

3.2. Determination of optical properties of reactive nanocomposites

Optical properties of photocatalysts were determined with diffuse reflectance spectroscopy. During the tests diffuse reflectance spectra of photocatalysts powders were registered with CHEM 2000 UV-VIS spectrophotometer.

3.3. Measurement of photocatalytic efficiency

Photocatalytic efficiency of nanocomposite films were characterized with photodegradation of ethanol on solid/gas interfaces. The concentration of ethanol in the reactor was analyzed with gas chromatography (Shimadzu GC-14B). During the characterization of photocatalytic efficiency the activating light source was 405 nm emitting LED-light.

3.4. Determination of the concentration of dissociated silver ions

The concentration of Ag^+-ions dissociated from functionalized photocatalysts were determined potentiometric with silver ion selective electrode (Radelkis OP-Ag-0711 P).

3.5. Determination of the concentration of the free radicals

Production of free radicals during photocatalysis can be proved with luminometry, the measurement is based on reaction of luminol and free radicals in alkaline medium. Reactive agents which are produced during photocatalysis react with luminol, it results to blue light, whose light intensity is proportional with produced radicals and can be detected with the luminometer.

3.6. Characterization of mechanical properties of reactive nanocomposites

Investigation of mechanical stability of reactive thin films were carried out according to EN ISO 2409 standard. During the investigations perpendicular scratches were made on the surface of reactive films with Elcometer 107 cross hatch cutter, afterwards adhesive tape was placed to the surface with scratches and unripped in angle of 60°. According to this method as much stable the films are, less material stay on unripped adhesive tape. Reactive films were characterized with spectrophotometry, unripped tapes were fixed on glass samples and absorbance of the films were determined at λ = 450 nm with Ocean Optics spectrophotometer. According to this method as much catalyst stay on the adhesive tape, less light can transmit through the film and more absorbance can be measured which adverts more instability.

3.7. Toxicity tests

Bioluminescence is a light emission of living systems, therefore it is the base many of environmental toxicity tests. Toxicity tests were carried out on different nanocomposite surfaces according to modified ISO 11348-3:2007 national standard. During the tests the changes in bioluminescence of Allovibrio fischeri via photocatalysis was measured with luminometer. The decrease of intensity of emitting light was proportional with the toxicity of reactive nanocomposites.

3.8. Determination of the amount of charge

During the investigation of adhesion of bacteria, the surface charge of bacteria and photocatalysts and the adhesion of bacteria on the surface of the photocatalyst particles was measured with MÜTEK PCD-04 particle charge detector. Streaming potential of the investigated systems was analyzed with titrating oppositely charged tenside solution. Surface charge of investigated systems (bacteria, photocatalysts) can be calculated in the view of the volume of tenside solution, the concentration of the surfactants as well as the known surface charge of surfactants.

3.9. Investigation of the photocatalytic effect on isolated peptidoglycan with transmission electronmicroscope

The effect of visible light activated Ag-TiO_2 on isolated bacterial cell wall component was investigated with Philips CM 10 TEM transmission electronmicroscope in case of *Escherichia coli* and *Staphylococcus aureus* peptidoglycan.

3.10. Determination of antibacterial effect of photocatalysts with flurescence microscope and fluorimetric measurements

Viability of bacteira on the surface of nanocomposites was determined with fluorescence labelling techniques. Fluorescence labelling of bacteria was carried out with Baclight LIVE/DEAD Bacterial Viability L7007 fluorescence stain kit, which includes two dyes with different emission spectrum (SYTO 9 and propidium iodie). SYTO 9 can permeate the cell wall of live and dead bacteria. Propidium iodide can not permeate intact cell wall, but if it is degraded PI can penetrate cell wall and decrease the emission intensity of SYTO 9. When both dyes are present the method is suitable to make visual difference between dead and live bacteria. The bacterial adhesion on surface of photocatalyst aggregates and viability of bacterial cells was observed with Leica DM IL LED FLUO microscope equipped with L5 and N2.1 filter system and phase contrast rings.

3.11. Quantitative measurement of antibacterial effect of reactive nanocomposites with colony count method

Antibacterial effect of photocatalyst/polymer nanocomposite films was measured with modified MSZ EN ISO 27447:2009 standard, method was optimized according to experimental conditions. The initial concentration of bacterial suspension was 1×10^5 - 5×10^5 CFU/ml, respectively, as described in standard. Reactive nanocomposites, which were infected with different human pathogen bacteria, were activated with LED light source, number of colony forming units were counted as the function of time. Decrease of the number of colony forming unit (%) was calculated from the ratio of initial and time-connected number of colony forming units: R/R_0.

New scientific results

1. Reactivity of nanocomposite surfaces

1.1. Photooxidation of ethanol on the surface of nanocomposite films [4]

The mechanical stability and the photocatalytic efficiency of the reactive nanocomposite films were significantly influenced by polymer content. According to mechanical stability and photocatalytic efficiency measurements the optimal ratio of the photocatalyst/polymer in nanocomposite films was obtained at 60/40%.

It was established that the TiO_2 nanocomposites with 0.5% silver content can degrade the highest concentration of the ethanol after 30 minutes (ΔcEtOH = 2.92 mmol/dm^3/g) while for ZnO nanocomposites the sample having 0.25% of silver concentration can degrade the most ethanol after 30 minutes (ΔcEtOH = 2.92 mmol/dm^3/g) under illumination of visible light (λ>400nm).

1.2. Results of producing hydroxyl radicals on the surface of nanocomposite films [3]

Concentration of OH·, which are produced on the surface of nanocomposites shows directly proportional to photocatalyst content and time. After 30 minutes of illumination nanocomposites with Ag-TiO_2 content show the highest concentration of OH· ($c_{OH\bullet}$ = 0.365 mM). With TiO_2 content this value was significantly lower ($c_{OH\bullet}$ = 0.294 mM), lowest values were determined with ZnO and Ag-ZnO content (ZnO: $c_{OH\bullet}$ = 0.151 mM; Ag-ZnO: $c_{OH\bullet}$ = 0.178 mM). It can be clearly seen in case of both photocatalysts (TiO_2, ZnO), that the present of silver nanoparticles on the surface of photocatalyst increases the recombination time of electrons, beside superoxide radicals are produced from electron interaction of hydroxyl radicals, which can play also an important role in increase of surface reactivity (see dissertation, page 30, fig.16.).

2. Determination of toxicity of nanocomposite surfaces with TiO_2 and ZnO content

2.1. Effect of reactive surface on bioluminescence of Allovibrio fischeri [2]

Toxicity of nanocomposite films was determined with measurements of light emission of bioluminescence *Allovibrio fischeri.* Decrease in bacterial bioluminescence was different on

surfaces with different photocatalyst content (TiO_2, Ag-TiO_2, ZnO, Ag-ZnO). After 120 minutes of illumination the intensity of bioluminescence decreased on nanocomposite films with Ag-TiO_2 content 95.86% compared to control (glass sample). In case of dark control decrease was only 29.52%, so it is proved, that the decrease of bioluminescence was because of the photocatalysis on illuminated Ag-TiO_2/polymer nanocomposite films.

Table 1 *Changes in bioluminescence of Allovibrio fischeri after 30 minutes of visible light illumnination on nanocomposite films with different photocatalyst content*

		Polymer content (40 wt%)	Photocatalyst content of nanocomposite films (60 wt%)			
		polymer	**TiO_2**	**Ag-TiO_2**	**ZnO**	**Ag-ZnO**
Bioluminescence decrease (ΔRLU%)	illuminated	7.09	16.03	22.10	54.17	82.96
	dark control	2.50	4.07	10.44	32.91	58.68

When ZnO was used as photocatalyst in nanocomposite films, the bioluminescence was significantly high even in case of dark control. Results can be explained with toxic Zn^{2+} ions, that dissociated from the surface of ZnO during the experiment. Bioluminescence decreased 58.68 % after 30 minutes of contact time in case of dark control (**Table 1.**), so according to results of photocatalytical and microbiological characterization (**Table 2.**) it can be concluded, that these surfaces are the most toxic of investigated nanocomposite films.

Table 2 *Investigation of reactivity of nanocomposites with different photocatalyst content*

Characterisation/photocatalyst content	**polymer**	**TiO_2**	**Ag-TiO_2**	**ZnO**	**Ag-ZnO**
Concentration of OH• produced on nanocomposite films with different photocatalyst content after 30 minutes of contact time (mM; t=30min)	0.043	0.294	0.365	0.151	0.178
Concentration of degraded EtOH on nanocomposites with different photocatalyst content after 30 minutes of contact time ($mM/dm^3/g$)	0.003	1.52	2.92	0.84	1.96
Biolumunescence of live bacteria according to initial bioluminescence on nanocomposites wit different photocatalyst content after 30 minutes of contact time [RLU% =(RLU/RLU_0)×100)]	2.5	4.07	10.44	32.91	58.68
Decrease of CFU on nanocomposites with different photocatalyst content after 30 minutes of illumination time R% = R/R_0	0.55	17.03	88.46	29.43	22.37

2.2. The rule of Ag^+-ions dissociated from nanocomposite films in expression of antibacterial effect [2]

Immersion/dissolution measurements showed that the concentration of Ag^+-ions (aq) dissociated from argentiferous nanocomposite films was 0.14 ppm after a week in distilled water, which is under antibacterial concentration of silver (literature data: 0.22 ppm). Microbiological measurements proved, that silver with above mentioned silver concentration (0.14 ppm) can not cause antibacterial effect, decrease of number of CFU after 120 minutes of illumination was only R_{120}/R_0= 4.74±4.51% compared to initial number of CFU (0 min).

3. Photodestructive effect of silver functionalized TiO_2 on isolated peptidoglycan of Gram-positive and Gram-negative bacteria [3]

Photocatalytic effect of photocatalysts was investigated on peptidoglycan layer (murein), which has the most important role to stabilize bacterial cell wall structure. New method was established to investigate the photocatalytic effect on isolated peptidoglycan (sacculus) structure. Tests were carried out on isolated peptidoglycan of *Escherichia coli* (Gram-negative) and *Staphylococcus aureus* (Gram-pozitive). Photocatalytic degradation due to Ag-TiO_2 was observed on the isolated bacterial cell wall component with transmission electronmicroscope after 60 and 120 minutes of illumination with 13500x magnification. Measurements proved, that free radicals, that are produced under the process of photocatalysis can degrade significantly peptidoglycan (major cell wall protection system) after 60 minutes of illumination in case of both investigated strains. It was also found, that in case of *Escherichia coli* saccule degradation effect was stronger, because of the thinner peptidoglycan layer of this Gram-negative bacteria.

4. The role of surface adhesion of bacteria in expression of antibacterial effect

4.1. Quantitative characterization of adhesion conditions [1]

Electrostatic interactions between photocatalysts and bacteria was – published firstly – investigated with surface charge titration method in case of *Escherichia coli*, *Pseudomonas aeruginosa* and methicillin resistant *Staphylococcus aureus* (**Table 3.**). Results clearly showed, that the bacteria are negatively charged and the following values were obtained in case of *Escherichia coli* the amount of surface charge was -1.33 μeq/10^9 CFU, for

Pseudomonas aeruginosa the amount of surface charge was -3.19 μeq/10^9 CFU and in case of methicillin resistant *Staphylococcus aureus* the amount of surface charge was -0.89 μeq/10^9 CFU (**Table 3**). The negative charge of bacteria is compensated by TiO_2 particles with +0.123 meq/g equivalent charge. For this reason bacterial cells can be completely enveloped by TiO_2 particles.

Table 3. *Surface charge of bacteria titrated with HDPCl surfactant and TiO_2 photocatalyst*

	HDPCl	**TiO_2**
Bacteria (10^9 CFU)	μeq/10^9 CFU	g TiO_2 / 10^9 CFU
Escherichia coli (Gram-negative)	-1.33	0.65
Pseudomonas aeruginosa (Gram- negative)	-3.19	2.07
methicillin resistant *Staphylococcus aureus* (Gram-positive)	-0.89	2.47

It was established, that the aggregation on cell wall as well as the specific cell wall structure of methicillin resistant *Staphylococcus aureus* play an important role in the interaction between photocatalysts and bacteria besides the electrostatic attraction. TiO_2 particles are connected stronger in case of Gram-positive bacteria than in case of Gram-negative bacteria, because of the location of peptidoglycan structure. For Gram-negative bacteria the destructive effect of TiO_2 particles and free radicals produced on their surface is expressed not directly to peptidoglycan layer, in this case only a thin polysaccharide layer can pretend the cell from external effects. Gram-positive bacteria can be pretended with outer thick peptidoglycan layer from external effects.

4.2. The effect of surface reactivity to the structure of the bacterial cell wall [1]

Antibacterial effect of reactive surfaces was proved with fluorescence labelling techniques. Based on this method live and dead bacteria can be visually separated. Results were evaluated with calculating the emission decrease of SYTO 9 dye (connected to live bacteria). In case of *Pseudomonas aeruginosa* at the initial point of microscopical observations damaged membrane can be seen strongly attached to the surface of Ag-TiO_2 photocatalyst aggregates, these results are in accordance with results of surface charge measurements. Decrease of fluorescence emission was 81.36% in case of *Escherichia coli.* Similar results were found for *Pseudomonas aeruginosa* (85.65%) and methicillin resistant *Staphylococcus aureus* (89.5%). These results are in accordance with microbiological measurments, where the most sensitive

strain to Ag-TiO_2 induced photocatalysis was methicillin methicillin resistant *Staphylococcus aureus* (R_{60}/R_0 = 42.83%). Above mentioned measurements revealed that results of different types of methods are compatible, results are consistent.

Table 4 *Chemical and microbiological characterization of nanocomposite films (photocatalyst/polymer content: 60wt%:40wt%) with different photocatalyst content*

Photocatalysts		**polymer**	**TiO_2**	**Ag-TiO_2**	**ZnO**	**Ag-ZnO**
Ethanol degradation ($mM_{ethanol}/dm^3/g_{\ photocatalyst}$)		0.00	1.51	2.92	0.84	1.96
Toxicity [$(RLU/RLU_0)\times100$)]		7.90	10.62	29.52	89.94	95.85
Antibacterial effect (R/R_0) t = 120 min	p(EA-co-MMA) $_{hydrophilic}$	17.41	98.65	99.99	97.10	86.23
	poly(styrol-co-acrylate) $_{hydrophilic}$	74.88	99.99	100.00	94.00	99.80
	poly(Bisphenol A-co-epichlorhidrin) $_{hydrophobic}$	89.83	99.53	99.86	100.00	100.00

5. Comparative investigation of antibacterial effect of nanocomposite films [3]

Results of microbiological measurements showed, that nanocomposite films with different photocatalyst content (TiO_2, Ag-TiO_2, ZnO and Ag-ZnO photocatalysts embedded in polymer matrix) have different degree of antibacterial effect in short-time comparative experiments.
Nanocomposites with hydrophilic Plextol polymer content showed the lowest toxicity from investigated polymers (R_{120}/R_0 = 17.4 %), among these are those nanocomposites, that contain Ag-TiO_2 photocatalyst (R_{120}/R_0 = 99.99 %) (**Table 4.**).
In case of hydrophobic Epoxi resin and hydrophilic Prolak pure polymer films the bacterial concentration on surface decreases even in dark control measurements (R/R_0 = 74.88 – 89.83 %), so these surfaces are not suitable to prove the photocatalysis induced antibacterial effect of photocatalysts embedded in polymer matrix, because these polymers has antibacterial effect without photocatalyst particles too. When ZnO photocatalyst was used in nanocomposite films the antibacterial effect is made up of additive effects, the toxicity of polymers and the toxicity of Zn^{2+}-ions (**Table 4.**).

Results showed that the antibacterial effect of Ag-ZnO was lower than ZnO when Plextol polymer was used. It proves, that in this case toxic Zn^{2+} ions played the main role to express antibacterial effect and not the process of photocatalysis. The developed nanocomposite films showed sufficient antibacterial effect, these surfaces are mechanically stable and non-harmful for the environment, so they can be a part of prevention strategy in the health care.

6. Application of nanocomposite films in health care

6.1. Application of dispersion paint with nanocomposites content

Nanocomposites with silver content were successfully applied in a separated room of the Department of Pediatrics Newborn at University of Szeged, where the walls was treated with dispersion paint containing Ag-TiO_2 (patent number: P1200745). After 0, 24 and 48 hours contact time the antibacterial effect was measured and the results were evaluated with colony count method. During pre-experiments the antibacterial effect of reactive surfaces (surface concentration of photocatalyst: 0.25 mg/cm^2-1 mg/cm^2) was tested according to modified standard ISO 27447:2009 against extended spectrum beta-lactamase producing *Enterobacter cloacae* (clinical isolate from Department of Pediatrics Newborn) and against methicillin resistant *Staphylococcus aureus*. Results showed satisfactory reduction of CFU after 120 minutes of contact time on the surface with 60wt% and 80wt% photocatalyst content, so considering mechanical stability values the separated room was treated with nanocomposite with 60 wt% photocatalyst content. At the end of the experiment initial CFU values decreased 99.9 % after 48 hours of contact time, according to control surfaces (wall painted only with dispersion paint). It can be concluded that, the reactive surfaces were able to inactivate microorganisms on the wall in a health care facility after 48 hours of contact time. Results were published in Global Medical Discovery, which is one of the leader medical journal in the world with themes of medical researches.

6.2. Application of reactive surfaces in air cleaning systems

Silver-functionalized photocatalyst surface was successfully applied under laboratory conditions for air cleaning as an inner layer in a reactive lamp (constructed by General Electric Hungary Kft.; patent number: US 2013/00942204). Beside the normal function, the reactive lamp can inactivate airborne microorganisms after 24 and 48 hours of contact time under illumination of the inner LED-lamp, thus ensuring a continuous air cleaning. During laboratory tests CFU reduction was measured connected to different contact times: R_{24h} = 74 ± 2.45 %; R_{48h} = 98 ± 1.9 %.

Publications:

Papers related to the dissertation:

[1.] **Szabolcs Péter Tallósy**, László Janovák, Elisabeth Nagy, Ágota Deák, Ádám Juhász, Edit Csapó, Norbert Buzás, Imre Dékány: Adhesion and inactivation of Gram-negative and Gram-positive bacteria on photoreactive TiO_2/polymer and Ag-TiO_2/polymer nanohybrid films. Applied Surface Science 371:139-150 (2016) (**IF: 2.711)**

[2.] **Szabolcs Péter Tallósy** , László Janovák, Judit Ménesi, Elizabeth Nagy, Ádám Juhász, László Balázs, István Deme, Norbert Buzás, Imre Dékány: Investigation of the antibacterial effects of silver-modified TiO_2 and ZnO plasmonic photocatalysts embedded in polymer thin films. Environmental Science and Pollution Research 21:1155-1167 (2014) **(IF=2.83)**

[3.] **Szabolcs Péter Tallósy**, László Janovák, Judit Ménesi, Elisabeth Nagy, Ádám Juhász and Imre Dékány: LED-light activated antibacterial surfaces using silver-modified TiO_2 embedded in polymer matrix. Journal of Advanced Oxidation Technologies 17:9-16 (2014) **(IF = 0.99)**

[4.] Ágnes Veres, László Janovák, Tamás Bujdosó, Tamás Rica, Eleonóra Fodor, **Szabolcs Péter Tallósy**, Norbert Buzás, Elisabeth Nagy, Imre Dékány: Silver and Phosphate Functionalized Reactive TiO_2/Polymer Composite Films for Destructions of Resistant Bacteria Using Visible Light. Journal of Advanced Oxidation Technologies, 15:205-216 (2012) **(IF = 0.99)**

Σ_{IF} = 7.521

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[5.] Ágota Deák, László László Janovák, **Szabolcs Péter Tallósy**, Tamás Bitó, Dániel Sebők, Norbert Buzás, István Pálinkó, Imre Dékány. Spherical LDH-Ag°-montmorillonite heterocoagulated system with a pH-dependent sol-gel structure for controlled accessibility of AgNPs immobilized on the clay lamellae. Langmuir. 31:2019-2027 (2015) (**IF=4.457**)

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[7.] **Szabolcs Péter Tallósy**, László Janovák, Judit Ménesi, Elisabeth Nagy, Ádám Juhász, László Balázs, István Deme, Norbert Buzás, Imre Dékány. Investigation of the antibacterial effects of silver-modified TiO_2 and ZnO plasmonic photocatalysts embedded in polymer thin films. Global Medical Discovery https://globalmedicaldiscovery.com/key-scientific-articles/investigation-antibacterial-effects-silver-modified-tio2-zno-plasmonic-photocatalysts-embedded-polymer-thin-films/

[8.] Dékány Imre, Janovák László, Nagy Erzsébet, Buzás Norbert, **Tallósy Szabolcs Péter**: A napenergia hasznosítása; A környezetre veszélyes anyagok lebontása egészségünk védelme céljából – Innovatív megoldások a vegyszermentes fertőtlenítés területén; Magyar Tudomány 10:1181-1188 (2013)

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Σ_{IF} = 12.712

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1. **Tallósy Szabolcs Péter**: Reaktív hibrid nanokompozit felületek antibakteriális hatásának vizsgálata; MTA kolloidkémiai munkabizottsági ülés 2014.május 23. Velence (**lecture**)

2. **Tallósy Szabolcs Péter**: Reaktív hibrid nanokompozit felületek antibakteriális hatásának vizsgálata; Anyagtudományi előadássorozat, Szegedi Akadémiai Bizottság Székháza 2014. április 1. (**lecture**)

3. **Tallósy Szabolcs Péter**: Fény hatására aktiválható nanohibrid kompozitok antibakteriális hatása; az MTA Szegedi Területi Bizottság által szervezett „A nanotechnológia alkalmazási lehetősége a környezet- és egészségiparban című" rendezvénye; Szeged, 2012. november 22. (**lecture**)

4. Dékány Imre, **Tallósy Szabolcs Péter**: Reaktív hibrid nano kompozit felületek öntisztuló és antibakteriális hatása; II. Nano fórum, Budapest, Kutatás-Fejlesztés-Innováció-Alkalmazástechnika BKIK Kézműipari Tagozat IX. Épülettisztító Szabadegyetem 2013. április 17. (**lecture**)

5. László Janovák, **Szabolcs Péter Tallósy**, Norbert Buzás, Imre Dékány. Intelligent drug releasing system for the treatment of female genital infection. Scientific meeting organized by the Reproductive Health Group, Szeged Committee of Hungarian Academy of Sciences; Szeged, 2013. november 28. (**lecture**)

6. **Szabolcs Péter Tallósy**, László Janovák, Norbert Buzás, Imre Dékány. Antifungal properties of silver and copper nanoparticles against Candida albicans. Scientific meeting organized by the Reproductive Health Group, Szeged Committee of Hungarian Academy of Sciences; Szeged, 2013. november 28. (**lecture**)

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7. Ádám Juhász, **Szabolcs Péter Tallósy**, Ágnes Veres, László Janovák, Norbert Buzás, Imre Dékány. Adhesion and Inactivation of G(+) and G(-) Bacteria on Photocatalyst/ Polymer Hybrid Surfaces. The 3rd International Conference on Photocatalytic and Advanced Oxidation Technologies for the Treatment of Water, Air, Soil and Surfaces 2015.szeptember 1-4. (**poster**)

8. László Janovák, **Szabolcs Péter Tallósy** , Ágnes Veres , Ádám Juhász , Norbert Buzás, Imre Dékány. Development of Photocatalyst Particle Containing Polymer Hybrid Films for the Inactivation of Bacteria by Visible Light; The 3rd International Conference on Photocatalytic and Advanced Oxidation Technologies for the Treatment of Water, Air, Soil and Surfaces 2015.szeptember 1-4. (**poster**)

9. **Szabolcs Péter Tallósy**, Elisabeth Nagy, Eleonóra Fodor, László Janovák, Judit Ménesi, Norbert Buzás, Imre Dékány: Antimicrobial activity of plasmonic photocatalysts in polymer nanohybrid layers against nosocomial pathogens Workshop „Functionalized Surfaces and Nanoboicomposites, Joint meeting of WG2 – WG4, COST action CM1101-Szeged-2013; (**poster**)

10. László Janovák, **Szabolcs Péter Tallósy**, Norbert Buzás, Imre Dékány: Antibacterial and antifungal effect of pH- sensitive hydrogels with embedded nanoparticles; Workshop „Functionalized Surfaces and Nanoboicomposites, Joint meeting of WG2 – WG4, COST action CM1101-Szeged-2013; (**poster**)

11. **Szabolcs Péter Tallósy**, László Janovák, Judit Ménesi, József Sóki, Elisabeth Nagy, Norbert Buzás, Ádám Juhász, Imre Dékány: Investigation of antibacterial effect of non-harmful, visible-light-activated photocatalysts; 113th General Meeting, American Society for Microbiology, May 18-21, 2013, Denver, Colorado (**poster**)

12. Janovák László, **Tallósy Szabolcs Péter**, Bitó Tamás, Buzás Norbert, Bártfai György, Dékány Imre: Hidrogél nanokompozit alapú hatóanyag leadó rendszerek antifungális hatása A „Nők Egészsége, Családok Egészsége- Védőnők és Orvosok az Egészségesebb Európai Polgárokért" Konferencia, Szeged, 2013. március 22. (**poster**)

13. **Szabolcs Péter Tallósy**, László Janovák, Elisabeth Nagy, Norbert Buzás, Ádám Juhász, Imre Dékány, László Balázs, István Deme: Antimicrobial effect of silver functionalized TiO_2 coated lamp surface in indoor air sample using LED light sources; 5th Szeged International Workshop on Advences in Nanoscience, 24-27, October, 2012, Szeged (**poster**)

14. **Szabolcs Péter Tallósy**, László Janovák, Elisabeth Nagy, Norbert Buzás, Ádám Juhász, Imre Dékány, László Balázs, István Deme: Silver functionalized TiO_2 coated lamp activated with LED light source has an antimicrobial effect in indoor air sample; A Magyar Mikrobiológiai Társaság 2012. évi Nagygyűlése, 2012. október 24-26., Keszthely (**poster**)

15. Sóki József, **Tallósy Szabolcs Péter**, Nagy Erzsébet, Janovák László, Dékány Imre: Ezüsttel funkcionalizált TiO_2 nano partikulumok hatása DNS-re; A Magyar Mikrobiológiai Társaság 2012. évi Nagygyűlése, 2012. október 24-26., Keszthely (**poster**)

16. **Szabolcs Péter Tallósy**, László Janovák, Judit Ménesi, Elisabeth Nagy, Norbert Buzás, Ádám Juhász, Imre Dékány; Antimicrobial activity of plasmonic photocatalysts in polymer nanohybrid layers against nosocomial pathogens; 3rd European Symposium on Photocatalysis 2013 szeptember 25 – 27. Portoroz (**poster**)

17. **Szabolcs Péter Tallósy**, László Janovák, Judit Ménesi, Elisabeth Nagy, Norbert Buzás, Ádám Juhász, Imre Dékány; Adhesion and inactivation of Gram-positive and Gram-negative bacteria on different photocatalysts; 8^{th} European Meeting On Solar Chemistry and Photocatalysis: Environmental Application 2014.06.24-28. Greece; Thessaloniki (**poster**)

Patents:

18. Imre Dékány, Norbert Buzás, László Janovák, Ádám Juhász, **Szabolcs Péter Tallósy;** *Eljárás antibakteriális festékrétegek felvitelére különböző falfelületeken* Magyar Szabadalom, bejelentés ideje: 2012., Registration number: **P1200745**

19. Dániel Sebők, **Szabolcs Péter Tallósy**, László Janovák, Imre Dékány, Antal Mészáros, Béla Onderó: *Eljárás baktériumok helyszíni detektálására, valamint eljárás antibakteriális anyag hatékonyságának kimutatására helyben izolált baktériumok detektálásával* Magyar Szabadalom, bejelentés ideje: 2016., Registration number: **P1600068**