Doctoral (Ph.D.) theses

Synthesis and characterization of functional composite systems and their application possibilities

Ágota Imre-Deák

Chemist

Supervisor

László Janovák, Ph.D.

Assistant Professor

Doctoral School of Chemistry

University of Szeged

Faculty of Science and Informatics

Department of Physical Chemistry and Materials Science

Szeged

2019

1. Introduction and objectives

Composite materials are playing an increasingly important role, due to the fact that composite materials created by the combination of components often have better properties than systems based on pure components.

Composite materials can be prepared by combining two or more materials, where the disperse phase is distributed in a continuous matrix. The use of composites is extremely wide, many industries - e.g. automotive, construction, electrical, electronic and pharmaceutical industries - deal with manufacturing and development of composites and they can also be used in other areas such as sports tools or renewable energy (wind power).

The main motivation of my research was to synthesize various functional composite materials and their components, as well as to characterize their material structure. Furthermore, my purpose was also to establish advantageous material properties of the hybrid materials formed by combining the obtained components and to demonstrate the various applications of the composites (e.g. medical/biomedical encapsulation, controlled release, self-cleaning surfaces, etc.).

The continuous phase of the composite materials was provided by polyacrylates with different hydrophilicity and for filler materials I used layered double hydroxide (LDH), layered double oxide (LDO), clay mineral (montmorillonite), and hydroxyapatite (HAp) with lamellar structure. My aim was to synthesize LDH lamellae with high specific surface area, surface charge density and anion exchange capacity, which may be suitable for the formation of drug carrier nanocomposite by drug intercalation into the pillars.

By modifying the synthesis conditions, my aim was to synthesize and characterize spherical LDH with new material structure properties besides the traditional lamellar LDH. My objective was also to verify whether the LDO filler with photocatalytic properties obtained by calcination of spherical LDH is suitable for the synthesis of composite thin films having photocatalytic and antibacterial properties.

Finally, composite layers were produced to achieve enhanced photocatalytic efficiency. Using the biocompatible and lamellar HAp filler, I designed TiO_2-containing polyacrylate-based composite coatings in which the photo-oxidation of the organic polymer matrix can be suppressed with the increased photocatalytic efficiency of the HAp component.

2. Composites and methods

During my doctoral work I have synthesized composites with different applications by using LDH, LDO, montmorillonite, HAp inorganic and acrylate based polymer components. Figure 1 summarizes the components and composites formed during my work, as well as a list of possible applications.

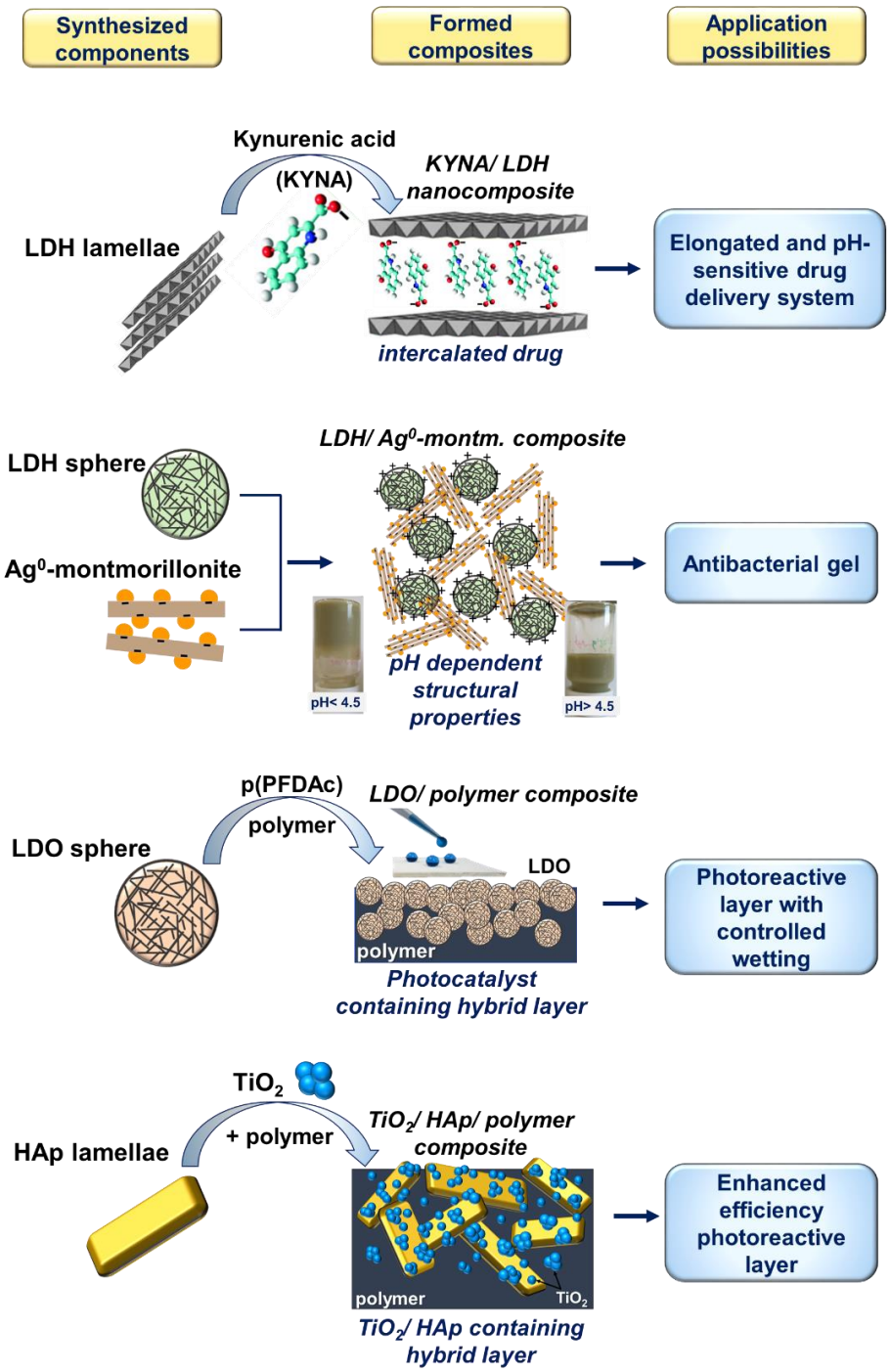

Figure 1. Scheme representing the components and the prepared composites, indicating the possible applications.

During the experimental work I characterized the produced systems by using the following measurement techniques and methods:

- X-ray powder diffraction (XRD, Bruker D8),
- Small angle X-ray scattering (SAXS, Philips PW 1820 X-ray tube, KCEC/3 Kratky Camera and PDS 50M detector),
- Fourier-Transformed Infrared Spectroscopy (FT-IR, BIO-RAD Digilab Division FTS-65A/896 and BIO-RAD Digilab Division FTS-40),
- Scanning Electron Microscopy (SEM, Hitachi S-4700 and Jeol FEG-SEM 7600F),
- Energy Dispersive X-ray Spectroscopy (EDS, Hitachi S-4700),
- Transmission Electron Microscopy (TEM, FEI Tecnai G2 20 X-Twin),
- UV-Visible Spectrophotometry (Ocean Optics UV-VIS USB4000),
- Thermoanalitical methods (Mettler-Toledo TGA/SDTA 851^{e}),
- Rheology (Anton Paar Physica MCR 301).

Other instruments used:

- Mütek PCD 02, particle charge detector,
- Micromeritics Gemini 2375, surface area analyzer,
- Dektak 8 (Veeco), profilometer,
- Easy Drop Krüss GmbH, drop shape analysis system,
- Gas Chromatograph (Shimadzu GC-14B),
- SiriusL Single Tube luminometer (Titertek Berthold, Germany),
- Infinite $200^{®}$ PRO, Tecan Austria GmbH, microplate reader.

3. New scientific results

T1. Synthesis and structure analysis of a layered double hydroxide (LDH)-based neuroactive kynurenic acid (KYNA)-containing composite system (LDH/KYNA) with pH-dependent solubility properties and its drug release study under gastrointestinal conditions.

T 1.1. As a new scientific result, 2:1 Mg/Al double hydroxide (2:1 Mg/Al-LDH) was successfully synthesized by co-precipitation method with high specific surface area (114.96 ± 0.48 m^2/g) and positive specific surface charge (+641 mmol/ 100 g). Anti-ulcerant kynurenic acid molecules were intercalated between the layers to obtain a KYNA/ LDH intercalation nanocomposite. By XRD and FT-IR measurements I proved that the intercalated KYNA molecules exhibit a paraffin-like monolayer arrangement within the layer. It was found that the amount of interlayer KYNA was 12-14 wt.%, which was in good agreement with the theoretically calculated KYNA content of the composite (12 wt.%).

T 1.2. Due to their chemical composition, the layered double hydroxides exhibited pH-dependent solubility and significantly higher solubility under acidic conditions. It was shown that the KYNA/ LDH composite system was appropriate for pH-dependent drug release under *in vitro* conditions. It was demonstrated by gravimetric and XRD measurements, that the prepared 2:1 Mg/Al-LDH was almost completely dissolved (in 6 hours) in the applied simulated gastric fluid media at pH= 1.5. The released kynurenic acid from the KYNA/ LDH nanohybrid system revealed a delayed release profile ($k= 1.49 \times 10^{-5}$ s^{-1}; $t_{1/2}$= 12.9 hours) compared to free KYNA ($k= 5.91 \times 10^{-5}$ s^{-1}; $t_{1/2}$ = 3.3 hours). Significant drug retention was observed, only 18 % of kynurenic acid was released from the KYNA/ LDH nanohybrid system after 4 hours. In contrast, release of free kynurenic acid at pH 6.70 showed concentration-dependent first order kinetics ($k = 4.75 \times 10^{-5}$ s^{-1}; R^2 = 0.9955; $t_{1/2}$ = 4.1 hours). The kinetics of the release of the drug at pH 1.50 were characterized by the Higuchi model, which described a diffusion-controlled process.

T2. Synthesis and characterization of spherical LDH and investigation of its structuring properties with Ag^0-montmorillonite by heterocoagulation. Verifying the antibacterial properties of the composite.

T 2.1. By adjusting the ratio of precursors ([Zn + Mg]:Al molar ratio 2:1 and Zn:Mg molar ratio 1:8) in the presence of urea at pH= 3, ZnMgAl-layered double hydroxide particles were synthesized with spherical morphology, over one week aging period.

I have shown that in the case of LDH spheres with a diameter of 25.31 ± 2.34 μm, the radial arrangement of the "conventional" LDH lamellas resulted in spherical structure. The obtained LDH spheres possessed high degree of crystallinity, structured (rough) surface and low specific surface area (14.75 m^2/g), which refered to a compact inner structure. It was established that the surface charge of spherical LDH showed pH-dependent properties. At low pH values (pH< 4) it has positive surface charge, while at higher pH values (pH> 4) it loses its positive charge. Spherical LDH has a high specific surface charge at pH= 3 (+273 mmol/ 100 g) which decreases at higher pH values.

T 2.2. Utilizing the special pH-dependent surface charge of LDH, a two-component LDH/ Ag^0-montmorillonite (= 25/75 wt.%) system was synthesized which formed a coherent gel at pH <4.5 and incoherent sol at pH> 4.5. Based on rheological (τ_B) and SAXS (Dimm; Dims; Kp) parameters, it was demonstrated that at low pH (pH <4.5), LDH spheres with a positive surface charge created electrostatic interactions with negatively charged Ag^0-montmorillonite forming a compact, shape-retaining gel structure (τ_B = 9.90 Pa). When the pH was raised (pH> 4.5), this gel structure disintegrated and acted as an incoherent sol of the LDH/ Ag^0-montmorillonite composite, which was explained by the loss of LDH particle charge.

T 2.3. The presence of 21.9 ± 2.9 nm AgNPs on montmorillonite clay lamellae was confirmed by spectrophotometric measurements and transmission electron microscopy. It was shown that by the disintegration of the coherent structure, the accessibility of the immobilized AgNPs on the surface of Ag^0-montmorillonite significantly increased and thus the sample had antibacterial properties. Based on the results, the Ag^0-montmorillonite composite was able to inactivate the bacterial film formed by *Escherichia coli* test bacteria (1.79×10^6 CFU/cm^2) even at low concentrations (30 μl of 25 ppm Ag^0-mont. suspension).

T3. Synthesis of ZnMgAl-layered double oxide (LDO) particles and their structural, morphological and optical properties.

T 3.1. I proved that the heat treatment of spherical LDH containing 12 wt.% Zn at 600 °C modifies the structure of LDH, the initial reflections disappeared 2Θ= 11.63º (003) and 23.4º (006) and new reflections appeared due to the formation of oxide phases. Bragg reflection (200) at angle of 2Θ= 43.60, indicateed the formation of MgO (Mg (Al) O) in the LDO structure, and 2Θ= 32.02°; 36.28° and 56.67° provided information of the presence of Bragg reflections (100), (101) and (110) typical of ZnO. The specific surface area (14.75 m^2/g) of the produced layered double oxide (LDO) increased slightly compared to the initial LDH (12.84 m^2/g).

T 3.2. Using a calcination method carried out at 600 °C, it was presented that the morphology of spherical LDH remained unchanged, the initial LDH structure did not collapse by the heat treatment. The surface of the obtained LDO particles remained structured both at micro and nano levels. Due to the ZnO content of LDO, UV-excited rough surface oxide particles were produced. The band gap energy of the LDO particles was determined by Kubelka-Munk method and the obtained E_g was 3.2 eV, which corresponds to the literature value of pure ZnO.

T4. Synthesis of self-cleaning LDO/ p(PFDAc) composite thin films and verifying their photocatalytic and superhydrophobic properties.

T 4.1. LDO particles are suitable for the preparation of photoreactive composite thin films with special wetting properties due to its specific morphology and photocatalytic properties. The surface immobilization of the particles was ensured by poly-perfluorodecyl acrylate p(PFDAc) polymer and it was confirmed that the photocatalytic efficiency can be increased by increasing the proportion of the photocatalyst in the layer. As an effect of 80 wt.% LDO content in the composite film (A = 25 cm^2), the concentration of the initial 0.17 g/L benzoic acid test molecule (in aqueous solution) was reduced by 24% during 240 min photocatalytic measurements.

T 4.2. I proved that the roughness of the films can be controlled by changing the ratio of LDO/ p(PFDAc) in the hybrid layers. The obtained roughness on the initial flat fluoropolymer film was R_q = 0.002 ± 0.0002 μm which value could be increased up to 15.30 ± 2.04 μm with increasing LDO content. Profilometric and AFM measurements showed that LDO/ p(PFDAc) composite

films acquired micro- and nano-roughness (R_q= 15.30 μm / profilometriy/; R_q= 38.4 nm /AFM/). The increasing roughness and structured surface of the layers was also evident in the electron microscopic images. The change in the apparent surface free energy values (determined by Drelich method) with increasing LDO particle content was also demonstrated. The surface free energy of the initial fluoropolymer (0 wt.% LDO content) γ_s^{tot}= 28.0 ± 3.91 mJ/ m^2 was reduced to γ_s^{tot}= 2.7 ± 0.65 mJ/m^2 when the LDO content was increased to 80 wt.%.

T 4.3. I have shown that by changing the surface roughness of LDO/ p(PFDAc) composites, the wetting properties of the layers can be controlled. The obtained contact angle of the initial flat surface fluoropolymer layer was Θ_w= 105.6° ± 0.76° which could be increased with increasing particle content. In the case of 80 and 90 wt.% of LDO containing polymer layers, superhydrophobic surface was obtained and the measured contact angles were 156.3° ± 1.88° and 157.1° ± 1.53°, respectively.

T 4.4. In case of *Staphylococcus aureus*, *Escherichia coli* and *Pseudomonas aeruginosa* bacteria, I proved that the wetting and morphological properties of the surfaces significantly influenced the strength of microbiological interactions and the extent of bacterial adhesion. With the increasing content of LDO particles (from 20 wt.% to 80 wt.%), the bacterial adhesion was also increased (OD_{620} = 0.2 to 1.54) based on the crystal violet staining process. SEM measurements also showed that bacteria with a size of 0.6-2 μm are located on the surface of hydrophilic LDO lamellae in the two-component layers, *i.e.* the bacteria were preferably ~~to~~ adhered on hydrophilic, high energy surface instead of the hydrophobic fluoropolymer. I presented that during the irradiation, the formed free radicals could inactivate the adhered bacteria. After 120 minutes of illumination time, the number of damaged bacteria cells were growing with 46%.

T5. Enhancing the durability of polymer-based composite layers with inorganic biocompatible HAp additive. Photocatalytic properties of TiO_2/ HAp/ p(EA-co-MMA) polymer composites and the synergistic effect of HAp lamellae in TiO_2/ p(EA-co-MMA) based thin films.

T 5.1. It was presented that the biocompatible and lamellar hydroxyapatite (HAp) with 116 m^2/g specific surface area, was suitable for immobilizing TiO_2 nanoparticles on their surface. A synergistic effect in case of TiO_2/ HAp composites, produced by precipitation method, was observed in the specific surface values. The obtained specific surface area of the 40/60 TiO_2/ HAp composite was 122 m^2/g, which was in good agreement with the specific surface area calculated from Small Angle X-ray Scattering (SAXS) (141 m^2/g) measurements.
Based on the photocatalytic measurements, the photocatalytic efficiency was higher in the case of 36 wt.% (5.61 mM EtOH/ g TiO_2) and 12 wt.% (4.26 mM EtOH/ g TiO_2) TiO_2 containing TiO_2/ HAp/ p(EA-co-MMA) thin films compared with HAp-free and 60 wt.% containing TiO_2 photocatalyst (4.04 mM EtOH/ g TiO_2). This synergistic effect was due to the HAp content in the composite, which provided higher dispersion and higher surface accessibility of the photocatalyst particles. This resulted higher photocatalytic efficiency with less photocatalyst content.

T 5.3. After 120 hours of illumination with LED-light source (λ_{max} = 405 nm), in the presence of HAp lamellae [36% TiO_2/ 24% HAp/ 40% p(EA-co-MMA)] the composite layer degradation of the polymer was only 15%, whereas the self-degradation of the polymer in composites without HAp lamellae [60% TiO_2/ 40% p(EA-co-MMA)] was 35%. Thus, I have demonstrated that lamellar HAp can serve as a suitable component to suppress photodegradation of photocatalyst/ polymer thin films as an inert "spacer" between the photocatalyst particles and the binder polymer matrix.

4. List of publications

Hungarian Scientific Bibliography (MTMT) identifier: 10055142
ORCID identifier: 0000-0002-6781-1727

Publications related to the scientific topic of the dissertation:

1. **Ágota Deák**, L. Janovák, SP. Tallósy, T. Bitó, D. Sebők, N. Buzás, I. Pálinkó, I. Dékány.
   Spherical LDH−Ag^0-montmorillonite heterocoagulated system with pH-dependent sol-gel structure for controlled accessibility of AgNPs immobilised on the clay lamellae.
   Langmuir 31:(6) (**2015**) 2019-2027.
   (IF_{2015}= 3.993)

2. **Ágota Deák**, L. Janovák, E. Csapó, D. Ungor, I. Pálinkó, S. Puskás, T. Ördög, T. Ricza, I. *Dékány*. *Layered double oxide (LDO) particle containing photoreactive hybrid layers with tunable superhydrophobic and photocatalytic properties*.
   Applied Surface Science 389 (**2016**) 294-302.
   (IF_{2016}= 3.387)

3. L. Janovák, **Ágota Deák**, Sz. P. Tallósy, D. Sebők, E. Csapó, K. Bohinc, A. Abram, I. Palinko, *I. Dékány*. *Hydroxyapatite-enhanced structural, photocatalytic and antibacterial properties of photoreactive TiO_2/HAp/polyacrylate hybrid thin films.*
   Surface and Coatings Technology, 326 (**2017**) 316-326.
   (IF_{2017}= 2.906)

4. **Ágota Deák**, E. Csapó, Á. Juhász, I. Dékány, L. Janovák.
   Anti-ulcerant kynurenic acid molecules intercalated Mg/Al-layered double hydroxide and its release study.
   Applied Clay Science 156 (**2018**) 28-35.
   (IF_{2017}= 3.641)

5. **Ágota Deák**, L. Janovák, Sz. P. Tallósy, K. Godič-Torkar, A. Abram, I. Dékány, K. Bohinc.
   Controlled adhesion and inactivation of nosocomial bacteria on photoreactive composite coating with designed wetting properties.
   International Journal of Antimicrobial Agents (**2019**) *submitted to journal*

Σ IF = **13.927**

List of other publications:

1. L. Janovák, Sz. P. Tallósy, M. Sztakó, **Á. Deák**, T. Bitó, N. Buzás, Gy. Bártfai, I. Dékány. *Synthesis of pH-sensitive copolymer thin solid films embedded with silver nanoparticles for controlled release and their fungicide properties*. **Journal of Drug Delivery Science and Technology** 24:(6) (**2014**) 628-636. (IF_{2014}= 0.476)
2. Sz. P. Tallósy, L. Janovák, E. Nagy, **Á. Deák**, Á. Juhász, E. Csapó, N. Buzás, I. 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 (**2016**) 139-150. (IF_{2016}= 3.387)
3. A. Györgyey, L. Janovák, A. Adam, J. Kopniczky, K. L. Toth, **Á. Deák**, I. Panayotov, F. Cuisinier, I. Dékány, K. Turzó. *Investigation of the in vitro photocatalytic antibacterial activity of nanocrystalline TiO_2 and coupled TiO_2/Ag containing copolymer on the surface of medical grade titanium*. **Journal of Biomaterials Applications** 31:(1) (**2016**) 55-67. (IF_{2016}= 2.310)
4. R. Masa, **Á. Deák**, G. Braunitzer, Zs. Tóth, J. Kopniczky, I. Pelsőczi-Kovács, K. Ungvári, I. Dékány, K. Turzó. *TiO_2/Ag-TiO_2 nanohybrid films are cytocompatible with primary epithelial cells of human origin: an in vitro study*. **Journal of Nanoscience and Nanotechnology** 18 (6) (**2018**) 3916-3924(9). (IF_{2016}= 1.483)
5. L. Merai, **A. Deak**, D. Sebok, E. Csapo, T. S. Kolumban, B. Hopp, I. Dekany, L. Janovak. *Photoreactive composite coating with composition dependent wetting properties*. **Express Polymer Letters** 12 (**2018**) 1061-1071. (IF_{2018}= 2.875)
6. L. Janovák, Á. Dernovics, L. Mérai, **Á. Deák**, D. Sebők, E. Csapó, A. Varga, I. Dékány, Cs. Janáky. *Microstructuration of poly(3-hexylthiophene) leads to bifunctional superhydrophobic and photoreactive surfaces*. **Chemical Communications** 54(6) (**2018**) 650-653. (IF_{2018}= 6.164)
7. L. Janovák, Á. Turcsányi, É. Bozó, **Á. Deák**, L. Mérai, D. Sebők, Á. Juhász, E. Csapó, M. M. Abdelghafour, Farkas E. *Preparation of novel tissue acidosis-responsive chitosan drug nanoparticles: Characterization and in vitro release properties of Ca^{2+} channel blocker nimodipine drug molecules*. **European Journal of Pharmaceutical Sciences** 123 (**2018**) 79-88. (IF_{2018}= 3.532)
8. L. Mérai, N. Varga, **Á. Deák**, D. Sebők, I. Szenti, Á. Kukovecz, Z. Kónya, I. Dékány, L. Janovák. *Preparation of photocatalytic thin films with composition dependent wetting properties and self-healing ability*. **Catalysis Today** 328 (**2019**) 85-90. (IF_{2018}= 4.888)
9. **Á. Deák**, D. Sebők, E. Csapó, A. Bérczi, I. Dékány, L. Zimányi, L. Janovák. *Evaluation of pH- responsive poly(styrene-co-maleic acid) copolymer nanoparticles for the encapsulation and pH-dependent release of ketoprofen and tocopherol model drugs*. **European Polymer Journal** 114 (**2019**) 361-368. (IF_{2018}= 3.621)

10. L. Janovák, **Á. Deák**, L. Mérai, I. Dékány.
Vízlepergető és fény hatására öntisztuló bifunkciós vékonyrétegek.
Magyar Kémikusok Lapja 74(2) (**2019**) 48-52.

11. L. Janovák, **Á. Deák**, L. Mérai, Sz. P. Tallósy, I. Dékány.
Öntisztuló felületek alkalmazása szerves anyagok eliminálására, ill. biológiai rendszerek ártalmatlanítására.
Magyar Kémiai Folyóirat – Kémiai Közlemények 125 (**2019**) 83-90.

Σ IF = **28.736**

Impact factors of all publications: ΣΣ IF = 42.663

Patents:

1. Dékány Imre, Janovák László, Buzás Norbert, **Deák Ágota**
Reverzibilis heterokoaguláció által szabályozott, pH érzékeny, gyógyszerhatóanyag kibocsájtó nanoszerkezetű rendszer, eljárás annak előállítására és alkalmazása.
Magyar Szabadalom, bejelentés ideje: **2013.**, Ügyiratszám: **P1300744**

2. Janovák László, Dékány Imre, **Deák Ágota**, Varga Norbert, Mérai László
Készítmény és eljárás szuperhidrofób és fotokatalitikus hatással rendelkező bifunkciós vékonyrétegek kialakítására.
Magyar Szabadalom, bejelentés ideje: **2018.**, Ügyiratszám: **P1800195**

List of oral presentations:

1. I. Dékány, L. Janovák, **Á. Deák**, M. Sztakó, Á. Juhász. *Properties of fluorinated acrylic copolymer/ SiO_2 hybrid superhydrophobic surfaces with tuneable wettability.* COST Action Workshop CM 1101 WG 2 and WG 5; Interactions in Colloidal Systems; TU Berlin, Institut für Chemie, Germany, 24-26.03. **2014**.
2. I. Dékány, L. Janovák, Sz. Tallósy, **Á. Deák**, J. Ménesi, M. Sztakó, Á. Juhász, N. Buzás. *Characterization of antibacterial silver and copper nanoparticles functionalized TiO_2 composite photocatalysts.* COST Action CM1101 WG3/WG4 Meeting; Belgrade, Serbia, 30.06.-01.07. **2014**.
3. L. Janovák, Sz. P. Tallósy, J. Ménesi, **Á. Deák**, Á. Juhász, N. Buzás, I. Dékány. *Development of photocatalyst/ polymer hybrid films for the inactivation of bacteria by visible light.* COST Action CM1101 WG3/WG4 Meeting; Belgrade, Serbia, 30.06.-01.07. **2014**.
4. L. Janovák, **Á. Deák**, Á. Juhász, I. Dékány. *Szuperhidrofób szilika/ polimer hibrid vékonyrétegek nedvesedési és morfológiai tulajdonságai,* MTA Kolloidkémiai Munkabizottsági ülés. Velence, Hungary, 04-05.06. **2015**.
5. L. Janovák, **Á. Deák**, N. Nánási, B. Gubán, Z. Veréb, J. Varga, I. Dékány, L. Kemény. *Biocompatible and biodegradable polymeric scaffold and hydrogel based carriers for stem cell,* VII. International Forum On Plastic Surgery, Szeged, Hungary, 17–19.09. **2015**.
6. A. Venkei, Á. Györgyey, A. Ádám, **Á. Deák**, L. Janovák, I. Dékány, K. Ungvári, K. Nagy, E. Urbán, K. Turzó. *TiO_2 és ezüsttel módosított TiO_2 nanorészecskék antibakteriális hatásának fotokatalítikus fokozása a Streptococcus salivarius in vitro modelljén*. In: s. n. (szerk.), Fogpótlástani Napok: Magyar Fogorvosok Egyesülete Fogpótlástani Társaságának XXI. kongresszusa és továbbképző tanfolyamai.
7. R. Masa, Á. Györgyey, Á. **Deák**, L. Janovák, K. Ungvári, Zs. Tóth, K. Nagy, I. Dékány, K. Turzó. *Oszteoblaszt sejtek letapadásának és proliferációjának vizsgálata TiO_2-Ag nanohibrid réteggel fedett titán implantátumon*. In: s. n. (szerk.) Fogpótlástani Napok: Magyar Fogorvosok Egyesülete Fogpótlástani Társaságának XXI. kongresszusa és továbbképző tanfolyamai. Pécs, Hungary, 24-26.09. **2015**.
8. A. Venkei, K. Ungvári, **Á. Deák**, L. Janovák, I. Dékány, E. Urbán, K. Turzó. *TiO_2 és ezüsttel módosított TiO_2 nanorészecskék antibakteriális hatásának fotokatalítikus fokozása a Streptococcus mitis in vitro modelljén.* A Magyar Fogorvosok Egyesületének Árkövy Vándorgyűlése. Perspektívák a paro-implantológiában és a komprehenzív fogászatban. Szeged, Hungary, 5–7.05. **2016**.
9. A. Venkei, Á. Györgyey, A. Ádám, **Á. Deák**, L. Janovák, K. Ungvári, J. Minárovits, I. Dékány, E. Urbán, K. Turzo. *Photocatalytic enhancement of antibacterial effects of TiO_2 and silver modified TiO_2 nanoparticles studied by in vitro Streptococcus salivarius model.* 26th European Congress of Clinical Microbiology and Infectious Diseases. Amsterdam, Nederland, 9-12. 04. **2016**.

10. R. Masa, Á. Györgyey, **Á. Deák**, L. Janovák, Zs. Tóth, I. Pelsőczi-Kovács, K. Ungvári, I. Dékány, K. Turzó. *MG-63 oszteoszarkóma sejtek letapadásának és proliferációjának vizsgálata TiO_2 és Ag-TiO_2 nanohibrid réteggel fedett titán implantátumon.* A Magyar Fogorvosok Egyesületének Árkövy Vándorgyűlése. Perspektívák a paro-implantológiában és a komprehenzív fogászatban, Szeged, Hungary, 5 – 7. 05. **2016**.

11. L. Janovák, **Á. Deák**, I. Dékány. *Szuperhidrofób és fotoreaktív bifunkcionális vékonyrétegek nedvesedési, morfológiai és fotokatalitikus tulajdonságai*. MTA Kolloidkémiai Munkabizottsági ülés, Velence, Hungary, 2-3.06. **2016**.

12. I. Dékány, **Á. Deák**, L. Janovák, Sz. Tallósy. *Novel Biocompactible TiO_2-Hydorxyapatie Composite Photocatalysts: Structural, Photocatalytic and Microbiologycal Properties.* New Photocatalytic Materials for Environment, Energy and Sustainability (NPM -1), Göttingen, Germany, 7-10.06. **2016**.

13. K. Bohinc, **Á. Deák**, K. Godič Torkar, G. Dražič, A. Abram, L. Janovák, I. Dékány. *Bacterial adhesion to material surfaces covered by thin films.* EURADH 2016 Adhesion'16, Glasgow, UK, 21-23.09. **2016**.

14. L. Janovák, **Á. Deák**, Sz. P. Tallósy, I. Dékány. *Synthesis and characterization of novel hybrid layers with superhydrophobic and photoreactive dual properties*. 9th European Meeting on Solar Chemistry and Photocatalysis: Environmental Applications – SPEA9; Strasbourg, France, 13-17.06. **2016**.

15. L. Janovák, Á. Deák, I. Dékány. *Structural and morphological characterization of hybrid thin films with superhydrophobic and photoreactive dual properties*. Nanotechnology and Nanomedicine Research (Nanomed-2016) Dubai, United Arab Emirates, 28- 29.11. **2016**.

16. **L. Janovák**, Á. Deák, I. Dékány. *Structural and Morphological Characterization of Semiconductor Hybrid Thin Films with Tunable Wetting Properties.* 21st Topical Meeting of the International Society of Electrochemistry, Szeged, Hungary, 23-26.04. **2017.**

17. **Á. Deák**, L. Janovák, I. Dékány. *Szuperhidrofób és fotokatalitikus tulajdonságú réteges kettős oxid rétegek előállítása és tulajdonságainak vizsgálata*. Tavaszi Szél Konferencia, Magyarország, Miskolc, Hungary, 31.03. – 2.04. **2017**.

18. D. Sebők, L. Janovák, **Á. Deák**, D. Kovács, A. Sápi, I. Dékány. *Comparative study of adsorption and scattering techniques to determine the surface fractal dimension of nanostructured materials*. International Conference on Mathematics in (bio)Chemical Kinetics and Engineering (MaCKiE), Budapest, Hungary, 25-27.05. **2017**.

19. L. Janovák, **Á. Deák**, I. Dékány. *Structural, morphological and photocatalytic characterization of photoreactive hybrid thin films with tunable wetting properties*. The 2nd International Conference on New Photocatalytic Materials for Environment, Energy and Sustainability (NPM -2), Ljubljana, Slovenia, 3-6.07. **2017**.

20. L. Janovák, **Á. Deák**, I. Dékány. *Development of smart hydrogel films for controlled drug delivery.* 2017 International Conference on Bio-Signal and Image Processing (ICBSIP 2017) Veszprem, Hungary, 22-24.07. **2017**.

21. I. Dékány, E. Csapó, H. Szokolai, Á. Juhász, **Á. Deák**, L. Janovák. *Design of colloidal drug delivery systems for controlled release of non-steroidal anti inflammatory drugs*. 6th World Conference on Physico Chemical Methods in Drug Discovery (IAPC-6) Zagreb, Croatia, 4-7.09. **2017**.

22. **Á. Deák**, *Réteges kettős hidroxidot tartalmazó intelligens kompozit anyagok előállítása és jellemzése (PhD elővédés)*, MTA Kolloidkémiai Munkabizottság, ELTE, Budapest, Hungary, 26.10. **2017**.

23. **Á. Deák**, K. Bohinc, K. Godič-Torkar, A. Abram, G. Dražić, I. Dékány, L. Janovák, *Structural and photocatalytic investigation of surface modified photocatalyst particles with special wetting properties*. International Conference on Catalysis and Surface Chemistry, 50-te Ogólnopolskie Kolokwium Katalityczne, Krakow, Poland, 18.-23.03. **2018**.

24. L. Janovák, **Á. Deák**, L. Mérai, I. Dékány. *Photocatalytic thin films with surface roughness driven wetting properties and its applications for water treatment.* International Conference on Catalysis and Surface Chemistry, 50-te Ogólnopolskie Kolokwium Katalityczne, Krakow, Poland, 18.-23.03. **2018**.

25. L. Mérai, **Á. Deák**, L. Janovák. *A felületi érdesség hatása fotoreaktív vékonyrétegek nedvesedési tulajdonságaira*. VII. Eötvözet Konferencia, Szeged, Hungary 6-7.04. **2018**.

26. L. Mérai, L. Janovák, **Á. Deák**. *Bifunkciós vékonyrétegek kialakítása és fejlesztése*. XII. Szent-Györgyi Albert Konferencia, Budapest, Hungary, 20-21.04. **2018**.

27. I. Dékány, E. Csapó, V. Hornok, Á. Juhász, **Á. Deák**, N. Varga, J. Janovák. *Self-assembled nanostructures for drug delivery: structural properties and thermodynamic state functions*, 11th Conference on Colloid Chemistry (11CCC), Eger, Hungary, 28-30.05. **2018**.

28. L. Janovák, **Á. Deák**, L. Mérai, I. Dékány. *Preparation of photocatalytic thin films with composition dependent wetting properties.* 10th European meeting on Solar Chemistry and Photocatalysis: Environmental Applications (SPEA10), Almería, Spain, 4-8.06.**2018**.

29. **Á. Deák**, K. Bohinc, K. Godič-Torkar, A. Abram, I. Dékány, L. Janovák. *Photoreactive hybrid films with tunable wetting properties*. 4th International Congress on Biomaterials and Biosensors (BIOMATSEN), Ölüdeniz, Turkey, 12-18.05. **2019**.

30. L. Janovák, **Á. Deák**, L. Mérai, I. Dékány. *Designed composites thin films and nanoparticles: from bio- inspired self- cleaning surface to stimuli responsive functional materials.* 4th International Congress on Biomaterials and Biosensors (BIOMATSEN), Ölüdeniz, Turkey 12-18.05. **2019**.

31. L. Janovák, L. Mérai, **Á. Deák**, I. Dékány. *Preparation of designed polymers and composites for the synthesis of multifunctional surfaces and intelligent drug release systems.* European Polymer Congress, EPF 2019, Hersonissos, Crete, Greece, 9-14.06. **2019**.

List of poster presentations:

1. L. Janovák, **Á. Deák**, E. Csapó, Á. Juhász, N. Varga, N. Nánási, I. Dékány, D. Sebők. Biocompatible hydrogel based nanostructured materials for controlled drug delivery. 11th International Conference on Diffusion in Solids and Liquids, Munich, Germany, 22-26.06. **2015**.
2. **Á. Deák**, L. Janovák, I. Dékány. Visible light active photoreactive hybrid layers with superhydrophobic properties. 6th International Colloids Conference, Berlin, Germany, 19-22.06. **2016**.
3. **Á. Deák**, L. Janovák, N. Nánási, I. Dékány. Nanostructured materials for controlled drug delivery. 8th year of the Central European Conference "Chemistry towards Biology" Brno, 28.08. – 01.09. **2016**.
4. L. Janovák, **Á. Deák**, I. Dékány. Structural and Morphological Characterization of Semiconductor Hybrid Thin Films with Tunable Wetting Properties. 21st Topical Meeting of the International Society of Electrochemistry, Szeged, Hungary, 23-26. 04. **2017**.
5. **Á. Deák**, L. Janovák, I. Dékány. Visible light active photoreactive hybrid layers with superhydrophobic properties, 21st Topical Meeting of the International Society of Electrochemistry, Szeged, Hungary, 23-26.04. **2017**.
6. A. Bérczi, R.-A. Domokos, **Á. Deák**, Zs. Szegletes, L. Janovák, I. Dékány, L. Zimányi. Integráns, transz-membrán fehérjék szolubilizálása kopolimerekkel. 47. Membrán-Transzport Konferencia, Sümeg, Hungary, 16-19.05. **2017**.
7. I. Dékány, **Á. Deák**, M. A. Varga, Cs. Janáky, L. Janovák. Wetting properties of roughened conducting polymer thin films with photocatalytic activity using visible light. The 2nd International Conference on New Photocatalytic Materials for Environment, Energy and Sustainability (NPM -2), Ljubljana, Slovenia, 3-6.07. **2017**.
8. **Á. Deák**, K. Bohinc, K. Godič Torkar, A. Abram, G. Dražić, I. Dékány, L. Janovák. Bacterial adhesion on photoreactive hybrid layers with tunable wetting properties. The 2nd International Conference on New Photocatalytic Materials for Environment, Energy and Sustainability (NPM -2), Ljubljana, Slovenia, 3-6.07. **2017**.
9. A. Bérczi, R.-A. Domokos, **Á. Deák,** Zs. Szegletes, L. Janovák, I. Dékány, L. Zimányi. Solubilization of trans-membrane proteins by styrene-maleic acid (SMA) copolymers 19th IUPAB Congress and 11th EBSA Congress, Edinburgh, UK, 16-20.07. **2017**.
10. A. Bérczi, R. Domokos, **Á. Deák**, Zs. Szegletes, L. Janovák, I. Dékány, L. Zimányi. Sztirol-maleinsav (SMA) kopolimerek mint biomembránt szolubilizáló detergensek. A Magyar Biofizikai Társaság XXVI. Kongresszusa, Szeged, Hungary, 22-25.08. **2017**.
11. **Á. Deák**, I. Dékány, L. Janovák. *Photoreactive hybrid films with superhydrophobic properties*, 11th Conference on Colloid Chemistry (11CCC), Eger, Hungary, 28-30.05. **2018**.

12. **Á. Deák**, L. Janovák, Á. Juhász, E. Csapó, E. Farkas, I. Dékány, F. Bari. *Drug release properties of pH-responsive chitosan nanoparticles.* 4th International Conference on Bio-Based Polymers and Composites, Balatonfüred, Hungary, 2-6.09. **2018**.
13. **Á. Deák**, I. Dékány, L. Janovák. *Photoreactive hybrid nanoparticles for elimination of interfacial pollutants from water surfaces,* 8th Szeged Workshop on Advances in Nanoscience, Szeged, Hungary, 7-11.10. **2018**.
14. L. Mérai, **Á. Deák**, L. Janovák, I. Dékány. *Preparation of composite layers to enhance surface roughness durability*. 8th Szeged Workshop on Advances in Nanoscience, Szeged, Hungary 7-11.10. **2018**.
15. **Á. Deák**, I. Dékány, L. Janovák. *Development of polymer based composite nanoparticles suitable for photocatalytic elimination of interfacial water pollutants.* European Polymer Congress 2019 (EPF 2019), Hersonissos, Crete, Greece, 9-14.06. **2019**.
16. I. Dékány, M. Mérai, **Á. Deák**, L. Janovák. *Preparation of low energy polymer based photoreactive composite layers to enhance surface roughness durability.* European Polymer Congress 2019 (EPF 2019), Hersonissos, Crete, Greece, 9-14.06. **2019**.