THESES OF DOCTORAL (Ph.D.) DISSERTATION

Application of layered double hydroxide nanoparticles to combat oxidative stress

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I. Introduction

Reactive oxygen species (ROS), such as superoxide radical anions ($O_2^{-\bullet}$), hydroxyl radicals ($OH^{\bullet}$), as well as non-radicals like hydrogen peroxide (H_2O_2), play an important role in many biological processes under physiological conditions. They have significant impacts on the modulation of cell death, differentiation, and intracellular signalling processes; however, their overproduction can have serious consequences. During the normal operation of living organisms, those are formed during mitochondrial respiration or as a by-product of enzyme-catalysed biochemical reactions. On the contrary, if there is a non-ideal function of the body due to external factors (*e.g.*, UV-irradiation, smoking, degradation of pharmaceutical agents), their concentration can be increased, leading to oxidative stress. To reduce the risk of the oxidative stress, living organisms take control of the concentration of these specimens using antioxidants as regulators. Once this well-controlled system is out of balance, oxidative stress can cause many serious diseases. Antioxidants can delay or inhibit the formation of oxidative stress. Based on their structure they can be enzymatic, with a well described protein structure, or molecular, like polyphenols, vitamins, or carotenoids. Next to their biomedical importance, antioxidants are also important additives in many industrial processes, however, both enzymatic and molecular antioxidants are highly sensitive to several environmental conditions (*e.g.* pH, temperature, light). As a result, the extraction and purification processes used to industrially produce these substances are generally expensive and elaborate. Immobilization enzyme processes or the production of enzyme-mimicking materials can overcome these problems. The latter one is a promising research direction, especially if they can be produced in the nanoscale size range.

In this way, layered double hydroxides (LDHs) attracted widespread contemporary attention as support materials for antioxidant molecules. LDHs are brucite-like ($Mg(OH)_2$) materials with positively charged layers, in which the charges are compensated by the interlayer anions. Beside the lamellar structure, delaminated LDH particles (dLDH) have also become widely investigated substances in the past decades due to the landmark development around the atomically thin 2D nanomaterials. Considering their advantageous features (*e.g.*, tuneable structure, anion exchange capacity, biocompatibility), several studies focused on the application of LDH/dLDH as host materials for various pharmaceutical agents, enzymes, and antioxidants. The bio-active molecules can be intercalated between LDH layers or adsorbed on dLDH or LDH surfaces by electrostatic interaction or covalent bonding. In addition to immobilize biomolecules, the incorporation of catalytically active metal cations into the structure can also

impart enzymatic activity to the LDHs. In this latter case, nanoparticles with enzymatic activity, the so-called nanozymes, can be produced, which may mimic the function of various enzymes, while possessing better stability under the same working conditions compared to the natural enzymes.

Beside functional stability, the colloidal stability of enzyme mimicking heterogeneous systems is an extremely important issue considering the potential areas of their use. Both industrial and biomedical applications require stable nanoparticle dispersions, since undesired aggregation can lead to reduced activity and durability in industrial fields as well as serious consequences (*e.g.*, formation of blood clots) in biomedical application. Functionalizing these nanozymes/enzyme-mimics with polymeric compounds offer a reasonable solution to improve the colloidal stability of the particles. Furthermore, the polyelectrolyte coating can even facilitate the cellular uptake.

In conclusion, heterogenized antioxidant systems are potential representatives in biomedical and industrial processes, where protection against ROS and ROS induced processes are a main aspect. By eliminating the negative properties of the native antioxidants, these formulated antioxidant systems could be promising materials in the future processes.

II. Objectives

The main objective of the present PhD research was to develop highly active antioxidant nanocomposites *via* surface and structural modification of layered double hydroxide (LDH) nanoparticles and nanosheets. To achieve this goal, several sub-objectives were set:

First, it was aimed to prepare delaminated LDH dispersions (dLDH) and study colloidal stability in the presence of monovalent ions.

Second, by using sequential adsorption of polyelectrolytes and antioxidant enzymes (SOD, HRP, CAT), surface modification of dLDH particles was aimed. By anchoring the enzymes onto the surface, the goal was to produce an antioxidant cascade composite, which can effectively reduce ROS concentration. Besides, by building polyelectrolyte layers adsorbed on the surface of the composites, the objective was to fine-tune the colloidal stability of modified LDHs and enhance the capability of the as-prepared particles of penetrating the cell membrane.

Third, the preparation of LDH/antioxidant composites was subjected on using different synthesis methods. With the phase pure, as-prepared composites in our hands, the objective was to identify the most influential structural-antioxidant activity relationships, taking advantage of which the efficiency of composites can be maximized.

Finally, in order to prepare LDH-based nanozymes, it was aimed to introduce a synthesis procedure that can allow the partial replacement of the divalent cations in a Mg_3Al LDH structure with charge valuable metal cations, such as Cu(II).

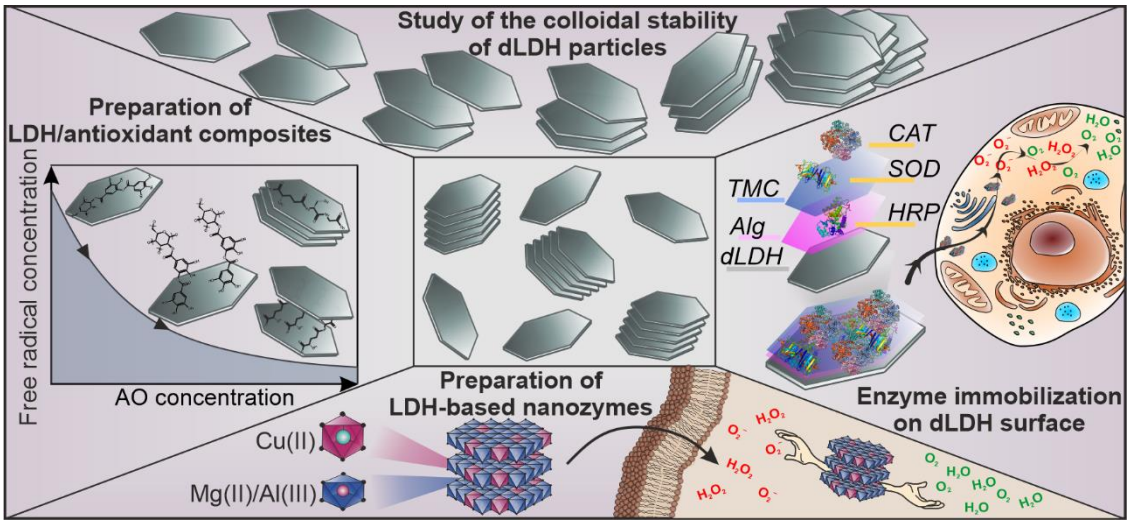

Figure 1. Schematic representation of the objectives.

III. Experimental part

LDH, dLDH and copper-containing LDH (CMA) particles were synthesized by the coprecipitation method. The hydrodynamic radii of the LDH/dLDH dispersions were investigated by dynamic light scattering (DLS) measurements, while charging properties were monitored by electrophoretic light scattering (ELS) technique.

The structure of the nanoparticles was studied with powder X-ray diffractometry (XRD), which was also applied to ascertain the intercalation of antioxidant molecules. The size and morphology features were investigated by atomic force microscopy (AFM), scanning electron microscopy (SEM) and transmission electron microscopy (TEM) in solid state. The specific surface area of dLDH nanoparticles was measured by N_2 sorption technique, using the BET method. CMA samples were further investigated by X-ray photoelectron spectroscopy (XPS), fluorescent lifetime measurement (FLIM).

Tannic acid (TA) and glutathione (GSH) were immobilized in/on LDH materials with two independent methods, namely, coprecipitation (LDH/TA/c and LDH/GSH/c) and surface adsorption (LDH/TA/a and LDH/GSH/a). Horseradish peroxidase (HRP), superoxide dismutase (SOD) and catalase (CAT) enzymes were co-immobilized by the sequential adsorption techniques using polyelectrolytes (alginate (Alg) and trimethyl chitosan (TMC)) to obtain the dLDHaHtSC multienzyme hybrid.

To prove the success of antioxidant immobilization, a wide range of instrumentation was applied. Accordingly, Raman microscopy, UV-VIS-NIR and infrared (IR) spectroscopy were applied. To determine the molecular antioxidant content, mass spectrometer coupled thermogravimetry (TG-MS) measurements were performed. Enzyme adsorption was examined by small angle X-ray scattering (SAXS) measurements.

The radical scavenging activity of TA- and GSH-containing samples was determined with 2,2-diphenyl-1-pycrylhydrazil (DPPH) test, while enzymatic ones included the Fridovich, guaiacol and catalase assays. Cellular measurements were carried out on HeLa cell lines. To assess potential cytotoxicity, the apoptosis/necrosis (APO/NECRO) assay was applied. Intracellular ROS concentration was detected with fluorescent microscopy, while cell penetration and DNA double strand break inhibition were investigated with direct stochastic optical reconstruction microscopy (dSTORM).

IV. New scientific results

T1. Mechanism of salt induced aggregation of dLDH nanosheets was revealed in aqueous dispersions. Restacking of dLDH was followed by formation of house of cards clusters depending on the experimental conditions. [4]

The restacking mechanism of dLDH nanosheets was proposed in the presence of monovalent salts. The reconstruction process of the lamellar structure was confirmed by DLS and turbidity measurements at low ionic strengths and short time intervals. Lamellar structure formed due to the plate-plate orientated aggregation of dLDH nanosheets, which does not affect the lateral dimension, only the thickness of the particles. Due to DLS is sensitive to the largest size parameter of particles, especially to the lateral extent of the monolayers in this case, this change in thickness indicated no alteration in the measured particle size. In contrast, turbidity is more sensitive to particle size of non-spherical particles. Thus, the growing thickness caused significant change in turbidity in contrast to the initial "transparent" dLDH dispersion.

Aggregation of the lamellar LDHs occurred after restacking indicated by steep increase of the hydrodynamic size of the particles. The results are in good agreement with the Derjaguin, Landau, Vervey and Overbeek (DLVO) theory. By increasing the electrolyte concentration, the electrical double layer repulsion became weaker between the particles and van der Waals forces start to dominate, resulting in house-of-card aggregation.

To describe the quasi-kinetic behaviour of the systems, the critical coagulation time (CCT) needed to be defined. This can be determined as the onset time of the house-of-card aggregation regime. The values of CCTs were dictated by the ionic strength that was controlled by the initial concentration of the monovalent salt. It became clear that the values of CCTs decrease with increasing electrolyte concentration. Due to the significant difference in the particle concentration, there is an alteration in the exact CCTs of DLS and turbidity measurements, however, the tendency was found to be the same.

After the addition of electrolyte solution, the thickness of the particles increased significantly in time. After reaching CCT, large aggregates formed, indicating the formation of house-of-card aggregates of lamellar LDH. XRD further revealed the formation of the lamellar structure. While dLDH nanosheets possessed amorphous diffractograms, crystalline phase was able to be identified after the restacking, indicating the formation of lamellar LDH particles.

The colloidal stability of the dLDH systems was assessed by DLS and turbidity measurements and the determined critical coagulation concentrations (CCCs) were in good agreement with each other despite the significant difference in the particle concentration. In

both cases, the obtained results can be interpreted by the DLVO theory. First the dispersion had high stability, while after the critical coagulation concentration fast aggregation occurred, the dispersion became unstable.

T2. An ROS scavenging nanocomposite was designed and developed by co-adsorbing SOD, HRP and CAT on dLDH surface by sequential adsorption method. The as-prepared composite possessed enhanced colloidal stability and showed remarkable antioxidant activity. Penetrating the cell membrane, it could normalize the ROS/antioxidant balance and did not show any cytotoxicity. [3]

Three antioxidant enzymes, HRP, SOD and CAT were co-immobilized on the dLDH surface by a sequential adsorption method and separated by polyelectrolyte layers. Initially, no change was observed at low polyelectrolyte doses, but when the polyelectrolyte concentration was further increased, the surface charge changed steeply, while after a certain dose the particle surface became oppositely charged. Due to the high surface charge, the dispersion was stable, and no aggregation occurred in the system. The enzyme doses did not affect the charge, thus the dispersion remained stable. The formation of polyelectrolyte and enzyme layers on the dLDH surface indicated an increasing electron density fluctuation, *i.e.*, the surface became more diffuse after functionalization underpinned by SAX measurements.

The polyelectrolyte layers conferred colloidal stability to the system. In salt induced aggregation measurements, the dispersion remained stable at low electrolyte concentration, while after CCC it became unstable, fast aggregation occurred. The results are in good agreement with the DLVO theory.

The composite showed excellent enzymatic activity, both in H_2O_2 degradation and superoxide anion decomposition. SOD maintained its activity after anchoring on the dLDH surface and the inhibitory concentration (IC_{50}) values did not change significantly after immobilization. CAT showed higher H_2O_2 decomposition activity after adsorption on the particle surface, which is a promising result compared to the former published results concerning with the immobilization of CAT. HRP also has a higher affinity for the substrate than in native form, because the positively charged particle surface of dLDHaHtSC is more attractive for the guaiacol.

dSTORM measurements showed that the composite could penetrate the cell membrane, which is due to the positive surface charge generated by the functionalization with polyelectrolytes. In addition, the APO/NECRO assay proved that the composites had no cytotoxic effect on the HeLa cell line. The nanocomposite successfully reduced the indicated

ROS production and thus can protect the cells from the ROS induced diseases. DNA double strand break measurements further proved this result, dLDHaHtSC was able to restore the normal ROS/antioxidant balance, protecting the cells from DNA damage.

T3. A clear relationship between the spatial arrangement of TA and GSH immobilized in/on LDH particles and their antioxidant activities was determined. The composites conferred structural stability to the antioxidants and preserved their radical scavenging activity over time. [2]

TA and GSH were successfully immobilized in/on LDH particles and the orientation of the antioxidants relative to the surface strongly correlated with the synthesis method. GSH intercalated among the LDH layers in the coprecipitation method but adsorbed on the other surface of LDH in the adsorption method. In contrast, TA adsorbed on LDH particles in both cases.

The orientation of TA on the LDH surface was in strong correlation with the synthesis method; moreover, the structure of TA was not damage under highly alkaline conditions as applied in coprecipitation. IR measurements showed, that TA adsorbed parallel to the LDH surface in coprecipitation, but was anchored perpendicular to the surface in the adsorption method.

For TA, its surface orientation has a determining influence on its own radical scavenging activity. The phenolic -OH - groups are more accessible when the guests are perpendicularly adsorbed on the surface. As a result, the activity of LDH/TA/a was higher than in the native form of TA, while highly reduced radical scavenging activity was experienced when the orientation of TA was parallel. For the GSH-containing samples, immobilization had no significant effect on the activity, which was similar to that of the native antioxidant.

In addition to the effect on their own activity, immobilization also affected the structural stability of the antioxidants. The native GSH showed significantly higher radical scavenging activity than the immobilized representatives after one month. This activity originated from the self-decomposition of GSH, whereas the immobilized GSH retained its original structure and thus exhibited the same activity as the fresh samples. Moreover, LDH/TA/a showed remarkable reusability, increasing its potential applicability in industry.

T4. The activity of SOD and CAT was successfully mimicked by partially replacing Mg(II) ions with Cu(II) ions in Mg_3Al LDH nanoparticles. The nanoparticles showed remarkable enzymatic activity as well as ROS and superoxide radical scavenging ability in a cellular environment. [1]

Introducing a modified coprecipitation method, in an Mg_3Al LDH framework, Mg(II) ions could be partially replaced by Cu(II) ions, as demonstrated by wide range of instrumentations. The increased interlayer space, which was verified by XRD measurements, indicated an isomorphous substitution, in addition, the shift of the Raman band related to the M-O-M vibration also indicated a structural change in the LDH layers. XPS measurements revealed the presence of the $Cu(OH)_2$ units, in addition, the shift in the binding energy of Al 2p also indicated the change in the chemical environment due to the incorporation of Cu(II) ions. The isomorphous substitution also affected the fluorescence lifetime of the CMA samples. The incorporation of Cu(II) can lead to a change in the surface defects and surface charge densities, resulting in a shorter fluorescent lifetime of the CMA samples.

By inserting Cu(II) ions into the layers, a nanozyme system could be prepared with remarkable catalase and superoxide dismutase activity. Compared to the native enzymes, the activity decreased slightly, however CMA samples showed remarkable superoxide dismutase activity, moreover, like catalase, it could also decompose H_2O_2.

The ROS scavenging activity of the copper-containing samples was also detected in cellular environments. Initially, the citotoxicity assay revealed that the nanoparticles had no cytotoxic effect on the cells. After CMA treatment, the presence of apoptotic/necrotic cells was negligible. Moreover, those can neutralize the induced superoxide radicals and ROS in the cells. After CMA treatment, the concentration of both ROS and superoxide radical decreased in the cells, thus the nanoparticles could inhibit the formation of these harmful molecules.

V. Applications

The detailed study of the colloidal properties of dLDH particles could provide comprehensive information on the restacking mechanism of dLDH nanosheets. Results on the restacking mechanism can find potential application in environmental remediation processes, considering the fact that numerous type of contaminants (e.g., arsenite, arsenate, nitrate) can be intercalated in the forming LDH materials.

The LDH-based antioxidant nanocomposites could be a promising tool to replace the expensive and sensitive antioxidant molecules and enzymes used so far in industry and in biomedical applications. The highly stable and robust LDH/GSH and LDH/TA composites could be used in cosmetics and food packaging, where anti-aging and shelf-life (respectively) properties are critical aspect for antioxidants.

The triple enzyme-containing system, dLDHaHtSC, could serve as an ROS scavenger by decomposing O_2^- and H_2O_2 molecules in biomedical processes. It could serve as a potential solution for the treatment of inflammatory bowel disease, which has become an urgent problem worldwide.

The stable colloidal dispersion of CMA samples could also serve a potential treatment in biomedical fields, where antioxidant treatments could enhance the recovery process. For instance, the antioxidant coatings on implants or the antioxidant assisted wound healing.

In conclusion, there is a need for new ROS scavenging materials in many biomedical and industrial fields. Therefore, the antioxidant systems presented in this work is probably of great interest to both academia and industry.

VI. Scientific publications

MTMT ID: 10073920

Papers related to the theses

1. **Adél Szerlauth**, Tamara Madácsy, Gergely Ferenc Samu, Péter Bíró, Miklós Erdélyi, Gábor Varga, Zhi Ping Xu, József Maléth, Istvány Szilágyi

   Reduction of intracellular oxidative stress with copper incorporated layered double hydroxide

   Chemical Communications 60 (2024) 1325

   DOI: 10.1039/D3CC05762C SJR indicator: Q1
   Independent citations: 0 IF: 4.9

2. **Adél Szerlauth**, Zsuzsanna D. Kónya, Gréta Papp, Zoltán Kónya, Ákos Kukovecz, Márton Szabados, Gábor Varga, István Szilágyi

   Molecular orientation rules the efficiency of immobilized antioxidants

   Journal of Colloid and Interface Science 632 (2023) 260

   DOI: 10.1016/j.jcis.2022.11.056 SJR indicator: Q1
   Independent citations: 2 IF: 9.9

3. **Adél Szerlauth**, Árpád Varga, Tamara Madácsy, Dániel Sebők, Sahra Bashiri, Mariusz Skwarczynski, Istvan Toth, József Maléth, István Szilágyi

   Confinement of Triple-Enzyme-Involved Antioxidant Cascade in Two-Dimensonal Nanostructure

   ACS Materials Letters 5 (2023) 565

   DOI: 10.1021/acsmaterialslett.2c00580 SJR indicator: Q1
   Independent citations: 2 IF: 11.4

4. **Adél Szerlauth**, Edina Balog, Dóra Takács, Szilárd Sáringer, Gábor Varga, Gábor Schuszter, István Szilágyi

   Self-assembly of delaminated layered double hydroxide nanosheets for the recovery of lamellar structure

   Colloid and Interface Science Communications 46 (2022) 100564

   DOI: 10.1016/j.colcom.2021.100564 SJR indicator: Q1
   Independent citations: 4 IF: 4.5

Papers not related to the theses

1.**Adél Szerlauth**, Szilárd Varga, István Szilágyi

Molecular antioxidants maintain synergistic radical scavenging activity upon co-immbilization on clay nanoplatelets

ACS Biomaterials Science & Engineering 9 (2023) 5622

DOI: 10.1021/acsbiomaterials.3c00909 SJR indicator: Q1
Independent citations: 0 IF: 5.7

2. Ibolya Zita Papp, **Adél Szerlauth**, Tímea Szűcs, Péter Bélteky, Juan Fernando Gomez Perez, Zoltán Kónya, Ákos Kukovecz

Fabrication and characterization of a bifunctional zincoxide/multiwaled carbon nanotube/poly (3, 4-ethylenedioxythiophene): polystyrene sulfonate composite thin film

Thin Solid Films 778 (2023) 139908

DOI: 10.1016/j.tsf.2023.139908 SJR indicator: Q2
Independent citations: 0 IF: 2.1

3. Bojana Katana, Kata Panna Kókai, Szilárd Sáringer, **Adél Szerlauth**, Dóra Takács, István Szilágyi

The Influence of Solvents and Colloidal Particles on the Efficiency of Molecular Antioxidants

Antioxidants 12 (2022) 99

DOI: 10.3390/antiox12010099 SJR indicator: Q1
Independent citations: 3 IF: 7.0

4. Marko Pavlovic, **Adél Szerlauth**, Szabolcs Muráth, Gábor Varga, István Szilágyi

Surface modification of two-dimensional layered double hydroxide nanoparticles with biopolymers for biomedical applications

Advanced Drug Delivery Reviews 191 (2022) 114590

DOI: 10.1016/j.addr.2022.114590 SJR indicator: Q1
Independent citations: 20 IF: 16.1

5. Nizar B Alsharif, Gergely F Samu, Szilárd Sáringer, **Adél Szerlauth**, Dóra Takács, Viktoria Hornok, Imre Dékány, István Szilágyi

Antioxidant colloids via heteroaggregation of cerium oxide nanoparticles and latex beads

Colloids and Surfaces B: Biointerfaces 216 (2022) 112531

DOI: 10.1016/j.colsurfb.2022.112531 SJR indicator: Q1
Independent citations: 5 IF: 5.8

6. **Adél Szerlauth**, Lilla Szalma, Szabolcs Muráth, Szilárd Sáringer, Gábor Varga, Li Li, István Szilágyi

Nanoclay-based sensor composites for the facile detection of molecular antioxidants

Analyst 147 (2022) 1367

DOI: 10.1039/D1AN02352G SJR indicator: Q1
Independent citations: 6 IF: 4.2

7. Bojana Katana, Dóra Takács, **Adél Szerlauth**, Szilárd Sáringer, Gábor Varga, Andrej Jamnik, Felix D Bobbink, Paul J Dyson, István Szilágyi

Aggregation of halloysite nanotubes in the presence of multivalent ions and ionic liquids

Langmuir 37 (2021) 11869

DOI: 10.1021/acs.langmuir.1c01949 SJR indicator: Q1
Independent citations: 7 IF: 4.331

8. Dóra Takács, Bojana Katana, **Adél Szerlauth**, Dániel Sebők, Matija Tomsic, István Szilágyi

Influence of adsorption of ionic liquid constituents on the stability of layered double hydroxide colloids

Soft Matter 17 (2021) 9116

DOI: 10.1039/D1SM01074C SJR indicator: Q1
Independent citations: 4 IF: 4.046

9. Szabolcs Muráth, **Adél Szerlauth**, Dániel Sebők, István Szilágyi

Layered double hydroxide nanoparticles to overcome the hydrophobicity of ellagic acid: An antioxidant hybrid material

Antioxidants 9 (2020) 153

DOI: 10.3390/antiox9020153 SJR indicator: Q2
Independent citations: 15 IF: 6.313

10. **Adél Szerlauth**, Szabolcs Muráth, István Szilágyi

Layered double hydroxide-based antioxidant dispersions with high colloidal and functional stability

Soft Matter 16 (2020) 10518

DOI: 10.1039/D0SM01531H SJR indicator: Q1
Independent citations: 9 IF: 3.679

11. **Adél Szerlauth**, Szabolcs Muráth, Sándor Viski, István Szilágyi

Radical scavenging activity of plant extracts from improved processing

Heliyon 5 (2019) e02763

DOI: 10.1016/j.heliyon.2019.e02763 SJR indicator: Q1

Independent citations: 24 IF: —

12. Szilárd Sáringer, Rita Achieng Akula, **Adél Szerlauth**, István Szilágyi

Papain adsorption on latex particles: charging, aggregation, and enzymatic activity

Journal of Physical Chemistry B 123 (2019) 9984

DOI: 10.1021/acs.jpcb.9b08799 SJR indicator: Q1

Independent citations: 12 IF: 2.857

Scientometric Data

Sum of peer reviewed publications: 16	In relation to the theses: 4
Cumulative impact factor: 92.826	In relation to the theses: 30.700
Sum of independent citations: 113	In relation to the theses: 8

Oral and poster presentations related to the theses

1. **Adél Szerlauth**, Árpád Varga, Tamara Madácsy, József Maléth, István Szilágyi (oral presentation)

   Confinement of triple enzyme cascade in layered double hydroxide-based nanocomposites to prevent oxidative stress

   96th ACS Colloid and Surface Science Symposium (2022) Golden, Colorado, USA

2. **Adél Szerlauth**, Árpád Varga, Tamara Madácsy, József Maléth, István Szilágyi (oral presentation)

   Immobilization of antioxidant enzymes on layered double hydroxide nanosheets to prevent oxidative stress

   18th European Student Colloid Conference (2022) Szeged, Hungary

3. **Adél Szerlauth**, Edina Balog, Dóra Takács, Szilárd Sáringer, Gábor Varga, Gábor Schuszter, István Szilágyi (oral presentation)

   Aggregation study on restacking ability of layered double hydroxide nanosheets

   The 33rd Australian Colloid and Surface Science Student Conference (2022) Mawson Lakes, Australia (online)

4. **Adél Szerlauth**, Edina Balog, Dóra Takács, Szilárd Sáringer, Gábor Varga, Gábor Schuszter, István Szilágyi (oral presentation)

   Aggregation study on the recovery of the lamellar structure of layered double hydroxides

   35th Conference of the European Colloid & Interface Society (2021) Athens, Greece (online)

Oral and poster presentations not related to the theses

1. **Adél Szerlauth**, Szilárd Varga, István Szilágyi (poster presentation)

   Heterogenization of synergistic antioxidants on 2D nanoparticles

   12th International Colloids Conference (2023) Palma de Mallorca, Spain

2. **Adél Szerlauth**, Adél Anna Ádám, Gábor Varga, István Szilágyi (poster presentation)

   Layered double hydroxide-based hybrid colloids for catalytic transfer hydrogenation

   11th International Colloids Conference (2022) Lisbon, Portugal

3. **Adél Szerlauth**, Szabolcs Muráth, István Szilágyi (poster presentation)
   Design of an efficient antioxidant composite of high functional and colloidal stability
   Geneva Colloids (2021) online

4. **Adél Szerlauth**, Szabolcs Muráth, Dániel Sebők, István Szilágyi (oral presentation)
   Ellagsav alapú réteges kettős hidroxid hibridek antioxidáns aktivitása
   XLII. Kémiai Előadói Napok (2019) Szeged, Hungary