

MATERJALI- JA KESKKONNATEHNOLOOGIA INSTITUUT

ANORGAANILISTE MATERJALIDE TEADUSLABOR

TEADUS- JA ARENDUSTEGEVUSE AASTAARUANNE 2017

1 Labori koosseis

Anorgaaniliste materjalide teaduslabor, juhataja van.tead/prof. Andres Triikkel
Laboratory of Inorganic Materials, laboratory manager sen.res.sci/prof. Andres Triikkel

Labori töötajad:

- Tiit Kaljuvee – vanemteadur
- Juha Kallas – vanemteadur
- Rein Kuusik –vanemteadur
- Andres Triikkel – vanemteadur
- Kaia Tõnsuaadu – vanemteadur
- Mai Uibu – vanemteadur
- Olga Velts-Jänes – teadur (lapsepuhkusel)
- Marve Einard – keemiainsener
- Kadriann Tamm – teadur
- Can Rüstü Yörük – insener
- Regiina Viires – laborant, magistrant
- Anastassia Žuravljova – laborant, magistrant

2 Uurimisgrupi tutvustus (eesti ja inglise keeles)

2.1 Uurimistemaatika

Anorgaaniliste materjalide labori tegevused hõlmavad anorgaaniliste materjalide keemia ja tehnoloogia valdkonda, täpsemalt alus- ja rakendusuringuid anorgaanilistes multikomponentsetes süsteemides, eesmärgiga töötada välja uusi materjale, leida täiendavaid kasutusvõimalusi Eesti mineraalsetele maavaradele ja vähendada tööstusheitmeid. Jäätmete taaskasutus põlevkivitööstuses ja põlevkivipõhises energiatootmises pidades silmas põlevkivituhka (PKT) ning kasvuhoonegaaside emissioonide vähendamine on olnud meie tööde fookuses juba pikemat aega. Praegused tegevussuunad saab reastada järgnevalt:

- PKT happeliste gaaside (SO_2 , CO_2) sidujana ja CO_2 mineraliseerimiseks;
- PKT kui võimalik sorbent fosfori taaskasutuseks või heitvete töötlemiseks;
- PKT kui tooraine sadestatud kaltsiumkarbonaadi saamiseks, täite- ja sideaineteks polümeerides ja keraamikatoodetes ja kui võimalik lisand teatud ehitusmaterjalides;
- PKT granuleerimine põlumajanduse vajadusteks (happeliste muldade neutraliseerijana);
- PKT kui sobiv materjal kaevanduskäikude tagasitäitmiseks ja teedehituses;
- Uute tuhaliikide iseloomustamine (jäätmepõletusjaamade tuhad, nn DeSOx tuhad väävlipüüduritest, Enefit tehnoloogiate tuhad);
- Süsiniku püüdmis- ja ladustamistehnoloogiad põlevkivienergeetikas ja tsemenditööstuses vähendamaks CO_2 emissioone (hapnikus-põletamine, CO_2 sidumine nn Ca-ringtsükli).

Arvestades varasemat oskusteavet ka katioonasendustega apatiitide keemia ja süntees eesmärgiga leida jätkusuutlikke lahendusi katalüsaatorite ja bioapatiitide vallas, aga samuti uued tehnoloogiad fosforiidi töötlemiseks, mis võivad hakata tulevikus taas huvi pakkuma, eeldusel, et suudetakse arvesse võtta kõik väärtuslikud kaasmineraalid (glaukoniit, graptoliit-argilliit, haruldased muldmetallid) ja kaasnevad keskkonnaohud. Eesti lubjakivi ning dolomiit on olnud uuritavate objektide hulgas võimalike sorbentidena

väävliipüüdmisses, Ca-ringtsükklis ja lisandite või katematerjalidena lämmastikväetise – ammoniumnitraadi käitlemisohutuse tõstmiseks.

Laboril on pikaajaline kogemus termilise analüüsi meetodite rakendamisel (TG/DTA kompleks gaas-tahke süsteemides toimuvate protsesside uurimiseks nii atmosfääri- kui kõrgematel rõhkudel kombineerituna lahkvate gaaside analüüsiga (MS, FTIR). Samuti omame erinevaid reaktorisüsteeme paljude heterogeensete protsesside uurimiseks (näit. multifunktsionaalne reaktorisüsteem Lara/Radleys). Kasutame ka mitmeid spektroskoopilise analüüsi (UV-Vis, IR) ja tahke materjali iseloomustamise meetodeid (poorsusjaotus, osakeste suurusjaotus, eripind) ja rakendame matemaatilise modelleerimise tarkvara (ASPEN Plus, HSC, Modest), mis võimaldab põhjalikumalt katseandmete üldistamist ning vastavate tehnoloogiate kujundamist.

2.2 Research topics

Activities of the Laboratory of inorganic materials cover chemistry and technology of inorganic materials, more specifically, fundamental and applied research of inorganic multicomponent systems in order to work out new materials, to find application and new utilization methods for Estonian mineral resources and to diminish industrial wastes. Waste management in oil shale industry and oil shale based power production to find usage for oil shale ash (OSA) and diminish GHG emissions has been our concern for a long period. The current research is focussed on:

- OSA as sorbent for acidic gases (SO₂, CO₂) and CO₂ mineralization;
- OSA as possible sorbent for recycling phosphorus or for waste water treatment;
- OSA as raw material for precipitated calcium carbonate (PCC), filling and curing materials, ceramics or as filler for polymers;
- OSA as additive in specific construction materials;
- Granulation of OSA for agricultural needs;
- Characterisation of OSA for backfilling purposes in mines or in road construction;
- Characterisation of new types of ashes (ashes from incinerators of municipal wastes, DeSO_x ashes from sulphur capture and ashes from Enefit technologies);
- CCS technologies for oil shale to diminish GHG emissions in power production or in cement industry (oxy-fuel combustion, Ca-looping).

In addition, related to earlier expertise, also on chemistry and synthesis of cation-substituted apatites, enabling to reach to feasible, environmentally safe applications (catalysts, bio-apatites). Sustainable processing technologies for phosphorite (acid treatment, thermal processes) are gaining attention due to large phosphorite resources of Estonia, the properties of which need studies on today's level keeping in mind all accompanying valuable minerals (rare earth metals, glauconite) and serious environmental concerns. Estonian limestone and dolomite have been studied as possible sorbents in sulphur capture, in Ca-looping process and as additives or coating materials for ammonium fertilizer prills to decrease their explosiveness.

Laboratory of inorganic materials has a long-term experience in applying various thermal analysis techniques (TG/DTA devices for analysing gas-solid systems at atmospheric and enhanced pressures) coupled with evolved gas analysis (MS, FTIR) and different scale computer-driven reactor systems for studying heterogeneous solid-liquid-gas systems (e.g. multifunctional reactor system Lara/Radleys). In addition, several other spectroscopic (UV-Vis, IR) and solid particle characterisation methods are employed (porosity, surface area and particle size distribution) as well as software for mathematical modelling (ASPEN Plus, HSC, Modest) that enable to widen and generalize the know-how obtained.

3 Uurimisgrupi aruandeaasta teadustulemuste kokkuvõte (*inglise keeles*)

The main research topics of the Laboratory of inorganic materials can be divided into three main groups as reported below.

Utilisation of oil shale processing wastes

Different types of oil shale ashes (OSA) have been systematically characterised for chemical and phase composition, physical properties, leaching characteristics and binder properties. Selective leaching of the key Ca-compounds – Ca(OH)₂, CaSO₄·2H₂O and CaS was studied in the model systems of different complexity. To clarify process mechanisms, experimental work and mathematical modelling was carried out to determine kinetic and equilibrium parameters, mass transfer coefficients, and the effect of

hydrodynamic conditions on precipitated Ca-carbonate (PCC) properties. A method for simulating the leaching streams from ash fields and leaching behaviour of various types of OSA was developed for the purpose of designing leaching reactors that can be used to produce PCC. Transformations of sulphur compounds in the course of aqueous carbonation were clarified, competitive reactions and their kinetics were explained.

In addition, selective Ca extraction from industrial wastes using ammonium salt solvents (NH_4Cl , NH_4NO_3 and $\text{CH}_3\text{COONH}_4$) was studied. Clarifying chemistry and developing the respective models will be continued. A simplified leaching mechanism for ash-solvent systems has been presented, that can be used for model calculations.

Combustion temperatures in new plants (Auvere, Enefit) have been decreased, resulting in lowered curing properties of OSA. A new study focusing on reusability of these new types of OSA was initiated to describe the dependencies between processing conditions (combustion temperature and its possible slight increase) and curing properties of ashes (important in utilisation e.g for building materials), considering also related boiler heat duties and gaseous emissions.

Environmental problems OSA utilisation can be related to its alkaline reaction with water and leaching of salts – chlorides and sulphates, but also Cr, Mo and Ba. The regularities of these processes were clarified. Possibilities for utilising OSA for production of constructional aggregates, focusing on the cementitious properties, CO_2 binding ability and leaching behaviour have been tested. Suggestions to maximize the CO_2 uptake and produce aggregates with respective mechanical and environmental characteristics have been worked out.

The main focus in 2019 will stay on utilisation and environmental impact of OSA – describing the dependencies between firing regimes, composition of ash and its binding properties. Modelling will be extended to generalise experimental data and obtain information about waste flows, gaseous emissions, and heat duties of combustion processes as well as to predict leaching behaviour of OS ashes and simulate utilisation options.

Clays and their mixtures with ashes can be used to make ceramic goods. Combined thermal analysis (TA) methods were utilised for studying the related processes. Thermal behaviour and kinetic characteristics of decomposition of different types of clays was described and analysed. The changes in the mineralogical composition of the samples at thermal treatment were clarified and kinetic parameters of the processes were determined. Different overlapping processes like thermo-oxidation of organic matter, dehydroxylation of illite, illite-smectite, mica, and kaolin and oxidation of pyrite were explained. The specifics of decomposition of clays and their blends with Estonian OSA and the differences in their thermal behaviour depending on the origin of clays were clarified.

Wide studies have been completed in utilisation of OSA as soil conditioner. It was shown that several ashes can be granulated, maintaining definite process parameters that depend on ash characteristics. Lysimetric tests indicated that granulation enables to regulate and control the leachability of ash components, to optimize the neutralising cycle of soils and to benefit granulated products with different microelements. The respective technologies have been worked out and proposed for utilisation.

Chemistry and applications of phosphates

Systematic investigation of the impact of different substitutions into hydroxyapatite structure on the sorption capacity of apatite bio-molecules and elucidation of the sorption mechanism is one object of the research grant as well as the study of adsorption processes of surfactants and amino acids. Precipitated Mg^{2+} , Zn^{2+} , Cu^{2+} , Sr^{2+} and Na^+ mono- and Na- di-substituted Ca-hydroxyapatite (HAp) samples have been analysed by chemical, XRD, FTIR and thermal analysis (TA) methods. It was shown that HAp crystal size and morphology depend primarily on the characteristics of the divalent cations introduced into the precipitate. The processes occurring on the apatite surface when treated with amino acid (AA) solutions depend strongly on pH and cationic composition of apatite as well as on the respective AA ionic states. The effect of Cu substitution level on L-Ser and L-O-P-Ser adsorption was clarified in this stage of research. Studies of the impact of substitutions in apatite structure on the bio-molecules sorption mechanism will be continued with the aim of inorganic-organic hybrid catalysts synthesis.

Specifics of phosphorus removal from municipal wastewater using OSA was clarified. The precipitates formed in the hydrated OSA leachate mixed with the solutions containing different P compounds characteristic to municipal waste waters ($\text{Na}_2\text{HPO}_4 \cdot \text{H}_2\text{O}$, washing powders and liquids, di-Na-phenyl phosphate, di-Na glycerol phosphate) and urea were analysed and the chemistry of these processes described. It was shown that P-organic compounds do not precipitate completely and their presence leads to increased solubility of precipitates. So, it is more important to consider the origin of P to be removed by precipitation than the presence of surface active compounds and urea in these processes. The results can be applied in small-scale water purification.

In 2018-2019 new studies related to growing interest in phosphates will concern adsorption processes taking place on natural phosphates in the course of beneficiation with the aim to find most efficient reagents for Estonian phosphorite flotation and possible technologies for obtaining wet process phosphoric acid and mineral fertilizers from phosphate concentrates.

Thermal processes for CCS

The object of this research is to develop fundamentals for oxy-fuel (OF) combustion of oil shale. Thermal analysis methods and mathematical modelling were used to clarify the respective heterogeneous processes together with the calculation of kinetic parameters of different process stages. Composition of evolved gases and properties of the ashes formed were described. Equilibrium composition and flows of gaseous and solid products as well as heat duties of the boiler and heat exchangers in a simplified process scheme were described by modelling.

A promising OF co-combustion process of Estonian oil shale (EOS) with its semi-coke (SC) and biomass taken in a certain proportion was proposed. The co-firing cases were simulated using the ASPEN Plus software tool. In the simulations dry and wet flue gas recycle strategies were applied by controlling the O₂ percentage in flue gas on the basis of maintaining similar temperatures of gas-solid mixture at the outlet of combustion reactor. The main target was to evaluate the effects of blending EOS with other fuels regarding the operation conditions of air and OF combustion and to calculate the specific boiler temperatures with the same thermal input. The composition of flue gas was estimated for different cases from mass-energy balance and equilibrium calculations. Involving kinetics in the calculations is the task of the next period. In addition, the process of CO₂ binding by dolomite samples was studied in Ca-looping – another promising CCS method suitable e.g for cement industry. Several possibilities for increasing the binding parameters were tested. Process modelling by equilibrium calculations using different software will be continued.

4 Olulisemad projektid ja lepingud

- IUT3319 – Multikomponentsete mineraal-orgaaniliste süsteemide käitlemise alused: keemia, modelleerimine ja kestlik kasutus; Fundamentals of multicomponent mineral-organic systems: Chemistry, modeling and sustainable processing (Andres Trikkel)
- Lepinguline uurimistö Lep16094 – Glaukoniit-liivakivi valitud proovide termoanalüütilised uuringud (Andres Trikkel, Kaia Tõnsuaadu)
- Lepinguline uurimistö Lep 17096 (RITA, MAARE) – Maapõueressursside efektiivsemate, keskkonnasõbralikumate ja säästvamate kasutusvõimaluste väljatöötamine (Andres Trikkel)
- KIK 17083 – Uuring tööstusjäätmetest ehituslike täitematerjalide saamiseks koos CO₂ sidumisega (Mai Uibu)
- VA17086 – FLY Ash to valuable MinEerals – FLAME (Andres Trikkel)
- VFP17114 – CLEAN clinker production by Calcium looping process — CLEANKER (Andres Trikkel)

5 Uurimisgrupi 3 olulisemat publikatsiooni aruandeaastal

- Gruselle, M.; Tõnsuaadu, K. (2017). Tunable calcium-apatites as solid catalysts for classical organic reactions. *Current Organic Chemistry*, 21 (8), 688–697. [10.2174/1385272821666161219155302](https://doi.org/10.2174/1385272821666161219155302).
- Tamm, K.; Viires, R.; Kuusik, R.; Uibu, M. (2017). Calcium extraction from Estonian industrial wastes based on Ammonium solvents. *WIT Transactions on Ecology and the Environment*, 224, 465–476.
- Kaljuvee, T., Štubňa, I., Húlan, T., Kuusik, R. (2017). Heating rate effect on the thermal behavior of some clays and their blends with oil shale ash additives. *Journal of Thermal Analysis and Calorimetry*, 127, 33–45. [10.1007/s10973-016-5347-4](https://doi.org/10.1007/s10973-016-5347-4)

6 Koostöö teiste TA asutuste ja ettevõtetega (sh välisriikidest)

TTÜ: Materjali- ja keskkonnatehnoloogia instituut, Keemiliste kiletehnoloogiate teaduslabor, Polümeeride ja tekstiilitehnoloogia labor; Mehaanika ja tööstustehnika instituut; Ehituse ja arhitektuuri instituut, Ehitusprotsessi uurimisrühm; Energiatehnoloogia instituut, Soojustehnika teadus- ja arenduskeskus;

Geoloogia instituut, Maavarade- ja rakendusgeoloogia osakond, Isotoopgeoloogia osakond; Loodusteaduskond, Keemia ja biotehnoloogia instituut.

Tartu Ülikool: Füüsika Instituut, Geoloogia osakond, Keemia Instituut, Tehnoloogiainstituut, Farmaatsiainstituut; Keemilise ja Bioloogilise Füüsika Instituut; Eesti Maaviljeluse Instituut; Eesti Energia AS; Heidelberg Cement Group AS Kunda Nordic Tsement; Eesti Geoloogiateenistus

Välispartnerid

- Aalto University;
- Pierre et Marie Curie University Paris;
- Institute of Mineralogy and Crystallography, Bulgarian Academy of Science;
- Constantine the Philosopher University in Nitra, Slovakia;
- Vilnius University;
- Rijnsburger Holding BV;
- University of Greenwich at Medway;
- Carbon8 Systems Limited;
- Politecnico di Milano, Italy;
- GTK MIntec Mineral Processing Laboratory in Outokumpu;
- Lappeenranta University of Technology;
- European Cement Research Academy;
- Buzzi Unicem SPA, Italy;
- Consorzio L.E.A.P. Laboratorio Energia e Ambiente Piacenza, Italy;
- Agencia Estatal Consejo Superior de Investigaciones Cientificas, Spain;
- Italcementi Fabbriche Riunite Cemento SPA, Italy;
- IKN GMBH, Germany;
- Quantis Sàrl, Switzerland;
- Tsinghua University, China;
- Universitaet Stuttgart, Germany;
- VDZ gGmbH, Germany;
- Associazione Amici della Terra, Italy

7 Juhendamine

Juhendatavad doktoritööd

Tõnis Meriste – Eesti põlevkivi hapnikuspõletamise alused, Juhendajad Andres Trikkel, Rein Kuusik

Kärt Kärner – Smart aerogels based on the wood nanostructured cellulose (Tselluloosi funktsionaalsed aerogelid). Juhendajad Urve Kallavus, Kaia Tõnsuaadu, Matti Elomaa

Ana Jurkevicut – Synthesis of modified resin resorcinol and oil alkylresocinols basis. (Modifitseeritud vaigu süntees resortsinoolide ja põlevkivi alküülresortsinoolide alusel. Nende struktuuri ja omaduste uurimine). Juhendajad Larisa Grigorieva, Kaia Tõnsuaadu

Hakan Berber – Kaasjuhendaja Mai Uibu

Juhendatavad magistritööd

Regiina Viires – Juhendajad Kadriann Tamm, Mai Uibu

Juhendatud ja kaitstud magistritööd

Serkan Sener – Thermal analysis and modelling studies of blended fuels in oxy-fuel combustion (Kütusesegude hapnikus põletamise termoanalüüs ja modelleerimine). Juhendajad Can Rüstü Yörük, Andres Trikkel

Juhendatud ja kaitstud bakalaurusetööd

Anastassia Zuravljova – Investigation of industrial waste leaching dynamics based on ammonium salt solvents (Tööstusjäätmete leostusdünaamika uurimine ammoniumsoola solventide baasil). Juhendaja Kadriann Tamm

Indrek Piir – Beneficiation of phosphate ore by flotation (Fosfaadimaagi rikastamine flotatsioonmeetodil). Juhendaja Kaia Tõnsuaadu.

Mari-Liis Leinus – Production constructional filler material from industrial waste with binding of CO₂ (Tööstusjäätmetest ehitusliku täitematerjali saamine koos CO₂ sidumisega). Juhendajad Kadriann Tamm, Mai Uibu.

Kätlin Otto – Calcium extraction from industrial waste based on ammonium solvents (Kaltsiumi ekstraheerimine tööstuslikest jäätmetest ammooniumsoolade basil). Juhendajad Kadriann Tamm, Mai Uibu.

Mari-Liis Kõiv – Characterization of the granules from industrial residues in water system (Tööstuslikest jäätmetest granuleeritud täitematerjalide iseloomustus vesikeskkonnas). Juhendajad Kadriann Tamm, Mai Uibu.

8 Teadlasaktiivsus

8.1 Liikmelisus organisatsioonides, tunnustused

Loetelu struktuuriüksuse töötajate olulisematest siseriiklikest ja välisriiklikest T&A-ga seotud tunnustustest.

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Loetelu struktuuriüksuse töötajatest, kes on riiklike T&A -ga seotud otsustuskogude liikmed.

Rein Kuusik, juhtivteadur/vanemteadur

- EV Riikliku Üliõpilastööde konkursitööde hindaja;

Loetelu struktuuriüksuse töötajatest, kes on välisriikide akadeemiate või muude oluliste T&A -ga seotud välisorganisatsioonide liikmed.

Juha Kallas, v.teadur

- International Ozone Assosiation, programmikomitee liige
- European-African-Australian Group, programmikomitee liige

Rein Kuusik, j.teadur/v.teadur

- Rahvusvahelise võrgustiku GlobalTraPs (Global Transdisciplinary Process For Sustainable Phosphorus Management), 2010-2015 rahvuslik ja TTÜ koordinaator;
- Ajakirjade Applied Geochemistry, Chemosphere, Fuel, Fuel Processing Technology, Oil Shale, Environmental Science and Technology, Journal of Environmental Chemical Engineering, Journal of Environmental Management, Net Journal of Agricultural Science, International Journal of Mineral Processing retsensent

Kaia Tõnsuaadu, v.teadur

- Läti teadusnõukogu projekti hindamiseksperit
- Ajakirjade J. of Thermal Analysis and Calorimetry, J. of Colloids and Surfaces, J. of Minerals Processing, J. of Hazardous Materials retsensent

Tiit Kaljuvee, v.teadur

- Ajakirja JTAC piirkondlik toimetaja, Central and Eastern European Conference on Thermal Analysis and Calorimetry organiseerimiskomitee liige
- Shota Rustaveli (Georgia) Rahvusliku Teadusfondi grandiprojektide hindamiseksperit;
- ICTAC (International Confederation for Thermal Analysis and Calorimetry) liige;
- Ajakirjade J. of Thermal Analysis and Calorimetry, Thermochemica Acta ja Fuel retsensent.

Andres Trikkel, v.teadur/prof.

- IGIP (International Society for Engineering Education and Modern Engineering Pedagogy) liige;
- Ajakirjade J. of Thermal Analysis and Calorimetry ja Fuel retsensent

Mai Uibu, v.teadur

- Rumeenia Rahvusliku Teadusfondi (UEFISCDI - The Executive Agency for Higher Education, Research, Development and Innovation Funding) grandiprojekti hindamiseksperit
- Ajakirjade Waste Management and Research, Chemical Engineering and
- Processing: Process Intensification, Environmental Science & Technology,

- Chemical Engineering Journal, J. of Hazardous Materials, Frontiers in Energy
- Research, International J. of Greenhouse Gas Control, J. of CO₂ Utilization, ChemBioEng Reviews, ja Construction & Building Materials retsent

Mihkel Veiderma, emeriitprofessor

- Eesti Teaduste Akadeemia energeetikanõukogu liige;
- Soome Tehnikateaduste Akadeemia välisliige;
- Soome Keemikute Seltsi kirjavahetajaliige;
- projekti GlobalTraPs juhtasutuse (Zürich) kirjavahetajaliige;
- Current Inorganic Chemistry külalistoimetaja

8.2 Teadlasmobiilsus

Rein Kuusik – juhtivteadur/vanemteadur

- teaduslik lähetus – Outokumpu, Soome; 18.01.2017; GTK MIntec Mineral Processing Laboratory;
- teaduslik lähetus –Lappeenranta, Soome; 21.02.-22.02.2017; Lappeenranta University of Technology;
- teaduslik lähetus – Tartu, Eesti; 01.09.2017; Tartu Ülikool;
- teaduslik lähetus – Tartu, Eesti; 28.09.- 29.09.2017; Tartu Ülikool;

Tiit Kaljuvee – vanemteadur

- konverentsil osalemine – Budapest, Ungari; 05.06.- 11.06.2017; 1st JTAC Congress;
- konverentsil osalemine –;

Andres Trikkel – vanemteadur

- teaduslik lähetus – Brüssel, Belgia; 26.09.-29.09.2017; Fly Ash to Valuable Minerals 3-5VA17086;

Mai Uibu – vanemteadur

- teaduslik lähetus – Helsinki, Soome; 15.02.2017; Granulation seminar at Aalto University;
- teaduslik lähetus – Helsinki, Soome; 11.05.- 12.05.2017; Aalto University;
- Teaduslik lähetus –Milano, Itaalia; 17.10.- 20.10.2017; Politecnico di Milano; Horizon 2020 projekti CLEANKER kick-off koosolek;
- teaduslik lähetus – Gillingham, Suurbritannia; 04.12.- 06.12.2017; University of Greenwich at Medway

Can Rüstü Yörük – insener

- teaduslik lähetus – Düsseldorf, Saksamaa; 06.11.- 08.11.2017; European Cement Research Academy;

Kadriann Tamm – teadur

- teaduslik lähetus – Outokumpu, Soome; 18.01.2017; GTK MIntec Mineral Processing Laboratory;
- teaduslik lähetus – Lappeenranta, Soome; 21.02.-22.02.2017; Lappeenranta University of Technology;
- teaduslik lähetus – Gillingham, Suurbritannia; 04.12.- 06.12.2017; University of Greenwich at Medway;

8.3 Väliskülalised

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9 Teaduspublikatsioonid (täisnimekiri, ETIS klassifikaatori alusel).

1.1. Teadusartiklid, mis on kajastatud Thomson Reuters Web of Science andmebaasis (v.a. Thomson Reuters Conference Proceedings Citation Index poolt refereeritud kogumikud) ja/või

Euroopa Teadusfondi humanitaarteaduste loendi ERIH (European Reference Index of the Humanities) kategooriates INT1 ja INT2 ja/või andmebaasis Scopus (v.a. kogumikud);

1. Tamm, K.; Viires, R.; Kuusik, R.; Uibu, M. (2017). Calcium extraction from Estonian industrial wastes based on Ammonium solvents. *WIT Transactions on Ecology and the Environment*, 224, 465–476.
2. Kaljuvee, T., Štubňa, I., Húlan, T., Kuusik, R. (2017). Heating rate effect on the thermal behavior of some clays and their blends with oil shale ash additives. *Journal of Thermal Analysis and Calorimetry*, 127, 33–45.10.1007/s10973-016-5347-4.
3. Ben Moussa, S.; Lachheb, J.; Gruselle, M.; Maaten, B.; Kriis, K.; Kanger, T.; Tõnsuaadu, K.; Badraoui, B. (2017). Calcium, Barium and Strontium apatites: A new generation of catalysts in the Biginelli reaction. *Tetrahedron*, 73 (46), 6542–6548.10.1016/j.tet.2017.09.051.
4. Gruselle, M.; Tõnsuaadu, K. (2017). Tunable calcium-apatites as solid catalysts for classical organic reactions. *Current Organic Chemistry*, 21 (8), 688–697.10.2174/1385272821666161219155302.
5. Sarapuu, A.; Kreek, K.; Kisand, K.; Kook, M.; Uibu, M.; Koel, M.; Tammeveski, K. (2017). Electrocatalysis of oxygen reduction by iron-containing nitrogen-doped carbon aerogels in alkaline solution. *Electrochimica Acta*, 230, 81–88.10.1016/j.electacta.2017.01.157.
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