LUT CENTRE FOR SEPARATION TECHNOLOGY
LUT EROTUSTEKNIIKAN KESKUS

CST BULLETIN 2016

CST year of celebration 2017

Centre for Separation Technology, CST will celebrate its 20th anniversary 2017. CST was established 1997 to enhance the sustainable use of natural resources by means of separation technology.

CST Member day 2016

CST member day was arranged in October. Chairman of the board Timo Vartiainen told about the collaboration of their family owned company with Lappeenranta University. We started the collaboration with LUT in learning language skills in early years of Larox. Larox was heading to international markets at that time. The long collaboration between Larox and university has taken the form of donation professorships to LUT. Timo Vartiainen encourages university to be more active in seeking collaboration with companies but reminded companies as well to be active in building long term collaboration.

”When university named laboratories according to collaboration partners my father asked me did we get one. I answered don’t worry, we got a whole building”, Timo Vartiainen told the participants of member day.

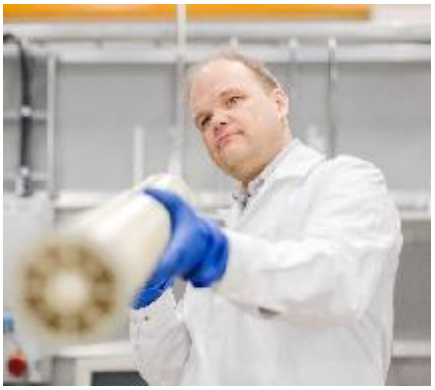
The prerequisite and culture of collaboration was discussed also after Petri Ajo told about his experiences of as Fullbright scholar at Caltech.

”There is no feeling that it is worthwhile keeping your best ideas to yourself” Petri told us. Participants stared to ponder what would be the actions to enhance this kind of culture in Finland as well.

We heard many presentations from the collaboration companies but from LUT as well. In between the presentations the discussions covered commercialization of innovations, the opportunities of digitalization and changes in energy production. Our research in separation technology was presented as the two multicompetence research platforms were presented; Re-Source and SAWE. Special presentations were given on recovering metals and waste water treatment.

LUT is already no 1 in separation technology in Finland. Next year is the 20th anniversary of CST and therefore both LUT and CST are looking to be in the international spear head with their collaboration partners.

Sisällys



NOFS
Nordic Filtration Symposium 2016

The focus of the 16th Nordic Filtration Symposium was on "Filtration for Circular Economy" and it was be organized by The LUT Centre for Separation Technology (CST) and The Nordic Filtration Society.

The oral sessions and poster exhibition covered the following main themes:

- Filtration in facilitation of sustainable water use
- Filtration applications in biorefining
- Filtration applications in mining and metallurgy sector
- Development of novel filtration and separation materials and matrices

We want to congratulate Professor Mika Mänttäri

who was Granted Science Award 2016. It is the biggest and most distinguished grant given by the LUT Research Foundation.

Doctoral dissertations
LUT Chemical Technology

New Docent

PhD Antero Laitinen has been appointed to docent to Separation Technology.

Elsi Strand

Enhancement of ultrafiltration process by pretreatment in recovery of hemicelluloses from wood extracts

Hemicelluloses are potential raw material for several items produced in future wood-based biorefineries. One possible method for recovering hemicelluloses from wood extracts is ultrafiltration (UF). However, low filtration capacities and severe fouling restrict the use of tight UF membranes in the treatment of wood extracts. The lack of suitable commercial membranes creates a need for pretreatment which would decrease fouling and increase the filtration capacity. This thesis focuses on the evaluation of the possibility to improve the filtration capacity and decrease fouling with the pretreatment of wood extracts. Methods which remove harmful compounds and methods which degrade them are studied, as well as combinations of the methods.
The tested pretreatments have an influence on both the concentration of different compounds and the molecular mass distribution of the compounds in the extract. This study revealed that in addition to which kind of compounds were removed, also the change in molecular size distribution affected the filtration capacity significantly. It was shown that the most harmful compounds for the filtration capacity of the hydrophobic 5 kDa membrane were the ones capable of permeating the membrane and fouling also the inner membrane structure. Naturally, the size of the most harmful compounds depends on the used UF membrane and is thus case-specific. However, in the choice of the pretreatment method, the focus should be on the removal of harmful compound sizes rather than merely on the total amount of removed foulants.

The results proved that filtration capacity can be increased with both adsorptive and oxidative pre-treatments even by hundreds of per cents. For instance, the use of XAD7 and XAD16 adsorbents in-creased the average flux in the UF of a birch extract from nearly zero to 107 kg/(m2h) and 175 kg/(m2h), respectively. In the treatment of a spruce extract, oxidation by pulsed corona discharge (PCD) increased the flux in UF from 46 kg/(m2h) to 158 kg/(m2h). Moreover, when a birch extract batch was treated with laccase enzyme, the flux in UF increased from 15 kg/(m2h) to 36 kg/(m2h). However, fouling was decreased only by adsorptive pretreatment while oxidative methods had a negligible or even negative impact on it. This demonstrates that filtration capacity and fouling are affected by different compounds and mechanisms.

The results of this thesis show that filtration capacity can be improved and fouling decreased through appropriate pretreatment. However, the choice of the best possible pretreatment is case-specific and depends on the wood extract and the membrane used. Finding the best option requires information on the extract content and membrane characteristics as well as on the filtration performance of the membrane in the prevailing conditions and a multivariate approach. On the basis of this study, it can be roughly concluded that adsorptive pretreatment improves the filtration capacity and decreases fouling rather reliably, but it may lead to significant hemicellulose losses. Oxidation reduces the loss of valuable hemicelluloses and could improve the filtration capacity, but fouling challenges may remain. Combining oxidation with adsorptive pretreatment was not a solution for avoiding hemicellulose losses in the tested cases.

Sara-Maaria Alatalo

Hydrothermal carbonization in the synthesis of sustainable porous carbon materials

Carbon materials are found versatile and applicable in wide range of applications. During the recent years research of carbon materials has focussed on the search of environmentally friendly, sustainable, renewable and low-cost starting material sources as well as simple cost-efficient synthesis techniques. As an alternative synthesis technique in the production of carbon materials hydrothermal carbonization (HTC) has shown a great potential. Depending on the application HTC can be performed as such or as a pretreatment technique. This technique allows synthesis of carbon materials i.e. hydrochars in closed vessel in the presence of water and self-generated pressure at relatively low temperatures (180-250 ˚C). As in many applications well developed porosity and heteroatom distribution are in a key role. Therefore in this study different techniques e.g. varying feedstock, templating and post-treatment in order to introduce these properties to the hydrochars structure were performed. Simple monosaccharides i.e. fructose or glucose and more complex compounds such as cellulose and sludge were performed as starting materials. Addition of secondary precursor e.g. thiophenecarboxaldehyde and ovalbumin was successfully exploited in order to alter heteroatom content. It was shown that well-developed porosity (SBET 550 m2/g) can be achieved via one-pot approach (i.e. exploitation of salt mixture) without conventionally used post-carbonization step. Nitrogen-enriched hydrochars indicated significant Pb(II) and Cr(VI) removal efficiency of 240 mg/g and 68 mg/g respectively. Sulphur addition into carbon network was not found to have enhancing effect on the adsorption of methylene blue or change acidity of the carbon material. However, these hydro-

chars were found to remove 99.9 % methylene blue and adsorption efficiency of these hydrochars remained over 90 % even after regeneration. In addition to water treatment application N-rich high temperature treated carbon materials were proven applicable as electrocatalyst and electrocatalyst support. Hydrothermal carbonization was shown to be workable technique for the production of carbon materials with variable physico-chemical properties and therefore hydrochars could be applied in several different applications e.g. as alternative low-cost adsorbent for pollutant removal from water.

Shila Jafari

Investigation of adsorption of dyes onto modified titanium dioxide

Titanium dioxide (TiO2) nanoparticles with different sizes and crystalloid structures produced by the thermal method and doped with silver iodide (AgI), nitrogen (N), sulphur (S) and carbon (C) were applied as adsorbents. The adsorption of Methyl Violet (MV), Methylene Blue (MB), Methyl Orange (MO) and Orange II on the surface of these particles was studied. The photocatalytic activity of some particles for the destruction of MV and Orange II was evaluated under sunlight and visible light. The equilibrium adsorption data were fitted to the Langmuir, Freundlich, Langmuir-Freundlich and Temkin isotherms. The equilibrium data show that TiO2 particles with larger sizes and doped with AgI, N, S and C have the highest adsorption capacity for the dyes. The kinetic data followed the pseudo-first order and pseudo-second order models, while desorption data fitted the zero order, first order and second order mod-els. The highest adsorption rate constant was observed for the TiO2 with the highest anatase phase percentage. Factors such as anatase crystalloid structure, particle size and doping with AgI affect the photocatalytic activity significantly. Increasing the rutile phase percentage also decreases the tendency to desorption for N-TiO2 and S-TiO2. Adsorption was not found to be important in the photocatalytic decomposition of MV in an investigation with differently sized AgI-TiO2 nanoparticles. Nevertheless C-TiO2 was found to have higher adsorption activity onto Orange II, as the adsorption role of carbon ap-proached synchronicity with the oxidation role.

Olga Oleksiienko

Physico-chemical properties of sol-gel synthesized titanosilicates for the uptake of radionuclides from aqueous solutions

Harnessing the power of nuclear reactions has brought huge benefits in terms of nuclear energy, medicine and defense as well as risks including the management of nuclear wastes. One of the main issues for radioactive waste management is liquid radioactive waste (LRW). Different methods have been applied to remediate LRW, thereunder ion exchange and adsorption. Comparative studies have demonstrated that Na2Ti2O3SiO4·2H2O titanosilicate sorption materials are the most promising in terms of Cs+ and Sr2+ retention from LRW. Therefore these TiSi materials became the object of this study. The recently developed in Ukraine sol-gel method of synthesizing these materials was chosen among the other reported approaches since it allows obtaining the TiSi materials in the form of particles with size ≥ 4mm. utilizing inexpensive and bulk stable inorganic precursors and yielded the materials with desirable properties by alteration of the comparatively mild synthesis conditions. The main aim of this study was to investigate the physico-chemical properties of sol-gel synthesized titanosilicates

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Marina Shestakova: Ultrasound-assisted electrochemical treatment of wastewaters containing organic pollutants by us-ing novel Ti/Ta2O5-SnO2 electrodes

Mehdi Hasan: Purification of aqueous electrolyte solutions by air-cooled natural freezing

Matti Lampinen: Development of hydrometallurgical reactor leaching for recovery of zinc and gold

for radionuclide uptake from aqueous solutions. The effect of synthesis conditions on the structural and sorption parameters of TiSi xerogels was planned to determine in order to obtain a highly efficient sorption material. The ability of the obtained TiSis to retain Cs+, Sr2+ and other potentially toxic metal cations from the synthetic and real aqueous solutions was intended to assess. To our expectations, abovementioned studies will illustrate the efficiency and profitability of the chosen synthesis approach, synthesis conditions and the obtained materials. X-ray diffraction, low temperature adsorption/desorption surface area analysis, X-ray photoelectron spectroscopy, infrared spectroscopy and scanning electron microscopy with energy dispersive X-ray spectroscopy was used for xerogels characterization. The sorption capability of the synthesized TiSi gels was studied as a function of pH, adsorbent mass, initial concentration of tar-get ion, contact time, temperature, composition and concentration of the background solution. It was found that the applied sol-gel approach yielded materials with a poorly crystalline sodium titanosilicate structure under relatively mild synthesis conditions. The temperature of HTT has the strongest influence on the structure of the materials and consequently was concluded to be the control factor for the preparation of gels with the desired properties. The obtained materials proved to be effective and selective for both Sr2+ and Cs+ decontamination from synthetic and real aqueous solutions like drinking, ground, sea and mine waters, blood plasma and liquid radioactive wastes.

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Titanium dioxide based nanomaterials for photocatalytic water treatment

Water treatment using photocatalysis has gained extensive attention in recent years. Photocatalysis is promising technology from green chemistry point of view. The most widely studied and used photo-catalyst for decomposition of pollutants in water under ultraviolet irradiation is TiO2 because it is not toxic, relatively cheap and highly active in various reactions. Within this thesis unmodified and modified TiO2 materials (powders and thin films) were prepared. Physico-chemical properties of photocatalytic materials were characterized with UV-visible spectroscopy, scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray photoelectron spectrometry (XPS), inductively coupled plasma optical emission spectroscopy (ICP-OES), ellipsometry, time-of-flight secondary ion mass spectrometry (ToF-SIMS), Raman spectroscopy, goniometry, diffuse reflectance measurements, thermo-gravimetric analysis (TGA) and nitrogen adsorption/desorption. Photocatalytic activity of prepared samples in aqueous environment was tested using model compounds such as phenol, formic acid and metazachlor. Also purification of real pulp and paper wastewater effluent was studied. Concentration of chosen pollutants was measured with high pressure liquid chromatography (HPLC). Mineralization and oxidation of organic contaminants were monitored with total organic carbon (TOC) and chemical oxygen demand (COD) analysis. Titanium dioxide powders prepared via sol-gel method and doped with dysprosium and praseodymium were photocatalytically active for decomposition of metazachlor. The highest degradation rate of metazachlor was observed when Pr-TiO2 treated at 450ºC (8h) was used. The photocatalytic LED-based treatment of wastewater effluent from plywood mill using commercially available TiO2 was demonstrated to be promising post-treatment method (72% of COD and 60% of TOC was decreased after 0 min of irradiation). The TiO2 coatings prepared by atomic layer deposition technique on Aluminum foam were photocatalytically active for degradation of formic and phenol, however suppression of activity was observed. Photocatalytic activity of TiO2/SiO2

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films doped with gold bipyramid-like nano-particles was about two times higher than reference, which was not the case when gold nanospheres were used.

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Ultrasound-assisted electrochemical treatment of wastewaters containing organic pollutants by using novel Ti/Ta2O5-SnO2 electrodes

Advanced oxidation processes (AOPs) are modern methods using reactive hydroxyl radicals for the mineralization of organic pollutants into simple inorganic compounds, such as CO2 and H2O. Among AOPs electrochemical oxidation (EO) is a method suitable for colored and turbid wastewaters. The degradation of pollutants occurs on electrocatalytic electrodes. The majority of electrodes contain in their structure either expensive materials (diamond and Pt-group metals) or are toxic for the environment compounds (Sb or Pb). One of the main disadvantages of electrochemical method is the polarization and contamination of electrodes due to the deposition of reaction products on their surface, which results in diminishing of the process efficiency. Ultrasound combined with the electrochemical degradation process eliminates electrode contamination because of the continuous mechanical cleaning effect produced by the formation and collapse of acoustic cavitation bubbles near to the electrode surface. Moreover, high frequency ultrasound generates hydroxyl radicals at water sonolysis. Ultra-sound-assisted EO is a non-selective method for oxidation of different organic compounds with high degradation efficiencies.

The aim of this research was to develop novel sustainable and cost-effective electrodes working as electrocatalysts and test their activity in electrocatalytic oxidation of organic compounds such as dyes and organic acids. Moreover, the goal of the research was to enhance the efficiency of electrocatalytic degradation processes by assisting it with ultrasound in order to eliminate the main drawbacks of a single electrochemical oxidation such as electrodes polarization and passivation. Novel Ti/Ta2O5-SnO2 electrodes were developed and found to be electrocatalytically active towards water (with 5% Ta con-tent, 10 oxide film layers) and organic compounds oxidation (with 7.5% Ta content, 8 oxide film layers) and therefore these electrodes can be applicable in both environmental and energy fields. The synergetic effect of combined electrolysis and sonication was shown while conducting sono-electrochemical (EO/US) degradation of methylene blue (MB) and formic acid (FA). Complete degradation of MB and FA was achieved after 45 and 120 min of EO/US process respectively in neutral media. Mineralization efficiency of FA over 95% was obtained after 2 h of degradation using high frequency ultrasound (381, 863, 1176 kHz) combined with 9.1 mA/cm2 current density. EO/US degradation of MB provided over 75% mineralization in 8 h. High degradation kinetic rates and mineralization efficiencies of model pollutants obtained in EO/US experiments provide the preconditions for further extrapolation of this treatment method to pilot scale studies with industrial wastewaters.

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Purification of aqueous electrolyte solutions by air-cooled natural freezing

Freeze crystallization is a particular type of a purification method where the solvent freezes out, which constricts the volume of the solution, leaving thus behind a more concentrated solution. In the case of freezing an aqueous solution, water is the solvent which crystallizes and can be separated from the concentrated solution by the virtue of buoyancy. In an ideal situation, freeze crystallization of an aqueous solution produces ice crystals that do not contain any of the impurities present in the original solution. As the process continues, the original solution becomes more concentrated and the freezing temperature declines progressively. Freezing point depression (FPD) is of vital importance in characterizing the freezing behavior of any solution. Due to this necessity, a new calculation method to predict FPD is presented in this work. In this method, designated ion-interaction parameters for the Pitzer model are extracted from reliable FPD data found in the literature, other than calorimetric data. The extracted parameters from FPD data are capable of predicting the freezing point more accurately than those resulted from the calorimetric data. The calculation method is exemplified for numerous 1-1 and 1-2 types of electrolytes. Impurities in excess of the maximum recommended limits must be removed from waste water prior to discharge because of their persistent bio-accumulative and detrimental nature. Natural freezing is suggested in the present work as a purification technique to treat huge volumes of waste water in a sustainable and energy-efficient manner. The efficiency of freeze crystallization in the purification of waste water by imitating natural freezing in a developed winter simulation with the provision of altering winter conditions is scrutinized in this thesis. Hence, natural freezing is simulated experimentally for ice crystallization from unsaturated aqueous Na2SO4 and NiSO4 solutions to assess the feasibility of such a technique to be used to purify waste waters containing electrolytes. This work presents a series of data in similitude of natural freezing of water from aqueous Na2SO4 and NiSO4 solutions in various concentrations and freezing conditions. The influence of solution concentration and different freezing conditions, such as ambient temperature, freezing time and freezing rate, on the efficiency of the purification process is investigated by analyzing the effective distribution coefficient (K) of the solute between ice and the solution. The experimental results demonstrate clearly that high purity ice can be obtained from slow freezing of the solution with the concentration typically found in industrial waste water. During freeze crystallization, the diffusion of impurities from the solid-liquid interface to the bulk of the solution, along with the growth mechanism of the solid phase play an important role in determining the purity of the ice layer. Therefore, a calculation method is introduced to estimate the concentration of the solution at the advancing ice–solution interface in terms of the limiting distribution coefficient (K*) from experimental K values at different growth conditions. The heat transfer -controlled growth rate of the ice limited by the free convective heat transfer coefficient of air (hair) rather than the thermal conductivity of the ice (kice) and the heat transfer coefficient of the solution (hsol) was found to prevail over the mass transfer of rejected solute molecules from the ice–solution interface to the bulk solution of experimental interest. A simplified and robust model is developed to estimate the thickness and growth rate of the ice layer formed from solutions at differ-ent freezing conditions, and the model is validated with experimental results. In addition, inclusion formation within the ice matrix during freezing is investigated for various solution concentrations, both macroscopically and microscopically.

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Development of hydrometallurgical reactor leaching for recovery of zinc and gold

Hydrometallurgical methods offer promising techniques for resolving the challenge of producing metals essential to modern life in an environmentally and economically sustainable manner. Leaching has a central role in most hydrometallurgical processes. Hence, leaching performance has a great impact on the performance of the hydrometallurgical process as a whole. Reactor leaching is an approach that enables leaching to be carried out with good control and relatively short leaching time. The main drawback of reactor leaching is the high cost. The challenge thus becomes to develop leaching processes that improve the process economics and at the same time fulfil technical and environmental requirements. There is potential to meet this challenge through continued development of existing reactor leaching technologies, but demand for breakthrough technologies also exists. Hydrometallurgical reactor leaching is a multiphase reaction system, and research and development of reactor leaching faces many of the difficulties typically found when investigating such systems. There are a large number of physical and chemical phenomena, only the most relevant of which can be taken into consideration and under study. The starting point of development should be a comprehensive understanding of the process solution and solid raw material behavior. This can be achieved by mastering the thermodynamics and kinetics of the processes involved using experimental methods and rigorous modeling and simulation approaches. Thereafter, reactor concepts can be investigated and reactors designed based on the mass and heat transfer aspects, flow dynamics and the desired capacity. The current work ex-amines two hydrometallurgical reactor leaching processes used for metal recovery: thiosulfate leaching for gold recovery and direct leaching for zinc recovery. The leaching processes studied are at different levels of technological development. Thiosulfate leaching can be considered a breakthrough technology that may initiate an era of cyanide-free gold production. Direct leaching processes have several industrial applications and they have been proven to meet the requirements set for the metals producing industry. Therefore, it is evident that direct leaching processes will play a significant role in zinc production also in the future and development of these processes is still ongoing. In this work, new experimental data are presented that improve understanding of chemical and physical phenomena related to the two reactor leaching processes studied. The ammoniacal thiosulfate leaching experiments of pressure oxidized gold concentrate show that gold can be effectively leached with thiosulfate as a lixiviant using low reagent concentrations in the leaching stage and pressure oxidation as a pretreatment method. This approach enables low reagent consumption and stabilizes the process solution, which facilitates the following recovery stage and makes re-use of the leaching solution possible. The experiments performed in this work provide new data on the leaching of gold with thiosulfate as a lixiviant and bring new insights into the leaching chemistry. New experimental results are also presented for direct leaching of zinc concentrate in conditions close to those of industrial leaching processes. The results from experiments of direct leaching of zinc concentrate show that the solution composition has a remarkable effect on the leaching kinetics, which clearly demonstrates that it is important to have experimental data for the leaching kinetics at the conditions of industrial leaching process. A modeling approach for leaching processes is presented, which brings new understanding to process development. The most significant contribution of the modeling approach in this work can be found in the quantitative modeling of the solid raw material, with inclusion of particle size distribu-

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tion, determination of the role of internal diffusion in the kinetics, and application of sophisticated mathematical methods (MCMC methods) to study the reliability of the established models and model parameters. The presented modeling approach offers a way to discriminate and study the phenomena behind the leaching process closely and with high reliability. The simulation approach developed for direct atmospheric leaching of zinc concentrates allows the role of different phenomena in the progress of the leaching to be evaluated. The simulation approach developed furthermore offers an effective tool for evaluation of leaching processes and downstream operations and thus aids attempts to increase the throughput of hydrometallurgical plants.

We are not working alone and isolated so here are some dissertations that are related to our research area and might also be of interest to you:

LBM, LUT School of Business and Management

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Analyzing the profitability of metal mining investments with system dynamic modeling and real option analysis

The importance of ex-ante analysis of metal mining investments has grown in recent years. The decreasing profitability of new projects and unpredictable metal markets pose a challenge to the currently applied models of profitability analysis. The purpose of this research is to investigate simulation and system dynamic (SD) models applicable to real option analysis of metal mining investments. Real options in general refer to flexibility of projects which can both decrease the negative effects of uncertainty and, on the other hand, enhance the positive future realizations of the projects. This thesis is a collection of articles with common theme of enhancing the simulation- and SD-models used for real option valuation of metal mining investments. Within the framework of real option analysis it is claimed that metal mining investments are a distinct object of study, which have specific characteristics that should be taken into account in their real option analysis. The research methods of this thesis include literature review and modeling. Two distinct simulation models are created: a system dynamic simulation model and a static simulation model. The models are used to run analyses with illustrative case examples that have their background in the metal mining industry. The results suggest that metal mining investments can be treated as techno-economic systems by using the SD-methodology and that the use of system dynamic simulation based analysis allows a more detailed and realistic ex-ante modeling of metal mining investments and of the connected uncertainties. It is shown that system dynamic models are able to model compound and interacting real options that exist on a single asset. Based on the results of this work it seems that under non-ideal conditions the profitability of metal mining investments is linked to the financing of these projects. High leverage with a fixed debt servicing schedule may inhibit the use of managerial flexibility that may cause a loss of project value. It is suggested that an optimal debt-equity ratio exists that maximizes the project value per percentage point of equity invested.

Doctoral dissertations at LBM, LUT School of Business and Management

Jyrki Savolainen: Analyzing the profitability of metal mining investments with system dynamic modeling and real option analysis

LES, LUT School of Energy Systems

Ekaterina Sermyagina: Modelling of torrefaction and hydrothermal carbonization and heat integration of torrefaction with a CHP plant

LES, LUT School of Energy Systems
Ekaterina Sermyagina

Modelling of torrefaction and hydrothermal carbonization and heat integration of torrefaction with a CHP plant

Biomass provides an excellent opportunity to increase the use of local resources and promote renewable energy generation. The considerable diversity of biomass materials and differences in their chemical structure require detailed evaluation of their properties and impact on the conversion processes. The unstable quality of untreated biomass poses certain problems for biomass utilization in a large scale. Hydrothermal carbonization and torrefaction present two possible ways of improving the characteristics of biomass. Comprehensive understanding and evaluation of all the influencing factors of these relatively novel methods is crucial for the development of the processes. This thesis describes the results of chemical analysis of nine biomasses with respect to thermochemical conversion: the impact of chemical components on thermal decomposition is evaluated. The performance of any conversion process depends not only on biomass properties but also on the process characteristics, and that is why the effect of the main reaction parameters on mass and energy yields during hydrothermal carbonization and torrefaction of coniferous biomass is studied experimentally and expressed with mathematical correlations. Since both processes require a certain amount of heat to be supplied, the development of the technologies in a large scale by means of heat integration with combined heat and power (CHP) plants has significant potential. A model of a torrefaction unit is developed and integrated with two different-sized CHP plants. The mutual effects of the torrefaction process and the operational mode of the CHP plant on the thermodynamic performance of the integrated plant are investigated with six integration scenarios. The analysis reveals notable differences in the impact of torrefaction-CHP integration at different operational modes of the CHP plant, and the influence of seasonal variations in the operation of a CHP backpressure plant is analyzed in detail with a developed multiperiod model. Profitability evaluation of the integrated schemes, together with stand-alone and co-located CHP and torrefaction plants make it possible to assess the economic potential of the integration. This study indicates that the heat integration of torrefaction and a CHP plant can be economically profitable over co-located plants (particularly for the integration options with the longest operation time). Additionally, this work assesses the main economic factors for the profitability of integrated plants and confirms the importance of detailed operational and economic analyses for the assessment of the potential of the integration options.

Doctoral dissertations at LBM, LUT School of Business and Management

Jyrki Savolainen: Analyzing the profitability of metal mining investments with system dynamic modeling and real option analysis

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