INSTITUTE OF CHEMICAL PROCESS FUNDAMENTALS OF THE ASCR

Group of thermal processes

Environmental Process Engineering Laboratory

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2. Introduction

Environmental Process Engineering Laboratory was established with the intention to concentrate most of the sustainable technologies research at ICPF. Several technologies have been developed within the laboratory, e.g. total recycling of PET (pilot plant is under construction in Poland), recovery of yttrium and europium oxides from compact fluorescent lamps (pilot plant under construction in South Africa). The laboratory is focused on research in the field of environmental processes and utilization of waste streams from industry and waste in general. Current projects are aimed e.g. on in-situ microwave desorption of organic pollutants, utilization of waste security paper, recovery of rare earth elements from waste electronic equipment, producer gas cleaning from gasification of alternative fuels, or metals recovery from municipal solid waste incineration residues. The systematic research, both fundamental and applied, enables also long-term cooperation with industrial partners.

The Group of thermal processes, one of three research groups of the Environmental Process Engineering Laboratory, is focused on the research in the fields of incineration and gasification and related processes providing ecological, economical and safe operation of advanced technologies, such as flue gas treatment or solid residues recovery. A number of research projects are solved in cooperation within the department or in a broader cooperation in the frame of our institute.

3. Fields of interest

- Advanced processes for gasification, gas cleaning and hydrogen production.
- Persistent organic pollutants and heavy metals behavior and emissions.
- Medium and high temperature gas cleaning (removal of HCl and H_2S from producer gas) for advanced applications.
- Advanced processes for waste-to-energy.
- Urban mining.
- Recovery of REE from coal ashes and slags (project proposal Research Fund for Coal and Steel).
- Recovery of EU critical commodities and metals from MSWI bottom ash and fly ash.
- Sewage sludge combustion and co-combustion with phosphorus recovery from ash.

4. Experimental facilities

The core experimental facilities are the fluidized bed incinerator together with the fluidized bed gasifier equipped with gas-mixing device, gas analyzers and other facilities for incineration and gasification tests. Further facilities include equipment for studies of properties and behaviour of incineration residues.

Fluidized bed incinerator

- Processes: incineration, drying.
- Thermal input: up to 10 kW.
- Operation temperature: up to 1000 °C.
- Heat supply: electric heating by four sections.

Fluidized bed gasifier

- Processes: gasification, suppression of tar formation.
- Thermal input: up to 10 kW.
- Operation temperature: up to 1000 °C.
- Heat supply: electric heating by three sections.
- High temperature unit for producer gas cleaning for studies of dust removal (up to 600 °C), sulphur and tar removal (up to 1000 °C).

Supporting facilities for fluidized bed reactors

- Gas-mixing unit for gasification media – enables accurate control of composition of gasification media which can consist of: air, O_2, N_2, H_2O a CO_2.
- On-line gas analyzers – incineration flue gas: CO, CO_2, O_2, NO_x, N_2O, SO_2; gasification producer gas: CO, CO_2, CH_4, H_2.
- Gas chromatographs for detailed analysis of producer gas and tar composition.
- Sampling lines for heavy metals, ammonia, halogenides and fly ash.

Facilities for characterization, testing and preparation of fuels and solid residues

- Grinders, mills and sieves for fuels preparation.
- Pelletiser for biomass materials.
- System for microwave digestion of solid materials.
- Equipment for leachability tests.
- Apparatus for determination of fluidization characteristics of powdered materials.
- Muffle furnaces up to 1200 °C.

5. Recent research projects

Advanced concepts and process schemes for CO_2 free fluidized and entrained bed co-gasification of coals

Joint research project with CNR (Italy), LNEG (Portugal), CIEMAT (Spain), TUV (Austria), ICL (United Kingdom), ELCOGAS (Spain), UNISA (Italy); supported by RFCS, 2010-2013.

The project aims at integrating gasification schemes for the co-gasification of coal, biomass and waste with processes for CO_2 separation and capture. Fluidized bed and entrained flow gasification processes are considered thanks to their flexibility and effectiveness for carrying out thermal conversion of different feedstock, for matching different requirements of producer gas end-users and for effective CO_2 separation. Fuel feeding in a form of solid particles, mixtures of solid particles and various slurries (suspensions of solid fuel particles) and different fluidized bed particulate materials (sand, dolomite, olivine) are compared in terms of their effects in fluidized bed gasification. Effects of both, primary measures (involved in overall conditions of a given gasification process) and secondary (downstream) measures on syngas properties (particularly composition, purity and heating value) and possible applications are studied as well as effects of partial substitution of steam by CO_2 in gasification medium on gasification characteristics and producer gas properties.

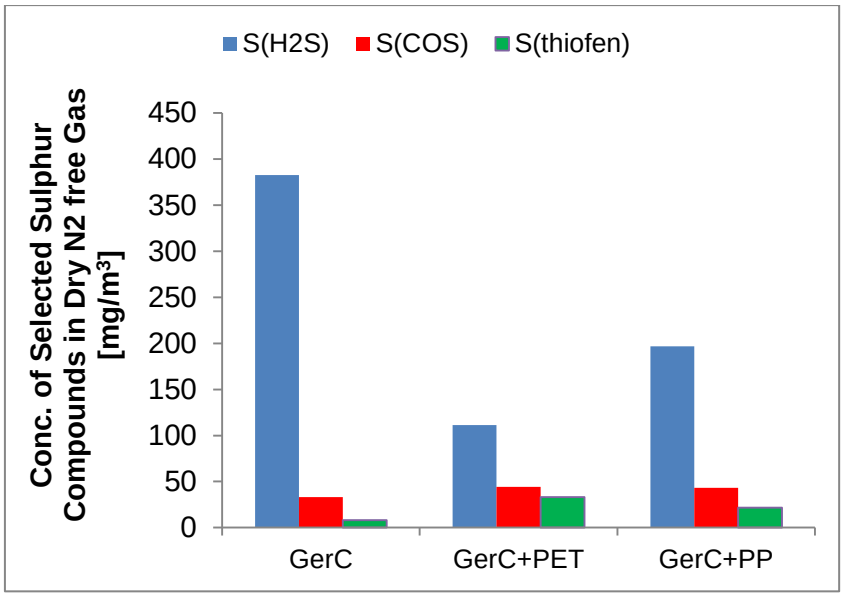

Fig. Comparison of concentrations of selected sulfur compounds (H_2S, COS and thiophene) in dry, N_2-free producer gas for fluidized bed (FB) gasification of German coal with gas concentrations of the sulfur compounds in FB co-gasification with PET (24 wt. %) and PP (20 wt. %). t = 850 °C, air/steam gas. medium, ER = 0.21, H_2O/C molar ratio ≈ 1, FB-material: sand/dolomite ≈ 1/1.

Brownfields - Source of renewable energy

Joint project with EVECO Brno Ltd., Life Science University Prague; supported by Technology Agency of the Czech Republic, 2011-2014.

The phytoextraction ability of some fast-growing plant species leads to the idea of connecting biomass production with soil remediation on contaminated industrial zones and regions. This biomass will contain significant amount of heavy metals and its energetic utilization has to be considered carefully to minimize negative environmental impacts. Therefore, the behavior of selected heavy metals was observed during thermal treatment of contaminated biomass. Moreover, a detailed analysis of trace and nutrient elements distribution and chemical speciation in ashes was performed. The potential of the application of these ashes and methods of treatment for heavy metals removal was evaluated. This knowledge is essential for further utilization of all products of thermal treatment. The concept of contaminated biomass growing and utilization was proposed.

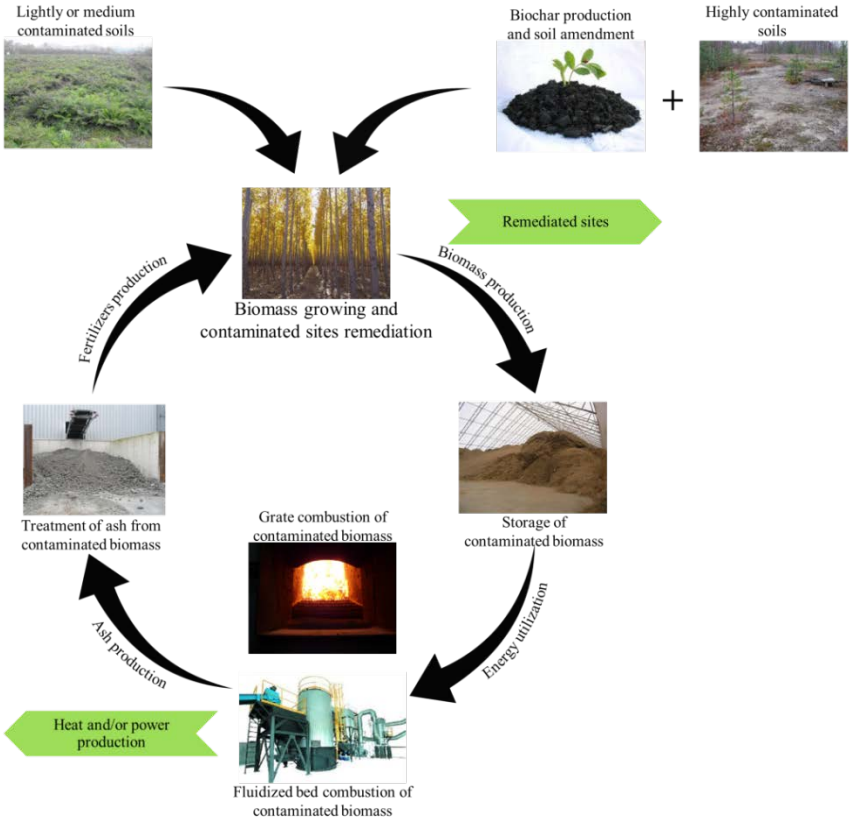

Fig. The concept of contaminated biomass growing and utilization

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Cleaning of syngas from fluidized-bed gasification of coal-biomass blends for advanced power generation

Joint project with INER Taiwan, supported by Czech Science Foundation, 2014-2016.

The research is aimed at study and solution of problems (thermodynamic constraints, reactivity, capacity and deactivation of the sorbents, textural changes, and interferences of HCl) in removal of sulphur compounds from fuel gas (gasification of coal-biomass) by solid sorbents at temperatures 400-600 °C.

A soda-based sorbent will be used for pre-cleaning of syngas and for study of important effects of accompanying gases (mainly H_2S, naphthalene) and temperature on the sorption process of HCl. Sorbents based on ZnO and CeO_x (on carriers) will serve for removal of H_2S, COS, and thiophene and for study of the interferences (CO_2, H_2O(g), HCl, naphthalene). For characterization of sorbents, TG, XRD, SEM/EDS, textural and other tools will be employed. The sorption reactions will be studied by means of a differential, fixed-bed reactor and by an integral fluidized-bed reactor.

Theoretical models with simplified reaction kinetics and particle structure for description and analyses of sorption process in fixed and fluidized bed will be developed and solved.

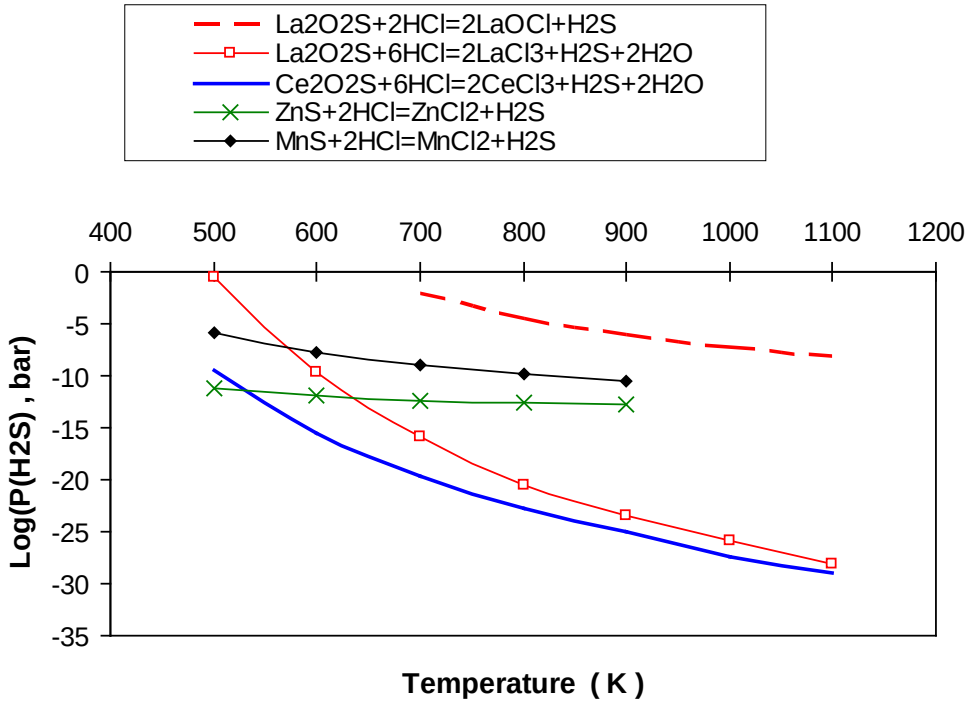

Fig. Dependence of equilibrium H_2S pressures (expressed as log(P_{H2S} - in bar)) on temperature in reactions of selected sulphides with HCl (P_{H2O} = 0.1 bar, P_{HCl} = 10^{-5} bar)

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Waste-to-energy Competence Center

Joint project with Technical University Brno, EVECO Brno Ltd., CEZ a.s., PBS a.s., ZVVZ Enven a.s.; supported by Technology Agency of the Czech Republic, 2014-2018.

Waste-to-Energy (WtE) Competence Centre activities are aimed at increasing competitiveness of the Czech Republic in the field of WtE. Activities are specified in such a way to be able to cover WtE from a primary idea to final products based on recent results of strategic planning, selection and design of up-to-date technologies and equipment. One of the main aims of the consortium is the development of small scale waste-to-energy plant (with capacity below 40 kt/year).

ICPF is leader of work package focused on innovation and re-design of components of WtE with respect to overall energy optimization and increase of efficiency.

Our research interests/tasks can be summarized as follows:

- Optimization of dry cleaning methods with simultaneous flue gas deNOx and dioxin removal on catalytic bag filters, handling of spent sorbents, etc.
- MSWI solid residuals (bottom ash and fly ashes) utilization and development of methods for recovery of non-ferrous metals, precious metals, REE etc. and application of selected fraction in construction industry.
- Sewage sludge combustion and co-combustion with other waste fuels.
- Phosphorus recovery from sewage sludge ash.

Fig. MSWI bottom ash

Design Optimization of Multi-stage Biomass Gasifier Generating Gas with Very Low Tar Content

Joint project with TARPO Ltd., Institute of Chemical Technology Prague; supported by Technology Agency of the Czech Republic, 2014-2016.

The aim of this project is a full utilization of the main advantages of a multi-stage gasification concept using original know-how of a unique multi-stage gasifier Tarpo. In order to achieve high efficiency in production of gas with very low tar content which is suitable for heat and power production with high efficiency (comparable to power plant) it is necessary to realize several adjustments and optimizations of existing technology and to determine the effect of fundamental technological and operational parameters. The measures will be based on studying the effects of woody biomass type and properties on the process performance and will include both operational conditions optimization and re-design of certain parts of the technology. Furhermore, the optimization of gas cleaning technology will result in minimization of environmental impact of the process.

Past research projects:

- Waste as raw material and energy source (cooperation with Technical University Brno, Eveco Brno Ltd., 2008-2011).
- Immobilization of Heavy Metals in Municipal Waste Incinerator Materials (cooperation with Faculty of Civil Engineering Czech Technical University in Prague and SINTEF Trondheim, 2009-2010).
- Emission Factors of POPs and Heavy Metals from Small Sources (cooperation with VSB-Technical University of Ostrava, Institute of Public Health in Ostrava, 2007-2010).
- Near zero emission advanced fluidised bed gasification (cooperation with CNR, INETI, Imperial College, TUV, CIEMAT, etc., 2008-2010).
- Optimisation of the off-gas cleaning system with safe and reliable dioxin destruction (cooperation with Termizo a.s., Technical University Brno, Eveco Brno Ltd., 2004-2008).

6. Selected research papers

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