Department of Multiphase Reactors

HEAD
MAREK RŮŽIČKA

DEPUTY
PETR STANOVSKÝ

SCIENTISTS
JIŘÍ DRAHOŠ, MARIE FIALOVÁ, JAROMÍR HAVLICA, SANDRA KORDAČ ORVALHO, VÁCLAV SOBOLÍK, MIROSLAV ŠIMČÍK, JAROSLAV TIHON, JIŘÍ VEJRAŽKA, ONDŘEJ WEIN, MÁRIA ZEDNÍKOVÁ

RESEARCH ASSISTANTS
VĚRA PĚNKAVOVÁ, VALENTIN TOVCHIGRECHKO

PhD STUDENTS
MARTIN BASZCZYŇSKI, LUKÁŠ KULAVIAK, PAVEL NOVÁK, LUCIE VOBECKÁ

LAB TECHNICIANS
STANISLAVA NOVÁKOVÁ

Fields of research

- Multiphase fluid dynamics and transport phenomena in different types of gas-liquid, liquid-solid or gas-liquid-solid systems
- Numerical simulations of transport in complex multiphase systems
- Influence of surface active agents on the multiphase flows
- Flow of microdispersions and liquids with complex rheological behavior
- Electrodiffusion diagnostics of the flow in microfluidic systems
- Flow characterization in fuel cells
- Hydroacoustic aspects of bubbles in natural environment
- Hydrodynamic concept of stromatactis formation in geology
- Stability and behavior of complex beverage foams

Research projects

Effect of surfactants on the multiphase flow dynamics

(J. Vejražka, vejrazka@icpf.cas.cz; supported by GACR, project No. P101/11/0806)

The effect of surface-active agents on two-phase flows is studied. Flow types "air bubbles in the liquid" and "liquid drops in another immiscible liquid" are focused. Some specific situations, in which the surfactants modify the flow at the bubble/drop scale and in which this modification cannot be explained by a simple change of the equilibrium surface tension, are investigated experimentally. These situations are (i) the shape oscillations of a bubble/drop, both freely-rising or attached at a capillary tip; focus is put on the modification of oscillation frequency and decay time by surfactants; (ii) the coalescence of bubbles/drops, and also their attachment to a solid surface, with a focus on the drainage of liquid film between them; (iii) the bubble-solid surface collision, with a focus on suppression of the bubble rebound caused by surfactants and also on the modification of the attachment time; (iv) break-up of bubbles in a turbulent flow. The research should enlighten and document the effect of interfacial properties other than surface tension on two-phase flows. [Refs. 1, 7]
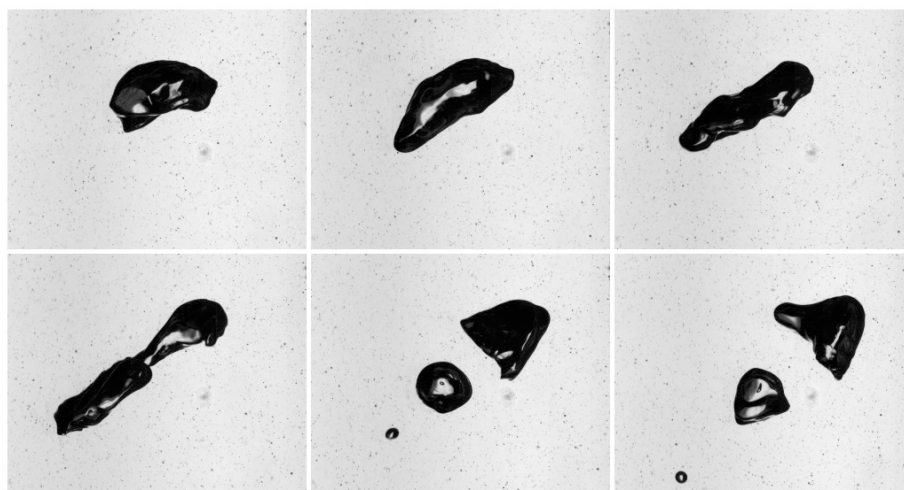

Break-up of a 5 mm bubble in a turbulent flow (interval between frames 12 ms)

Hydroacoustical distinguishing between fish and bubbles, and quantification of methane bubble ebullition in freshwater reservoirs of temperate zone

(P. Stanovský, stanovsky@icpf.cas.cz; joint project with Institute of Hydrobiology, Biology Centre of the ASCR, v. v. i.; supported by GA CR, project No. P504/12/1186)

The acoustic parameters of rising methane bubbles will be measured by echosounders at different frequencies at man-made bubbles. The special algorithms using multi-frequency record will be developed to distinguish the bubble echoes from the fish echoes having the same acoustic size. The obtained method will be used to estimate of fish abundance and biomass more accurately. Further, the model describing the bubble rise and dissolution in will be modified for freshwater lakes. The relation between bubble volume and acoustic echoes from experiments with man-made bubbles will be used to gain more exact data about the amount of the methane bubbles ebullated from the chosen reservoirs in temperate zone. The spatio-temporal changes in their productions will be monitored also. At the end, the research should enlighten the correlation of the quantity and quality of ebullated methane bubbles with the environmental conditions.
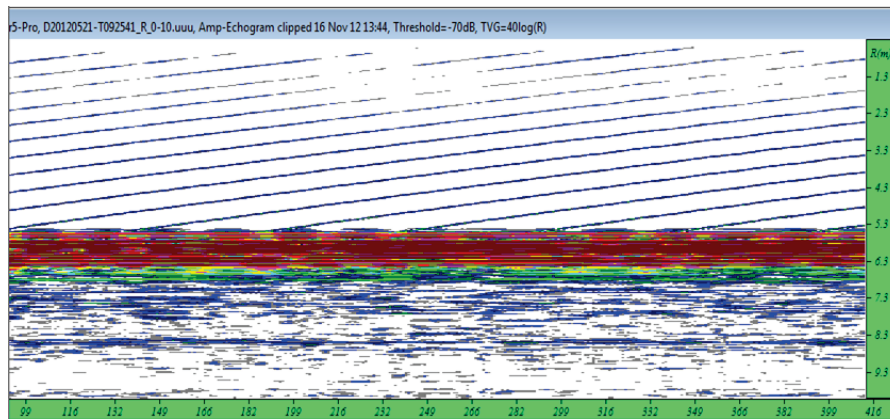
Acoustic echoes of 3 mm bubbles acquired by vertical 120 kHz sonar.
Blue lines represent rising bubbles and brown bar represents bottom of the lake
(ordinate – water depth, abscissa – time scale in signal pings)

Optimal heat integration of fuel cell systems

(J. Tihon, tihon@icpf.cas.cz; joint project with Aristotle University of Thessaloniki, Greece; supported by MEYS, FP7, project No. 7AMB12GR018)

    Objectives of the project are as follows:

1. Develop electrodiffusion microsensors suitable for diagnosing flow in microfluidic devices using photolithography.

2. Use electrodiffusion and micro-PIV (particle image velocimetry) measurement technique to study the structure of the flow in microchannels with complex geometry.

3. Perform CFD (computational fluid dynamics) numerical simulations to study the effect of the geometry of heat exchangers for heat transfer and temperature homogeneity blocks PEM (polymer electrolyte membrane) fuel cells.

4. Propose a methodology for efficient management of heat transfer in mini heat exchangers used to cool the PEM fuel cells.
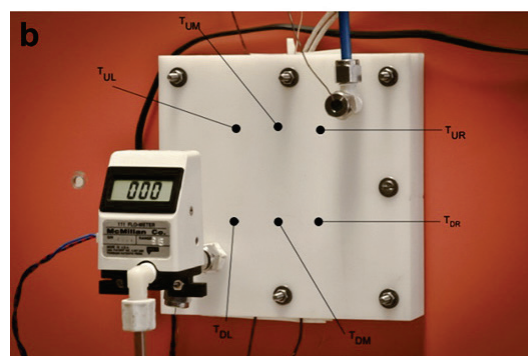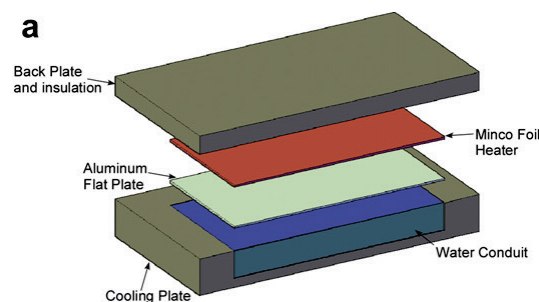

The experimental unit for the study of thermal behavior of the PEM fuel cells in Thessaloniki:
(a) schematic representation, (b) photograph with the marked positions of thermocouples

Application of the electrodiffusion sensors to the flow diagnostics in microfluidic systems

(J. Tihon, tihon@icpf.cas.cz; supported by GACR, project No. P101/12/0585)

The project is focused on characterization of two-phase flows in microfluidic systems. The high-tech fabrication techniques will be used to produce microdevices with precisely located microelectrodes. These electrodiffusion sensors for the near-wall flow diagnostics will be, for the first time, implemented at a microfluidic scale. The proposed measurements will provide information on the wall shear stress, the local flow structures, and the effect of bubbles/particles on the near-wall flow region (e.g. the liquid film under bubbles, the apparent wall slip in microdispersions). The application of the particle image velocimetry together with the microscopic visualization techniques will complete the hydrodynamic picture of the studied microfluidic flow configurations (junction, crossing, sudden expansion). It is expected that the electrodiffusion method will be proved as a suitable tool for microdevice diagnostics. The obtained experimental knowledge and the derived physical models will be useful for design, control, and optimization of microfluidic devices. [Ref. 6]
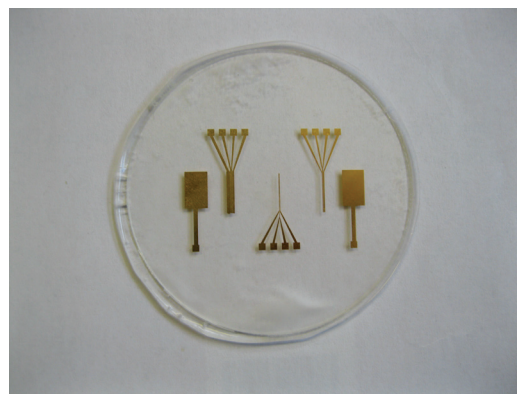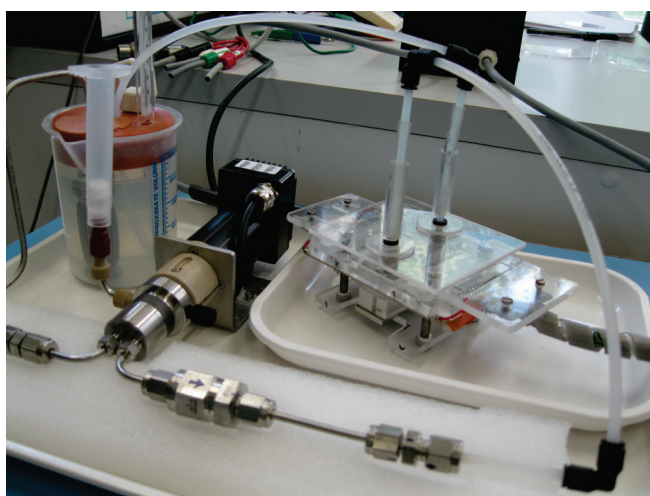

Experimental set-up used for electrodiffusion diagnostics of the flow in microchannels (left) and shown in detail the chip with microsensors (right)

Hydro-mechanical interactions of particles in solid-fluid systems

(J. Havlica, havlica@icpf.cas.cz; joint project with ICT; supported by GACR, project No. P105/12/0664)

The solid-fluid dispersions are very complicated multiphase systems with a wide range of interactions of different physical nature. The suggested project is focused on specific topic from this field: the hydromechanical interactions between the solid particles (discrete phase) dispersed in a carrying fluid (continuous phase). The typical feature of these dispersions is the presence of two kinds of force interactions: the fluid forces on the dispersed particles and the mechanical forces between the particles at collisions. These interactions have crucial importance for prediction of flow behavior in process apparatuses or for correct design of industrial technologies. The main aim is to develop physical modeling concepts for solid-fluid dispersions. This concept is based on numerical simulations of these systems and benchmark experiments on static and dynamic behavior. We expect that the project brings important original results, which will help to understand flow behavior of multiphase systems.
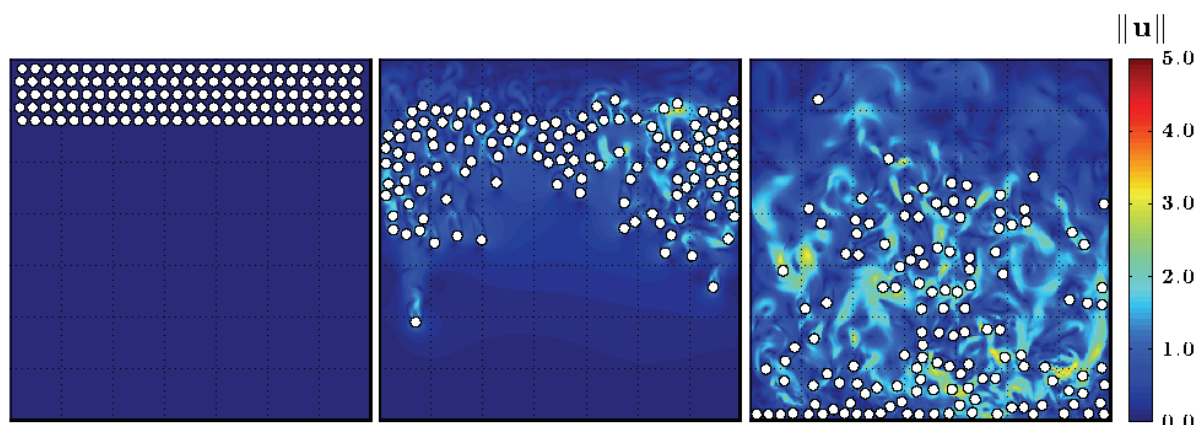
Sedimentation of 135 rigid particles simulated with immersed boundary method

Estimate of mass transfer rate via Nernst model with ohmic losses

(O. Wein, weinbrevnov@seznam.cz; supported by GACR, project No. 104/08/0428)

The liming current technique, employed e.g. in electrodiffusion flow diagnostics, is based on an oversimplified electrochemical concept, which accounts only for the convective transport of depolarizers across a diffusion layer with constant bulk and wall concentrations. However, there are additional transport resistances that cannot be neglected: Faradaic resistance at surface of working electrode, and Ohmic losses in the bulk of electrolyte solution. Effect of these additional resistances is analyzed using the Nernst model of a two electrode cell (no reference electrode). The Faradaic resistances due to electrode kinetics are considered for a single redox couple O + ne = R according to the Butler-Volmer electrode kinetics. The effect of Ohmic losses is accounted for, considering primary current distribution for a uniformly accessible circular electrode. [Ref. 8]
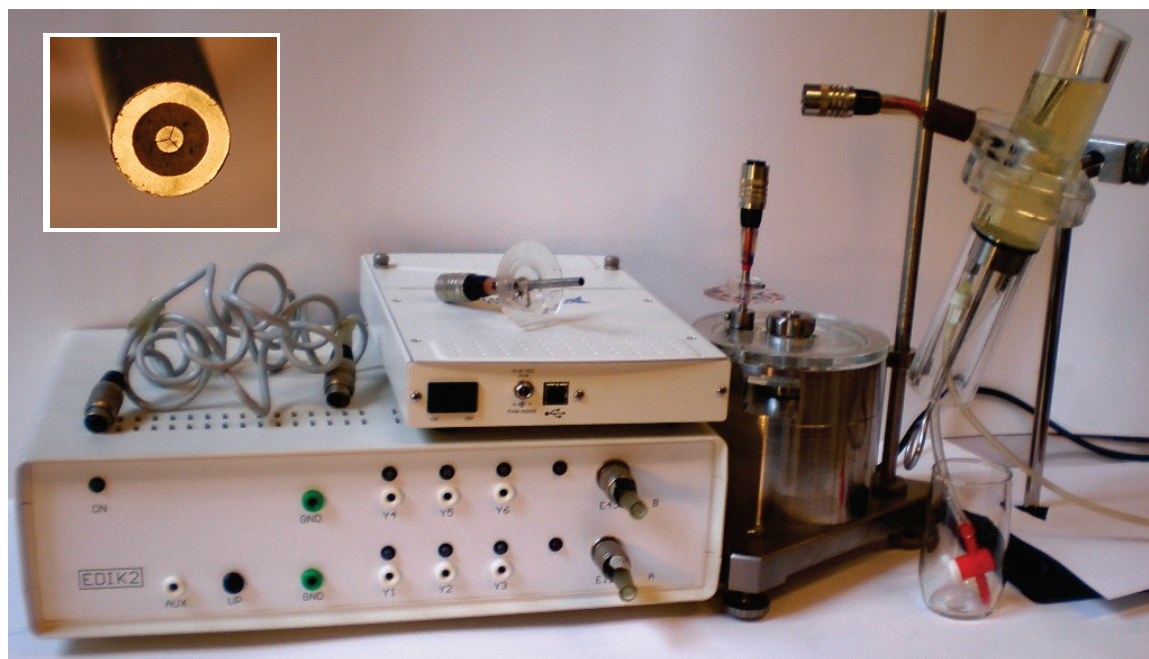

Setup for electrodiffusion experiments, used here in a voltamperometric study with three-segment electrodes

Smart RTD (residence time distribution) for multiphase flow systems
(M. Šimčík, simcik@icpf.cas.cz, cooperation with University of Minho, Braga, Portugal)

A relatively new concept is presented for evaluation of the fluid age distribution within the interior of an apparatus. In the standard RTD approach, the tracer study is performed and RTD is obtained. In the new approach denoted as SRTD, the fluid age is considered as the field quantity and the governing equation is formulated for its spatio-temporal distribution within the flow domain. There are only few studies devoted to this alternative approach, which typically concern only the single-phase flow systems. In this contribution we investigate its applicability also to multiphase systems. In the case of a bubble column, both the RTD and SRTD concepts are employed and discussed. The results are calculated numerically and compared with the experimental observations. [Ref. 5]
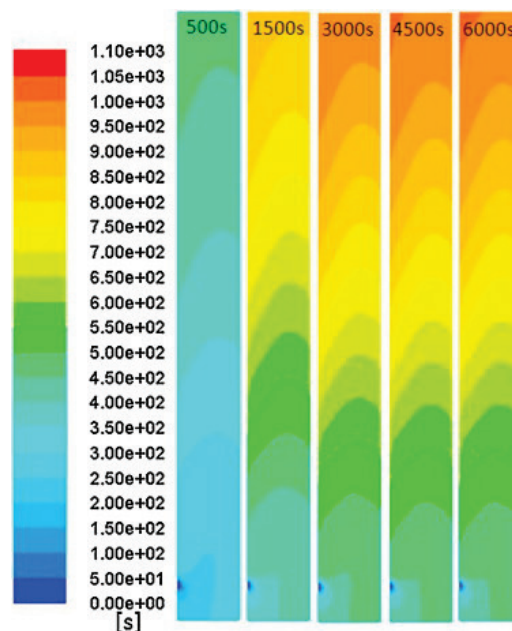

Patterns of the spatio-temporal dynamics of the liquid age distribution in a bubble column. Shown in the domain symmetry plane for Q_L = 80 l/h

Hydrodynamic concept of stromatactis formation in geology
(M. Růžička, ruzicka@icpf.cas.cz; joint project with Institute of Geology of the ASCR, v.v.i.; supported by GA ASCR, project No. IAAX 00130702)

Stromatactis cavities are present in fine-grained carbonate sediments in nature, forming the specific shapes and reticulate arrays. However, the mechanisms behind the origin of these cavities are subjects of heated discussions in geology for 125 years. Numerous biotic and abiotic factors were considered, but with unclear results. Most recently, our team produced a critical analysis of these sedimentary structures and formulated a new hypothesis that these cavities would likely originate during the rapid deposition of extremely polydisperse and multimodal granular mixtures. Although the first experiments simulated the production of these cavities with a considerably high level of similarity, there is a lot of work to be done if we wish really explain these unique phenomena in terms of hydrodynamics. The interdisciplinary study is novel, and the results are fundamental for sedimentology and hydrodynamics, with possible implications in related technologies.
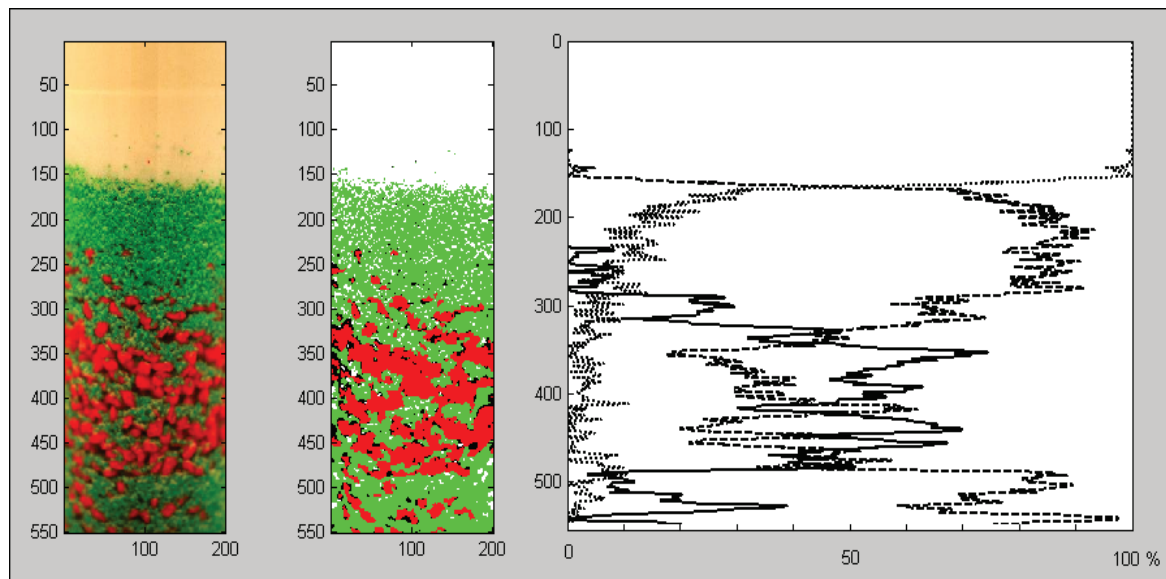
Image analysis of the deposit pictures. The photo (left) was converted into binary numbers (middle) from which was calculated distribution of particle fractions along the deposit height (right). Abscissa - percentage of individual size fractions of particles, ordinate - deposit height; the largest size fraction (red) - full line, middle size fraction (green) - dashed, the smallest size fraction (white) - dotted

International co-operations

Berlin Institute of Technology, Germany: Multiphase flow diagnostics
CRTT, Saint Nazaire, France: Microfluidics
Institute of Fluid Mechanics, Toulouse, France: Effect of surfactants on multiphase flows
University of Valenciennes, France: Electrodiffusion diagnostics of the flow
Aristotle University of Thessaloniki, Thessaloniki, Greece: microfluidics
Norwegian Institute of Technology (NTH), SINTEF, Trondheim, Norway: Bubble columns
University of Minho, Braga, Portugal: Multiphase bubble bed reactors

Visitors

S. Grillo, Universita degli Studi di Napoli Federico II., Italy (Erasmus)
Q. Mouret, ENSEEIHT Toulouse, France (Erasmus)
N. Begue, INP Toulouse - ENSIACET, France (Erasmus)
A. Lemarchand, INP Toulouse - ENSIACET, France (Erasmus)
A. Rollin, INP Toulouse - ENSIACET, France (Erasmus)

Teaching

J. Drahoš, M. Růžička: ICT, Faculty of Chemical Engineering, postgraduate course
    "Multiphase Reactors"
J. Havlica: UJEP, Faculty of Science, courses   "Mathematics", "Chemical Engineering",
    "Programming in Chemistry", "Numerical Simulation of Transport Process"
J. Tihon, J. Vejražka: ICT, Faculty of Chemical Engineering, postgraduate course "Bubbles,
    drops, and particles"

Visits abroad

V. Sobolík: University of La Rochelle, France (12 months)

Publications

Original papers

[1] Abi Chebel N., Vejražka J., Masbernat O., Risso F.: Shape Oscillations of an Oil Drop Rising in Water : Effect of Surface Contamination. *J. Fluid Mech.* 702, 533-542 (2012).

[2] Izák P., Kárászová M., Vejražka J., Friess K., Randová A., Jansen J.C.: The Effective Upgrading of Raw Biogas to Methane by Selective Membranes. *Procedia Eng.* 44, 429-431 (2012).

[3] Kárászová M., Vejražka J., Veselý V., Friess K., Randová A., Hejtmánek V., Brabec L., Izák P.: A Water-Swollen Thin Film Composite Membrane for Effective Upgrading of Raw Biogass by Methane. *Sep. Purif. Technol.* 89, 212-216 (2012).

[4] Růžička M.: Režimy toku ve vícefázových plyno-kapalinových soustavách. (Czech) Flow Regimes in Gas-Liquid Multiphase Systems. *Akademický bulletin AV ČR* 7-8, 20 (2012).

[5] Šimčík M., Růžička M., Mota A., Teixeira J.A.: Smart RTD for Multiphase Flow Systems. *Chem. Eng. Res. Des.* 90(11), 1739-1749 (2012).

[6] Tihon J., Pěnkavová V., Havlica J., Šimčík M.: The Transitional Backward-Facing Step Flow in a Water Channel with Variable Expansion Geometry. *Exp. Therm. Fluid Sci.* 40, 112-125 (2012).

[7] Vobecká L., Vejražka J., Orvalho S.P., Zedníková M., Tihon J.: Dynamics of Shape Oscillations of a Bubble Attached to a Capillary Tip. *EPJ Web of Conferences* 25, 02029 (2012).

[8] Wein O.: Estimate of Mass-Transfer Rate via Nernst Model with Ohmic Losses. *Russ. J. Electrochem.* [*Elektrokhimiya* 48(7), 778-785 (2012)] 48(7), 704-711 (2012).

Patents

[9] Hájek M., Sobek J., Brustman J., Veselý V., Drahoš J.: Method for the Chemical Depolymerization of Waste Polyethylene Terephthalate. Pat. No. CN101688015/200880002443.4. Applied: 10.01.12, patented: 12.09.19.

[10] Izák P., Kárászová M., Vejražka J.: Způsob separace plynné směsi a zařízení k provádění tohoto způsobu. (Czech) A Process for the Separation of a Gaseous Mixture and an Apparatus for Carrying Out the Same. Pat. No. CZ303107/PV 2010-438. Applied: 11.06.20, patented: 12.04.04.

[11] Izák P., Poloncarzová M., Vejražka J.: Způsob obohacení bioplynu z čističek odpadních vod nebo zemědělské prvovýroby o methan a zařízení k jeho obohacení. (Czech) The Method and the Apparatus for Methane Enrichment of Biogas from Sewage Plant and Agriculture. Pat. No. CZ303106/PV 2010-437. Applied: 10.06.02, patented: 12.02.23.