# Department of Multiphase Reactors

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## Fields of research

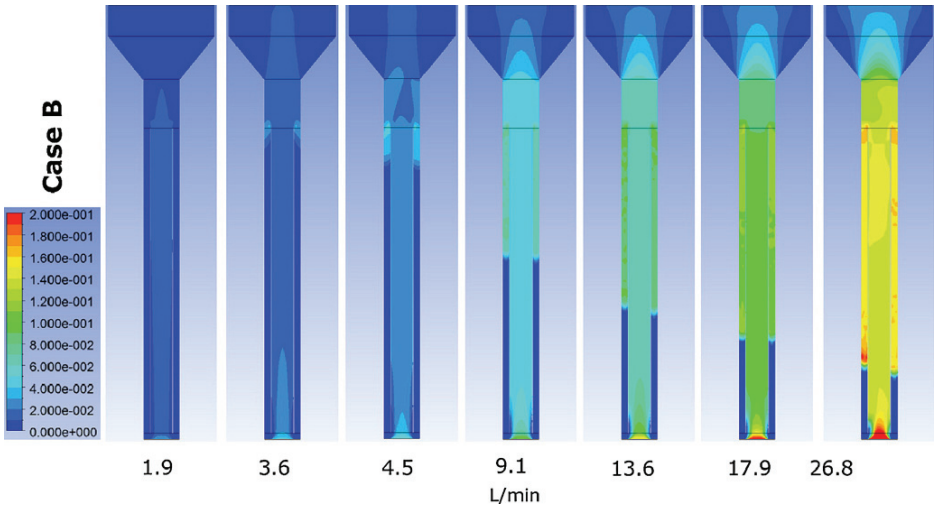
- Multiphase fluid dynamics and transport phenomena in different types of gas-liquid, liquid-solid or gas-liquid-solid systems
- Transport and reaction processes in complex multiphase systems
- Influence of surface active agents on the multiphase flows
- Flow of microdispersions and liquids with complex rheological behaviour
- Electrodiffusion diagnostics of the flow
- Flow characterization in T-shaped and cross-shaped micromixers
- Hydrodynamic concept of stromatactis formation in geology
- Determination of the coalescence efficiency of bubbles in liquids
- Dynamics of bubble formation at submerged orifices: Simultaneous formation and synchronous regimes
- Stability and behaviour of complex beverage foams

## Research projects

### Hydrodynamics and transport phenomena in multiphase systems: from microscale to macroscale

(M. Růžička, ruzicka@icpf.cas.cz; joint project with TU of Ostrava; supported by GACR, grant No. 104/07/1110)

Essence of the research project is the investigation into the basic physical mechanisms involved in hydrodynamics and transport phenomena in complex multiphase systems. Transport of mass and momentum in both two-phase systems (gas-liquid) and three-phase systems (gas-liquid-solid) were studied. The stress is put on the momentum transfer between the phases, i.e. on the hydrodynamics of multiphase flows. Hand in hand with the understanding the multiphase motion, the mass transfer phenomena were explored. The typical feature of the multiphase systems is the existence of a microstructure, given by the presence and configuration of the dispersed particles. The microstructure has a multi-scale nature and determines the system rheology. The project is aimed at resolving the relation between the microstructure and the macroscopic behaviour of the multiphase systems. [Refs. 5, 6, 10-12, 15, 18-22, 24]

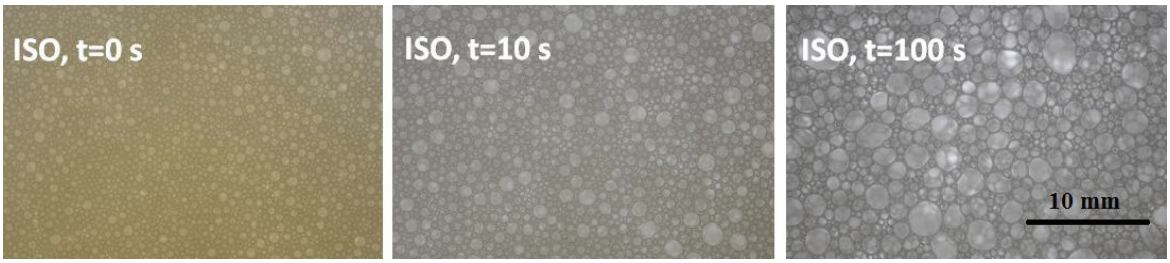



**Local gas holdup (volume fraction of gas phase) in airlift for various gas flow rates on entrance**

### Transport and reaction processes in complex multiphase systems

(J. Drahoš, drahos@icpf.cas.cz; joint project with ICT and UPa; supported by GACR, grant No. 104/08/H055)

Project is focused on training of doctoral students in the field of chemical engineering via targeted research in modern branches of chemical, pharmaceutical, biological and process industries with emphasis on research in new areas such as micro- and nanotechnologies and material engineering. It includes theoretical and experimental work of 20 students of Chemical Engineering Departments at ICT and UPa, and at ICPF. Particular research programmes involve 16 areas from microsystems to industry-scale processes. Project is led by 18 supervisors. Students take part in national and international projects of cooperation with major research laboratories. The project output are publications in impacted international journals, presentations at conferences and special workshops with lectures by students, supervisors and invited specialists, published in proceedings. [Refs. 9, 13, 14, 29-33]

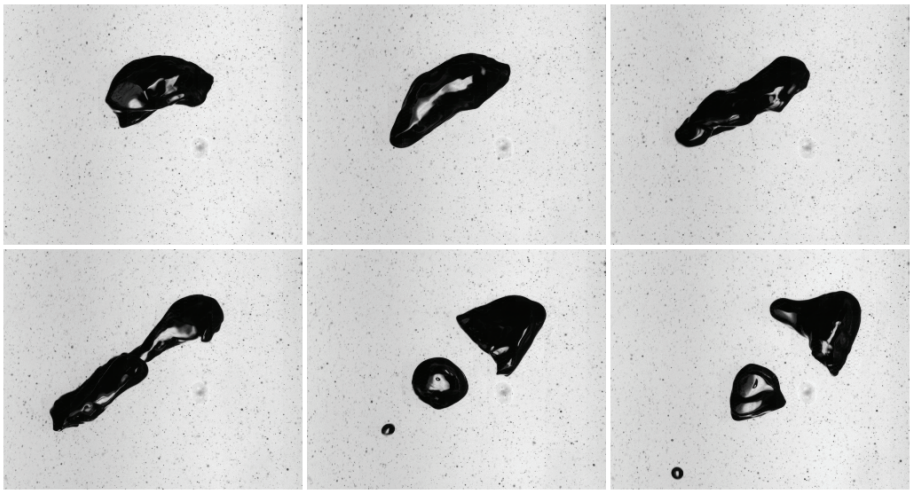



**Structural changes in model beer foam with addition of a natural stabilisator (hop Iso-α-Acids)**

## Effect of surface-active agents on two-phase flows

(J. Vejražka, vejrazka@icpf.cas.cz; supported by GACR, grant No. 101/11/0806)

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. 8, 28-32]

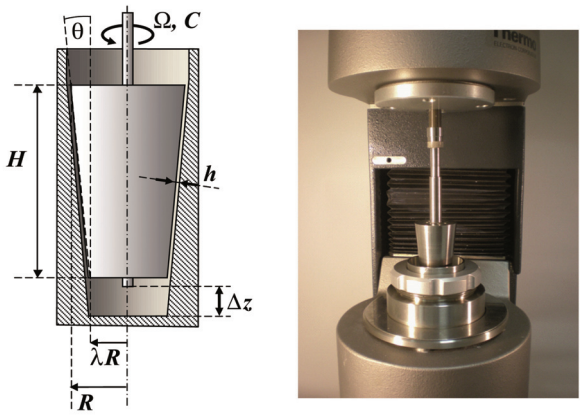


**Break-up of a 5 mm bubble in a turbulent flow (interval between frames 12 ms)**

## Wall effect in flowing microdisperse liquids: apparent slip and electrokinetical potential

(O. Wein, wein@icpf.cas.cz; joint project with TU of Ostrava; supported by GACR, grant No. 104/09/0972)

The project aims at a phenomenological characterization of liquid micro-dispersions (aqueous nanofluids and colloidal clay suspensions) by means of three experimental methods. Theory of the electrodiffusion friction probes, including their automated calibration, has been extended to non-linear velocity profiles. AWS viscometry and routine measuring of zeta-potential ($\xi$) have been applied for a class of nanofluids, prepared using several different dispersing methods. [Refs. 2, 7, 16, 25-27, 33-35]

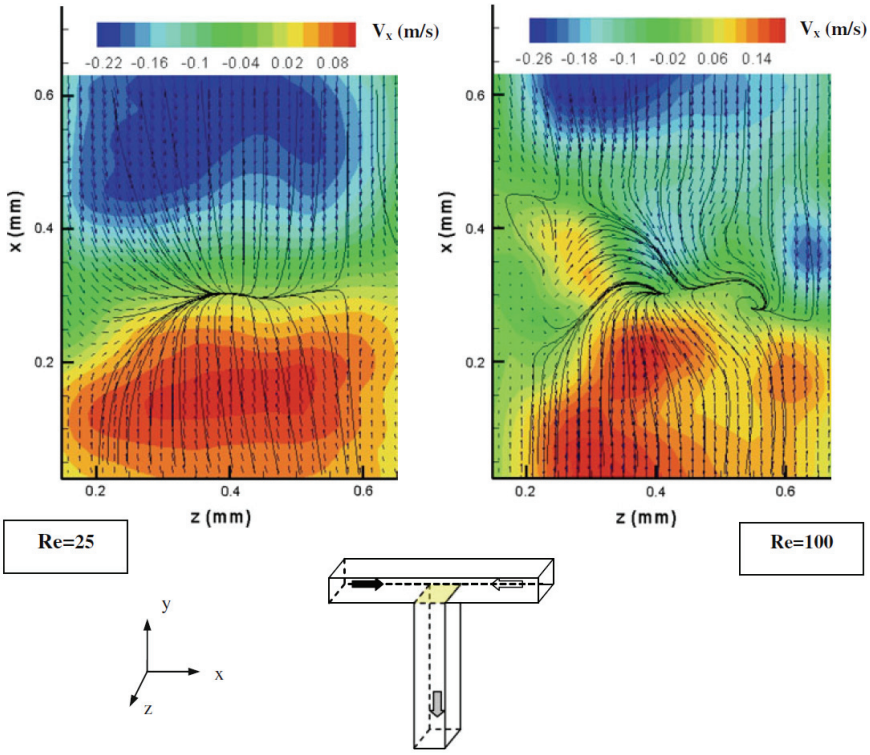



**Original KK sensor for AWS viscometry**

## Flow characterization in T-shaped and cross-shaped micromixers

(J. Havlica, J. Tihon, havlica@icpf.cas.cz, tihon@icpf.cas.cz; joint project with GEPEA UMR-CNRS, Ecole des Mines de Nantes and University of Nantes, Saint-Nazaire, France;
supported by )

The understanding of physical phenomena such as flow behavior and mass transfer performance is needed in order to develop appropriate micromixers for industrial or biomedical applications. In this article, the flow behavior of the T-shaped and the cross-shaped micromixers with square cross-section are studied through numerical and experimental investigations. For experimental measurements of flow characterization were used particle image velocimetry (PIV) and electrodiffusion method. Results indicate that the cross-shaped micromixer could improve the mixing process in comparison with the micromixers having T geometry. [Refs. 1, 4, 23]

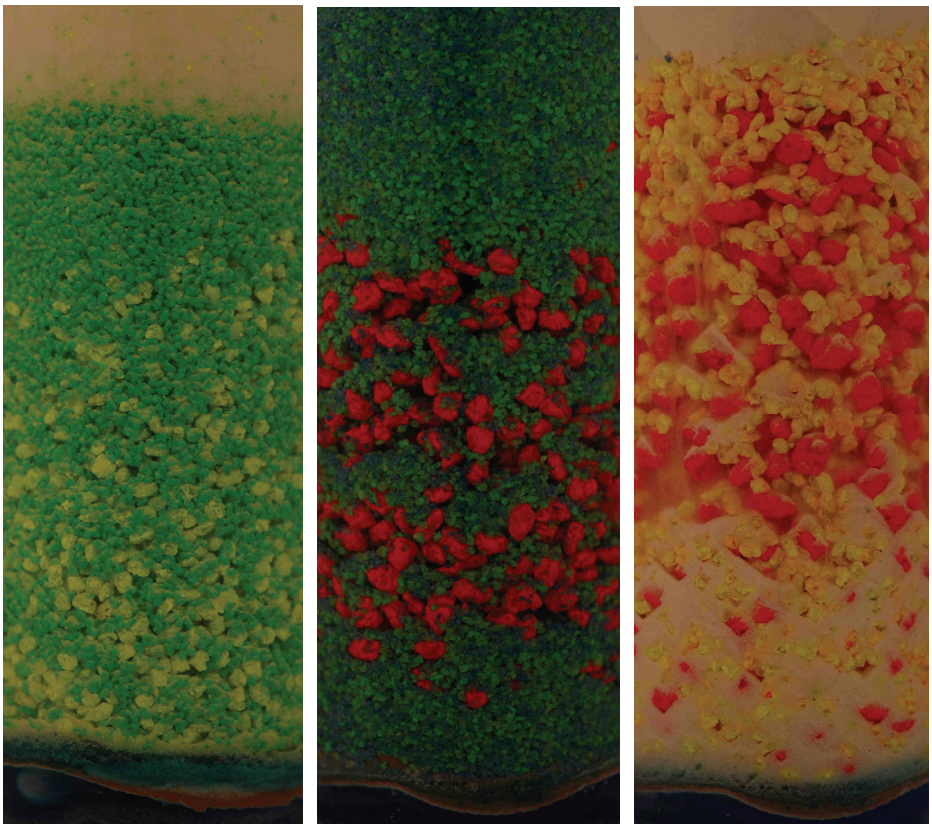



**Velocity fields, streamlines and velocity profiles $v_x$ in T-shaped micromixer for Re = 25 and Re = 100**

## 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, grant 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. [Refs. 11, 12]

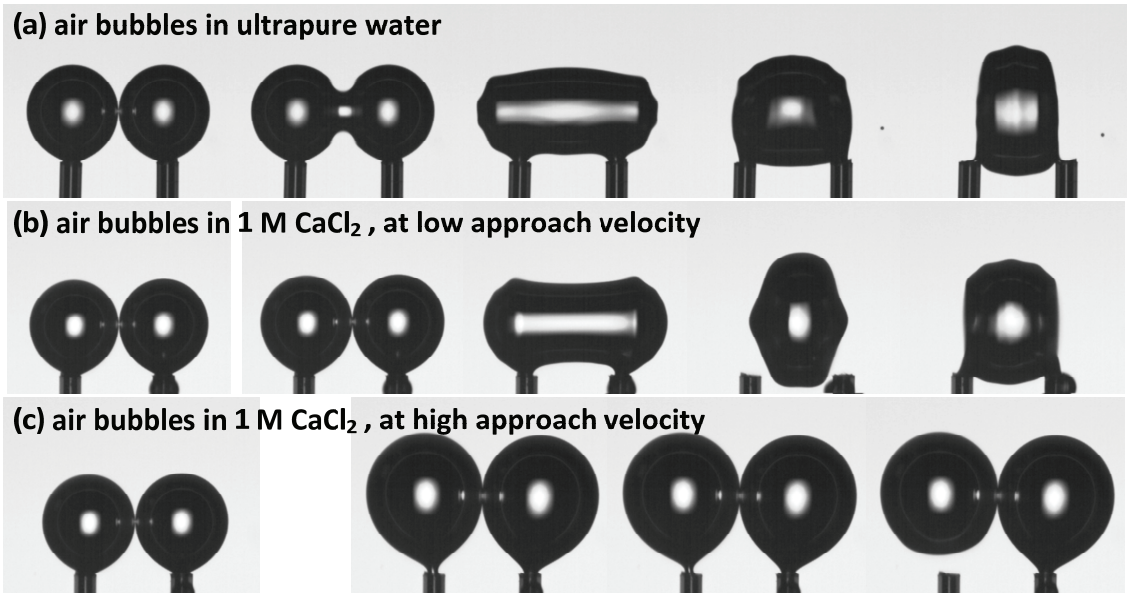


**Effect of the missing fraction in five-fraction system on the formation of cavities**

## Determination of the coalescence efficiency of bubbles in liquids

(S. Kordač Orvalho, orvalho@icpf.cas.cz; supported by GACR, grant No. 104/09/P255)

The coalescence phenomenon is of capital importance in the design and performance of multiphase contactors. Although studied for several decades, it is still not completely understood. The present project aims to improve our knowledge on the subject in the following way: to determine experimentally a relation between coalescence efficiency and the crucial control parameters (bubble properties, liquid properties and liquid flow conditions). Bubble coalescence was studied experimentally in a laboratory cell (pairwise first, multiple then) under well-defined conditions. Then, these small scale data have been related to the coalescence in real gas-liquid dispersions in bubble column reactors. [Refs. 10, 15]

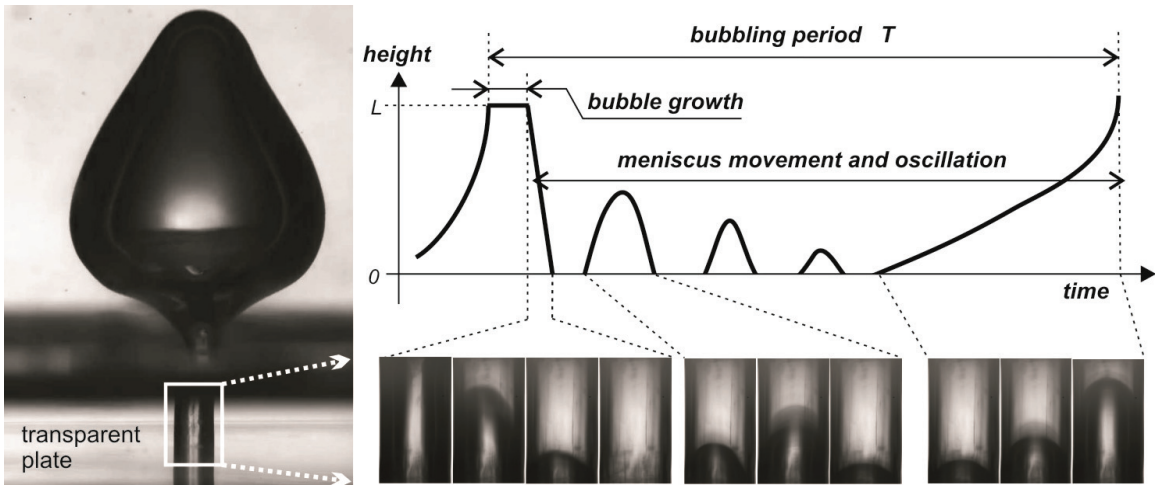



**Effect of the approach velocity on the coalescence of air bubbles in coalescent ultrapure water and in non-coalescent calcium chloride, c(CaCl2) = 0.056 M**

## Dynamics of bubble formation at submerged orifices: Simultaneous formation and synchronous regimes

(P. Stanovský, stanovsky@icpf.cas.cz; supported by ASCR, grant No. KJB200720901)

Aim of this project is an experimental study of the dynamics of interfacial meniscus inside an orifice during bubble formation from a submerged orifice. Incorporation of the meniscus dynamics into a mathematical model of the bubble formation allows explaining aperiodicity in the bubble formation at one orifice. The project objectives are the experimental verification of the model in a wide range of parameters coupled with the study of interactions between two orifices together recorded with the meniscus motion. Finally, an extension of the model from one orifice to more orifices are done in order to explain a mechanism leading to an asynchronous regimes appearance during bubble formation at more orifices as well as an acquirement of new experimental data about simultaneous formation at multi-orifice spargers. [Refs. 5, 18-20]




**Meniscus oscillation influencing the bubble size variability and formation synchronicity**

**Presidency of the European Federation of Chemical Engineering (EFCE)**
(J. Drahoš, drahos@icpf.cas.cz; supported by MEYS, INGO II, project No. LA11014)

The EFCE is one of the most important institutions in the field of chemistry. Prof. Jiří Drahoš successfully served for four years as its President for the period 2006-2009 and he continue its work as the member of Executive board. Together with Prof. Růžička, he also participates at the activities of the EFCE Working Party Multiphase Fluid Flow.

## 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
Norwegian Institute of Technology (NTH), SINTEF, Trondheim, Norway: Bubble columns
University of Minho, Braga, Portugal: Multiphase bubble bed reactors
Worchester Polytechnic Institute, Worchester, MA, USA: CFD

## Visits abroad

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

## Visitors

N. Menuier, Institut National Polytechnique de Toulouse, France (Intership)
Ch. Faure-Llorens, Institut National Polytechnique de Toulouse, France (Intership)
J.-B. Henry, Institut National Polytechnique de Toulouse, France (Intership)
J. Conté, Institut National Polytechnique de Toulouse, France (Intership)
M. Azevedo, University of Minho, Braga, Portugal, (Intership)
S. Grillo, Universita degli Studi di Napoli Federico II., Italy (Erasmus)
R. Lau Wai Man, Nanyang Technological University, Singapore
V.V. Buwa, Indian Institute of Technology-Delhi, India
A .Byalko, Russian Acad.Sci., Landau Institute, Chernogolovka, Russia
H.A. Jakobsen, Norwegian University of Sci. and Technol.,Trondheim, Norway

## Teaching

J. Drahoš, M. Růžička: ICT, Faculty of Chemical Engineering, postgraduate course "Multiphase Reactors"
J. Havlica: UJEP, Faculty of Science, course "Mathematics", "Petrochemistry"
J. Tihon, J. Vejražka: ICT, Faculty of Chemical Engineering, postgraduate course "Bubbles, drops, and particles"

# Publications

### Original papers

[1] Ait Mouheb N., Montillet A., Solliec C., Havlica J., Legentilhomme P., Comiti J., Tihon J.: Flow Characterization in T-Shaped and Cross-Shaped Micromixers. *Microfluid. Nanofluid.* 10(6), 1185-1197 (2011).

[2] Pěnkavová V., Tihon J., Wein O.: Stability and Rheology of Dilute $TiO_2$ – Water Nanofluids. *Nanoscale Res. Lett.* 6(1), 273 (2011).

[3] Poloncarzová M., Vejražka J., Veselý V., Izák P.: Effective Purification of Biogas by Condensing-Liquid Membrane. *Angew. Chem.-Int. Edit.* 50(3), 669-671 (2011).

[4] Sobolík V., Jirout T., Havlica J., Kristiawan M.: Wall Shear Rates in Taylor Vortex Flow. *J. Appl. Fluid Mech.* 4(3), 25-31 (2011).

[5] Stanovský P., Růžička M., Martins A., Teixeira J.A.: Meniscus Dynamics in Bubble Formation: A Parametric Study. *Chem. Eng. Sci.* 66(14), 3258-3267 (2011).

[6] Šimčík M., Mota A., Růžička M., Vicente A., Teixeira J.: CFD Simulation and Experimental Measurement of Gas Holdup and Liquid Interstitial Velocity in Internal Loop Airlift Reactor. *Chem. Eng. Sci.* 66(14), 3268-3279 (2011).

[7] Wein O., Tovčigrečko V.: Voltage-Step Transient on Circular Electrodes. *J. Appl. Electrochem.* 41(9), 1065-1075 (2011).

### International conferences

[8] Basařová P., Hubička M., Vejražka J.: Influence of Bubble Surface Mobility on Motion of a Spherical Bubble in Neighbourhood of a Falling Particle. 38th International Conference of Slovak Society of Chemical Engineering, Proceedings, p. 212-221, Tatranské Matliare, Slovakia, 23-27 May 2011.

[9] Baszczyński M., Novák P., Brányik T., Růžička M., Zedníková M.: Effect of Different Hop Extracts on Beer Foam Quality. 8th European Congress of Chemical Engineering, Programme, P44.27, Berlin, Germany, 25-29 September 2011.

[10] Fialová M., Orvalho S.P., Zedníková M., Drahoš J., Růžička M.: Effect of Electrolytes on Mass Transfer and Hydrodynamics in Bubble Column Operated in Homogeneous and Heterogeneous Conditions. 10th Conference on Gas-Liquid and Gas-Liquid-Solid Reactor Engineering, Book of Abstracts, p. 55, Braga, Portugal, 26-29 June 2011.

[11] Kulaviak L., Hladil J., Růžička M., Drahoš J., Saint-Lary L.: Struktura vápencového sedimentu. (Czech) Structure of Sedimentary Calcite. 58. Konference chemického a procesního inženýrství CHISA 2011, Sborník, p. 80 (D3.1), Srní, Šumava, Czech Republic, 24-27 October 2011.

[12] Kulaviak L., Hladil J., Růžička M., Drahoš J.: Patterns Formation in Sedimentary Deposit. 10th Conference on Gas-Liquid and Gas-Liquid-Solid Reactor Engineering, Book of Abstracts, p. 35, Braga, Portugal, 26-29 June 2011.

[13] Novák Pavel, Baszczyński M.: Influence of Wettability of Container Wall on Beer Foam Structure and Stability. 8th European Congress of Chemical Engineering, Programme, P44.05, Berlin, Germany, 25-29 September 2011.

[14] Novák Pavel, Baszczyński M., Brányik T., Růžička M., Zedníková M., Drahoš J.: Effect of Container Wall Properties on Beer Foam. 33rd European Brewery Convention Congress, Poster Abstracts, P34, Glasgow, Great Britain, 22-26 May 2011.

[15] Orvalho S.P., Růžička M.: Effect of the Bubble Characteristics on the Validity of Transition Concentration for Coalescence Behaviour of Electrolyte Solutions. 10th Conference on Gas-Liquid and Gas-Liquid-Solid Reactor Engineering, Book of Abstracts, p. 28, Braga, Portugal, 26-29 June 2011.

[16] Pěnkavová V., Večeř M., Wein O.: AWS viskozimetrie mikrodisperzí - detekce zdánlivého skluzu na stěně. (Czech) AWS Viscosimetry of Microdispersions - Detection of Apparent Wall Slip. 58. Konference chemického a procesního inženýrství CHISA 2011, Sborník, 6 pp. full text on CD-ROM, p. 47 (B2.3), Srní, Šumava, Czech Republic, 24-27 October 2011.

[17] Poloncarzová M., Vejražka J., Veselý V., Izák P.: Effective Purification of Biogas by a Condensing-Liquid Membrane. 38th International Conference of Slovak Society of Chemical Engineering , Proceedings, p. 102, Tatranské Matliare, Slovakia, 23-27 May 2011.

[18] Stanovský P., Růžička M.: Oscilace mezifázového menisku při tvorbě bublin. (Czech) Oscillation of Interfacial Meniscus during the Formation of Bubbles. 58. Konference chemického a procesního inženýrství CHISA 2011, Sborník, p. 188 (V61), Srní, Šumava, Czech Republic, 24-27 October 2011.

[19] Stanovský P., Růžička M.: Motion and the Oscillation of Interphase Meniscus Inside an Orifice during bubble Formation. 8th Liquid Matter Conference, Conference Book, p. 113 (P7.113), Wien, Austria, 06-10 September 2011.

[20] Stanovský P., Růžička M., Drahoš J.: The Influence of Operational Conditions on the Meniscus Dynamics in Bubble Formation. 10th Conference on Gas-Liquid and Gas-Liquid-Solid Reactor Engineering, Book of Abstracts, p. 18, Braga, Portugal, 26-29 June 2011.

[21] Šimčík M., Mota A., Růžička M., Vicente A., Teixeira J., Drahoš J.: CFD Simulation and Experimental Measurement of Gas Holdup and Liquid Interstitial Velocity in Internal Loop Airlift Reactor. 10th Conference on Gas-Liquid and Gas-Liquid-Solid Reactor Engineering, Book of Abstracts, p. 70, Braga, Portugal, 26-29 June 2011.

[22] Šimčík M., Růžička M.: CFD simulace proudění v laboratorním airlift reaktoru. (Czech) CFD Simulation of Laboratory Scale Airlift Reactor Hydrodynamics. 58. Konference chemického a procesního inženýrství CHISA 2011, Sborník, p. 191 (V64), Srní, Šumava, Czech Republic, 24-27 October 2011.

[23] Tihon J., Pěnkavová V., Havlica J., Šimčík M.: The Transitional Regime of Backward-Facing Step Flows. Experimental Fluid Mechanics 2011, Proceedings, p. 1022-1039, Jičín, Czech Republic, 22-25 November 2011.

[24] Večeř M., Leštinský P., Wichterle K., Růžička M.: Bubble Rising in Countercurrent Flow. 12th International Conference on Multiphase Flow in Industrial Plants, Book of Abstracts, p. 11, Ischia, Napoli, Italy, 21-23 September 2011.

[25] Večeř M., Pěnkavová V., Wein O.: Rheometric Study of Apparent Wall Slip in Microdispersions. The Nordic Rheology Conference, Annual Transactions the Nordic Rheology Society, p. 307-312, Helsinki, Finland, 8-10 June 2011.

[26] Večeř M., Pěnkavová V., Wein O.: The Role of Apparent Wall Slip Effect in Experimental Rheology. 8th European Congress of Chemical Engineering, Programme, P14.07, Berlin, Germany, 25-29 September 2011.

[27] Večeř M., Wein O.: Rotational Vicometry under Apparent Wall Slip. 38th International Conference of Slovak Society of Chemical Engineering, Proceedings, p. 471-478, Tatranské Matliare, Slovakia, 23-27 May 2011.

[28] Vejražka J., Vobecká L., Kantorová J., Zedníková M., Orvalho S., Tihon J.: Shape Oscillations of Attached Bubbles in Pure Liquids and in Surfactant Solutions. 64th Annual Meeting of the APS Division of Fluid Dynamics, Bulletin of the American Physical Society, 56 (18), p. 147-148, Baltimore, USA, 20-22 November 2011.

[29] Vejražka J., Vobecká L.: Oscilace bublin a kapek přichycených na jehle. (Czech) Oscillations of a Bubble Attached to a Capillary Tip. 58. Konference chemického a procesního inženýrství, Sborník, 8 pp. full text on CD-ROM, p. 29 (B1.6), Srní, Šumava, Czech Republic, 24-27 October 2011.

[30] Vobecká L., Vejražka J., Tihon J.: Experimentální studium oscilací bublin v roztocích různých surfaktantů. (Czech) Experimental Study of Bubble Oscillations in Solutions of Different Surfactants. 58.

Konference chemického a procesního inženýrství CHISA 2011, Sborník, 9 pp. full text on CD-ROM, p. 187 (V60), Srní, Šumava, Czech Republic, 24-27 October 2011.

[31] Vobecká L., Vejražka J., Zedníková M., Orvalho S.P., Tihon J.: Oscillations of a Bubble Attached to a Capillary Tip in Solution of non-Ionic Surfactant. (Eng) 38th International Conference of Slovak Society of Chemical Engineering, Proceedings, p. 586–594, Tatranské Matliare, Slovakia, 23-27 May 2011.

[32] Vobecká L., Zedníková M., Vejražka J., Růžička M.: Experimental and Theoretical Study of Bubble Interactions with the Solid Surface. 10th Conference on Gas-Liquid and Gas-Liquid-Solid Reactor Engineering, Book of Abstracts, p. 30, Braga, Portugal, 26-29 June 2011.

[33] Wein O.: AWS Viscometry – Principles and Applications. 58. Konference chemického a procesního inženýrství CHISA 2011, Sborník, 18 pp. full text on CD-ROM, p. 46 (B2.2), Srní, Šumava, Czech Republic, 24-27 October 2011.

[34] Wein O.: A New Look on the Nernst Model in Electrochemistry. 58. Konference chemického a procesního inženýrství CHISA 2011, Sborník, p. 124 (C5.3), Srní, Šumava, Czech Republic, 24-27 October 2011.

[35] Wein O., Večeř M., Tihon J., Pěnkavová V.: AWS Viscometry - Principles and Applications. Novel Trends in Rheology IV, Novel Trends in Rheology IV, pp. 127-146, Zlín, Czech Republic, 27-28 July 2011.