

## Department of Multiphase Reactors

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## Fields of research

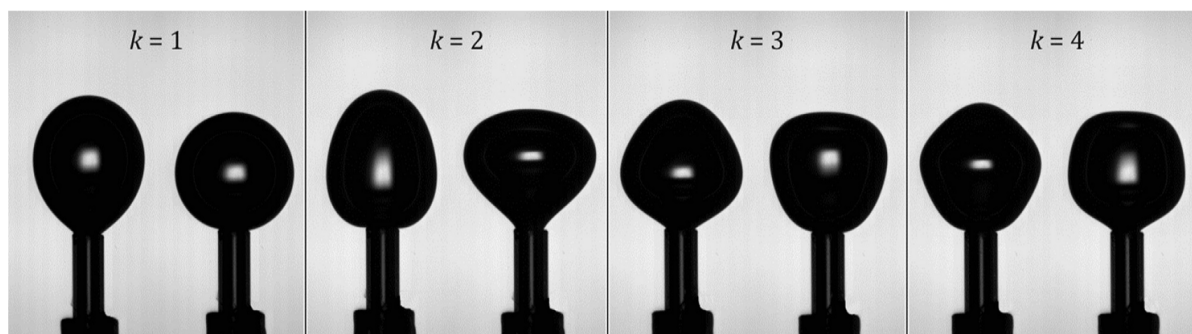
- Fluid dynamics and transport phenomena in multiphase systems of gas-liquid, liquid-solid or gas-liquid-solid type
- Influence of surface active agents on the multiphase flows
- Powder rheology, sedimentation of granular mixtures or complex assemblages
- Numerical simulations of the gas-liquid and granular systems (with Fluent, CFX, DEM)
- Flow of a liquid or gas-liquid dispersions in channels or microchannels
- Electrodiffusion diagnostics of the flow
- Hydroacoustic detection of bubbles using sonar in shallow reservoirs
- Complex rheological behavior of microdispersions
- Stability and behaviour of complex beverage foams

## Research projects

### Effect of surfactants on the multiphase flow dynamics

(J. Vejražka, [vejrazka@icpf.cas.cz](mailto: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. [Ref. 8]

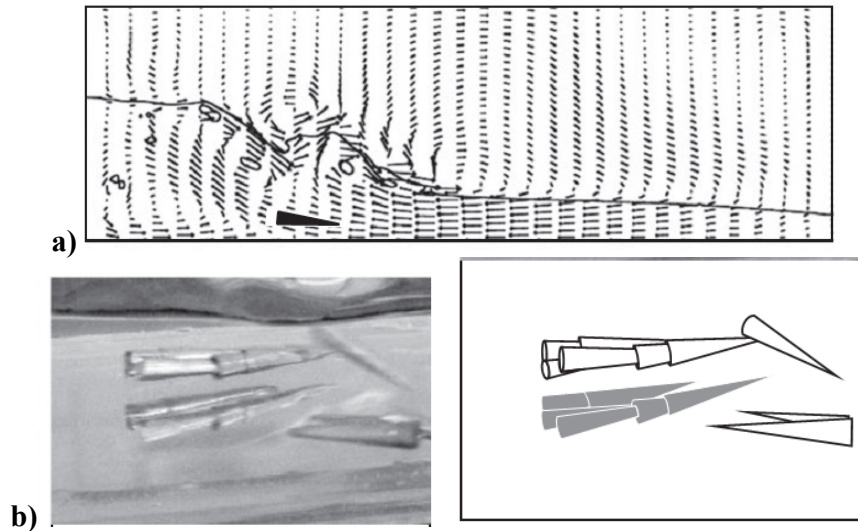


Shape of first four eigenmodes of an oscillating 1mm bubble at a small capillary

### Hydrodynamic experiments on dacryoconarid shell telescoping

(M. Růžička, [ruzicka@icpf.cas.cz](mailto:ruzicka@icpf.cas.cz); joint research with Institute of Geology CAS)

It is not uncommon that small conical dacryoconarid shells are found inserted one into another, however, no satisfactory explanation has been provided. We performed experiments under laboratory conditions using narrow aluminum cones as replicas of these shells. Two different flow regimes were tested to mimic the probable hydrodynamic conditions in the ocean. First, large-scale rhythmic back and forth coherent motion of water over the seabed was reproduced in an oscillating sloshing tank (sloshing mode). Second, small scale irregular stirring motion in turbulent bulk was imitated in cylindrical containers placed into a shaker (mixing mode). With sloshing, a high production of irreversibly telescoped cones was present in clear water and at driving frequencies comparable to the upper limits known for sea waves. With shaking, both coalescence and break-up of the cones were observed, as the quasi-random hydrodynamic forces generated by vigorous liquid motion were roughly comparable with the mechanical forces holding the cones together. In addition, a simple mathematical model was suggested for the flow interaction with a submerged conical particle in the case of the sloshing mode, providing an interesting insight into the evolution of strong deceleration zones. [Ref. 3]

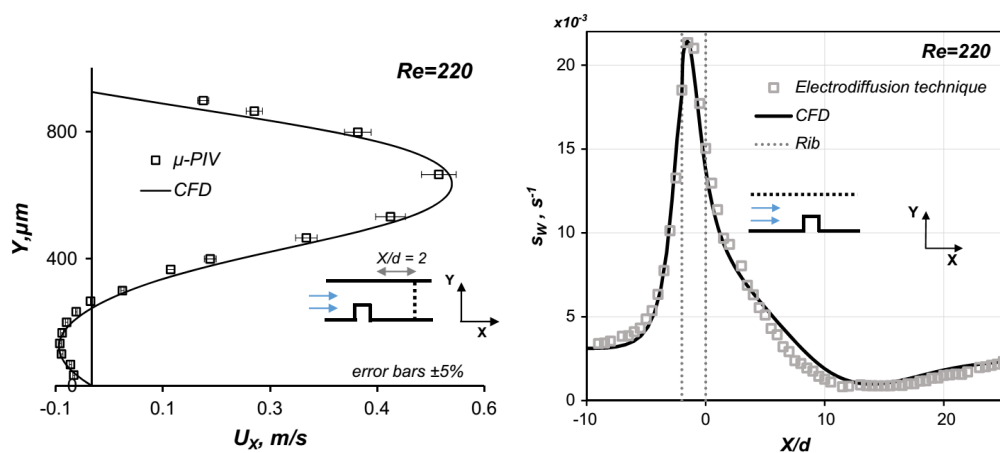


**Experimental and numerical evaluation of the origin of conical shell concentrates:**  
 a) Numerical simulation of particle motion in a sloshing tank,  
 b) Photos of shells and redrawn picture illustrating moment of telescoping

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

(J. Tihon, [tihon@icpf.cas.cz](mailto: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. [Refs. 1, 5, 7]

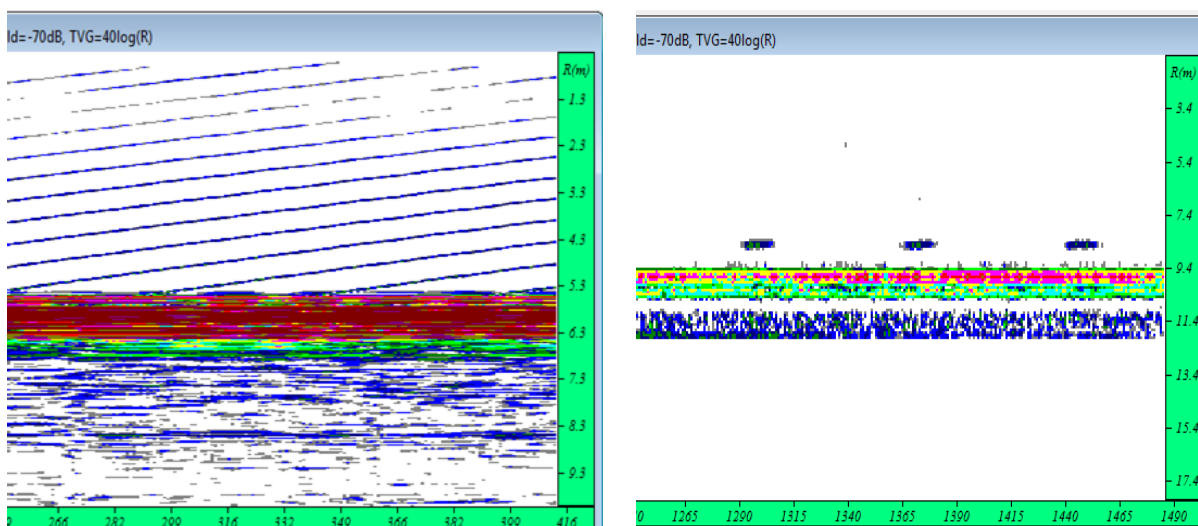


**Velocity profile reconstruction from  $\mu$ -PIV for laminar region (left) and corresponding shear rate on the wall above the rib along the X-axis using the electrodiffusion technique (right). Both measurements were compared with CFD simulation**

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

(P. Stanovský, [stanovsky@icpf.cas.cz](mailto:stanovsky@icpf.cas.cz); joint project with Institute of Hydrobiology and Biology Centre of the CAS; supported by GACR, project No. P504/12/1186)

The acoustic parameters of rising methane bubbles will be measured by echo sounders 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.

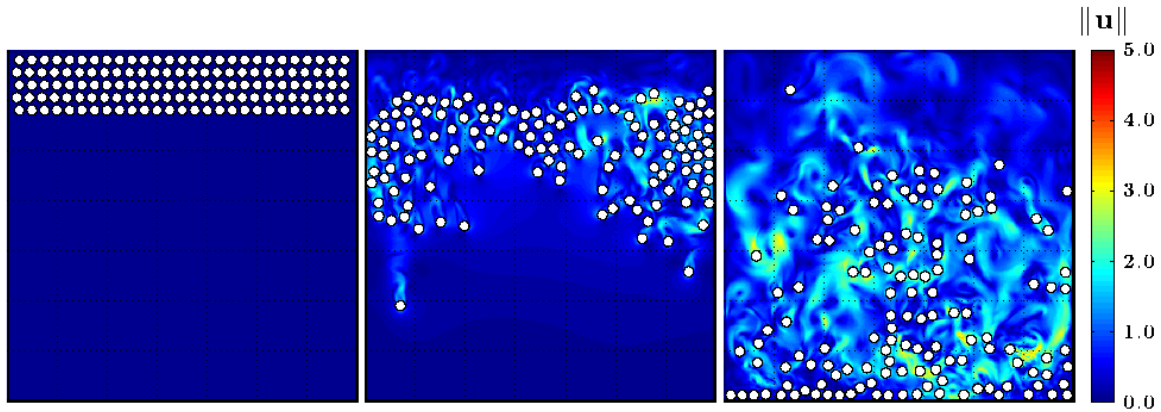


Acoustic echoes of 3 mm bubbles recorded by vertical (left) and horizontal (right) sonar. Blue lines (rep. spots) represent rising bubbles and brown bar at left image represents bottom of the lake (ordinate – water depth, abscissa – time scale in signal pings)

### Hydro-mechanical interactions of particles in solid-fluid systems

(J. Havlica, [havlica@icpf.cas.cz](mailto:havlica@icpf.cas.cz); joint project with UCT, Prague; 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.

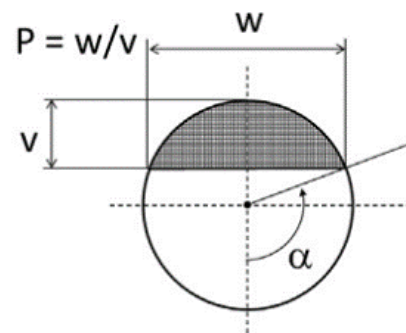
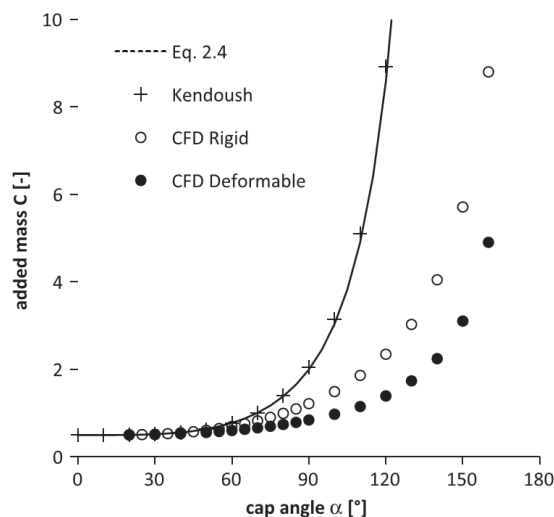


**Sedimentation of 135 rigid particles simulated with immersed boundary method**

### Added mass of spherical cap body in multiphase flow

(M. Šimčík, [simcik@icpf.cas.cz](mailto:simcik@icpf.cas.cz); supported by ICPF)

The added mass coefficient  $C$  was determined for a single spherical-cap body moving in a uniform unbounded fluid. An approximate simple physical model for  $C$  was suggested and was well compared with the analytical result of Kendoush, which likely is the only available theoretical result in the literature, up to date. The correct result for  $C$  was obtained via direct numerical flow simulation with CFD. Both the rigid and deformable (bubble, drop) cap body was considered. An approximate model was suggested for the collective added mass in a swarm of spherical cap bodies. A relation was found between the added mass of an unbounded cap body and a bounded spherical body. Practical explicit correlation formulas for  $C$  were obtained, suitable for engineering modelling of multiphase flow systems with bubbles, drops and solids. A relation between the added mass, Darwin drift, and fluid mixing was also noted. [Ref. 6]



**Added mass coefficient  $C$  for a spherical-cap body. Kendoush - approximate analytical solution for a rigid cap by Kendoush (2003). Blank points- Direct numerical solution by CFD for deformable cap-body. Full points - Direct numerical solution by CFD for rigid cap-body. Equation (2.4) - approximate physical model for a rigid cap.**

### International co-operations

Institute of Fluid Mechanics, Toulouse, France: Effect of surfactants on multiphase flows  
Norwegian Institute of Technology (NTH), SINTEF, Trondheim, Norway: Bubble columns

Centre de Recherché et de Transfert de Technologies, Saint Nazaire, France: Microfluidics  
Aristotle University of Thessaloniki, Thessaloniki, Greece: Microfluidics  
University of Nottingham, United Kingdom: Multiphase diagnostics in gas-liquid flows  
Università degli Studi di Napoli Federico II., Italy: Bubble columns and coalescence

## Visitors

L. Muscat, INP ENSEEIHT Toulouse, France

## Teaching

J. Drahoš, M. Růžička: UCT, Prague, Faculty of Chemical Engineering, postgraduate course "Multiphase Reactors"

J. Havlica: UJEP, Faculty of Science, courses "Mathematics", "Chemical Engineering", "Programming in Chemistry"

J. Tihon, J. Vejražka: UCT, Prague, 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] Böhml L., Sepideh J., Tihon J., Bérubé P.R., Kraume M.: Application of the Electrodiffusion Method to Measure Wall Shear Stress: Integrating Theory and Practice. *Chem. Eng. Technol.* 37(6), 938-950 (2014).
- [2] Dolejš P., Poštulka V., Sedláková Z., Jandová V., Vejražka J., Esposito E., Jansen J.C., Izák P.: Simultaneous Hydrogen Sulphide and Carbon Dioxide Removal from Biogas by Water-Swollen Reverse Osmosis Membrane. *Sep. Purif. Technol.* 131, 108-116 (2014).
- [3] Hladil J., Šimčík M., Růžička M., Kulaviak L., Lisý P.: Hydrodynamic Experiments on Dacryoconarid Shell Telescoping. *Lethaia* 47(3), 376-396 (2014).
- [4] Morávková L., Vopička O., Vejražka J., Vychodilová H., Sedláková Z., Friess K., Izák P.: Vapour Permeation and Sorption in Fluoropolymer Gel Membrane Based on Ionic Liquid 1-Ethyl-3-Methylimidazolium bis(trifluoromethylsulfonyl)Imide. *Chem. Pap.* 68(12), 1739-1746 (2014).
- [5] Stogiannis I.A., Passos A.D., Mouza A.A., Paras S.V., Pěnkavová V., Tihon J.: Flow Investigation in a Microchannel with a Flow Disturbing Rib. *Chem. Eng. Sci.* 119, 65-76 (2014).
- [6] Šimčík M., Punčochář M., Růžička M.: Added Mass of a Spherical Cap Body. *Chem. Eng. Sci.* 118, 1-8 (2014).
- [7] Tihon J., Pěnkavová V., Vejražka J.: Wall Shear Stress Induced by a Large Bubble Rising in an Inclined Rectangular Channel. *Int. J. Multiphase Flow* 67, 76-87 (2014).
- [8] Vejražka J., Vobecká L., Orvalho S.P., Zedníková M., Tihon J.: Shape Oscillations of a Bubble or Drop Attached to a Capillary Tip. *Chem. Eng. Sci.* 116, 359-371 (2014).
- [9] Wichterle K., Večeř M., Růžička M.: Asymmetric Deformation of Bubble Shape: Cause or Effect of Vortex-Shedding? *Chem. Pap.* 68(1), 74-79 (2014).

### Patents

- [10] Brányik T., Růžička M., Poštulková M.: Zařízení pro stanovení přepěňování sycených nápojů. Apparatus for Gushing Analysis in Carbonated Beverages. *Pat. No. 26362/UV 2013-28285*. Applied: 13.08.05, Patented: 14.01.20.
- [11] Veselý V., Drahoš J., Šírek M.: Process for Recovering Terephthalic Acid. *Pat. No. EP2061744/PCT/CZ2007/000086*. Applied: 07.09.06, Patented: 14.04.30.