Materials Science and Tehcnology PhD School
Kerpely Antal

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Foam evolution and stability at various gravity conditions

Book of theses

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1 Background and objectives

Foams are dispersion of gas in a liquid or solid phase. These materials play an essential role in nature and in our artificial world as well. They can act as structural or functional materials in the industry – food, construction, furniture, transport, aerospace – and we always meet them in the everyday life.

Engineers constantly try to find the best method to achieve well controllable manufacturing of foams with homogeneous cell structure, good stability and tailorable functionality, or, on the contrary, want to completely get rid of the unwanted foams in several processes (e.g. paper industry). Understanding the evolution and stability of foam structures is therefore indispensable and always a truly interdisciplinary field where chemistry, physics, mathematics and materials science can all have a significant role.

The call for microgravity and studying gravity-related effects on foams is obvious: gravity has a key role in the life of foams. The liquid due to gravity and capillary forces drains out of the foam resulting cell wall thinning and finally rupture. Gas diffusion through the cell walls leads to coarsening - the bubbles becoming larger with time. Bubble coalescence, coarsening due to diffusion, or film rupturing all depend on foam liquid fraction and they are interconnected through the gravity-driven drainage. These key effects can be separated by the elimination of gravity which is very important from the scientific point of view [1, 2, 3].

ADMATIS Ltd. in Hungary started to research aluminium foams back in 2003 in the frame of the ESA[1] project called 'Advanced Foams under Microgravity'[2], as a co-investigator and facility supplier. Aluminium foams are stabilised solely by solid particles. Particle stabilisation of foams or emulsions is also a hot topic due to the good potential for aluminium foams in transportation industry, and a vast amount of applications for aqueous systems in food and pharmaceutical industry. ADMATIS initiated a project called 'FOCUS - Foam Casting and Utilisation in Space'[3] in 2006 to investigate foaming and stability of particle stabilised aqueous foams using a new type of foam generator (henceforth FG) that can create foams at various gravity conditions. Main experiment objective was a technological demonstration that the new technology is capable of producing particle stabilised foams under microgravity. In parallel, a project for increased gravity measurements was running with the support of the Hungarian Space Office[4]. The above activities ensured an ideal background for me as a PhD student at the University of Miskolc and as an employee at ADMATIS to do scientific work with the following highlighted objectives:

[1] European Space Agency

[2] Project ID: AO-99-075, contract no: 98009, 2003-2006

[3] FOCUS is part of the SURE (International Space Station: a Unique Research Infrastructure) project, financed by ESA, ID: SURE AO-019 / PECS 98045, and co-funded by the EC project SURE, contract no: RITA-CT-2006-026069.

[4] Investigation of particle stabilised foams under macrogravity, TP-212

1. Investigation of particle-stabilisation effect in aqueous foams and to find relation experimentally between the particle contact angle and the foamability of the system.
2. Utilising the benefits of FOCUS FG, my aim was to study the role of gravity and the direction of foaming measured to gravity vector in the foamability and stability of FOCUS suspension (see below).
3. Further aim was to investigate the change in foam structure and bubble size distribution by varying the foaming direction and gravity environment, using FOCUS FG and FOCUS suspension (see below).

2 Summary of scientific work

2.1 Materials and methods

To investigate particle stabilisation effect in aqueous foams I used micron sized emulsion type PVC particles (Vestolit B7021, 10wt%) mixed into water-ethanol solution. Contact angle variation of the PVC particles measured to the solution was carried out by changing the ethanol concentration (0, 33, 55, 78, 90, 96 ethanol vol.%). Foams were produced out of 15ml liquid using a porous SiC ceramic sparger[5] with 0.3bar bubbling pressure (using N_2) for 10 seconds.

For macro - and microgravity experiments I used 2wt% hydrophobic SiO_2 nanoparticles (HDK H15, Wacker) suspended in distilled water containing 0.05 wt% SDS (Sodium Dodecyl Sulphate, Rectapur, VWR Prolabo). The suspension was prepared by first adding the SDS into the water and then portioning the SiO_2 particles in a stepped way, using continuous mixing at 1200RPM for 90 minutes. This suspension was baptised to 'FOCUS suspension' in my work.

Prior to foaming, FOCUS suspension was filled into the FG-s. These FG-s were made of open cell polyurethane foams (Eurofoam K2790) - sponges - with cylindrical shape. All FG-s were washed using distilled water before the filling of the suspension. 4.2±0.2g and 3.8±0.2g suspension was filled for macro and microgravity experiments, respectively.

I also investigated the shelf life of FOCUS Suspension because of experiment integration issues. 50% foamability loss was observed within 2 weeks when storing the infiltrated FG-s at room temperature. This means that only 50% less foam could be obtained compared to the freshly infiltrated suspension. Therefore using the same age suspensions in all reference experiments was critical. For increased gravity measurements I had the possibility to use fresh suspensions, but for microgravity probes 11 day old samples were used.

The effect of increased gravity to FOCUS suspension was studied using the ZARM Hyper-G Centrifuge at Bremen, Germany, with a special automated test pad assembled

[5] Universal Multizone Foaming Apparatus - Low Temperature Foaming Cartridge, ADMATIS

at ADMATIS premises. Nitrogen gas was used for foaming (10 seconds foaming time with 0.125l/min flow rate).

Long-term decreased gravity environment was achieved on board of the International Space Station European Columbus Module and the experiment was carried out using the FOCUS flight hardware developed by ADMATIS (Figure 1). The foaming gas in microgravity and in the reference measurements was HFC-245fa (Honeywell). Three foaming cartridges were used having 0.08, 0.125 and 0.23 l/min flow rates with 42, 40 and 37 seconds foaming times, respectively.

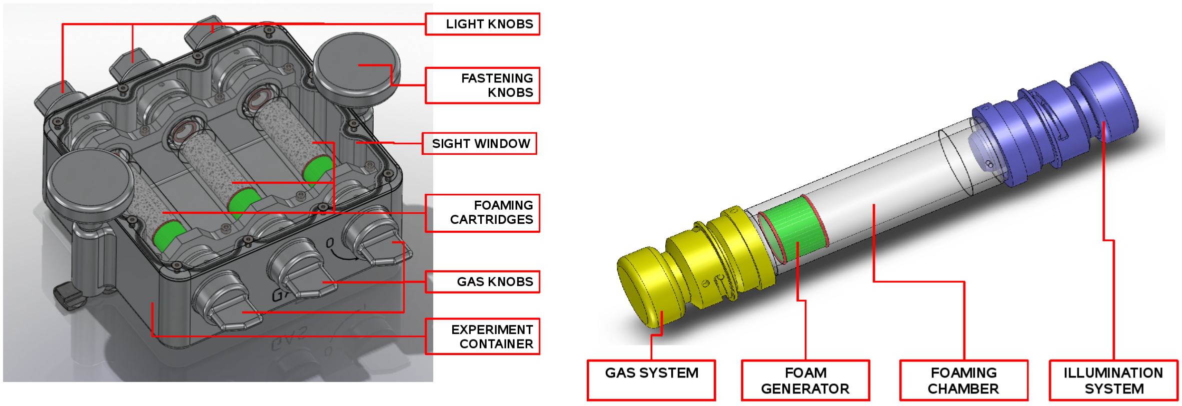

Figure 1: FOCUS Flight Hardware overview.

All experiments were recorded using CCTV or digital camera and the foam volumes and bubble sizes were evaluated using image analysis. The most important process parameters for foaming, like foaming pressure, gas flow rate, temperature, ambient pressure were controlled and/or measured in all cases. The direction of foaming was measured always to the gravity vector (180° stands for normal 'bottom-up' foaming, 90° is for 'horizontal' and 0° is for foaming 'downward'). G-level was determined using accelerometers mounted onto the hardware during macro-g investigations. Columbus g-level data (< 0.016g) was provided by the flight operators for the decreased g experiments. All experiments were done at normal laboratory conditions, having ambient pressure and room temperature (23 ± 1 °C) in all cases.

Foamability data were characterised by the generated foam volumes within a given foaming time at a fixed gas flow rate. Foam volume is the volume of the generated foam with homogeneous cell structure. Cells ('holes') that have sizes greater than 10% of the entire volume were not considered as part of the foam. The initial foam volume is the amount of foam right after switching off the gas inlet.

Foam stability can be featured by the foam half-lives or the foam lives. The ratio (given in %) of the 3 minutes old foam volume and the initial foam volume was also used.

Average bubble sizes in macro-g experiments were determined from the high resolution photos taken after each experiment cca. 5 minutes after foaming. Data are given in pores per inch (PPI), by dividing the number of bubbles by the half inner perimeter of the foaming cartridge (henceforth FC). The number of bubbles were counted at 10mm distance from the FG.

In the microgravity measurements we could use high resolution images during the whole foaming process and the average bubble sizes were calculated by counting the bubbles along the half-perimeter of the FC at every 5 millimetres, measured from the FG surface. Those cases where the foam did not fill the whole half perimeter of the cartridge, only the appropriate arc length was considered.

2.2 New scientific results (theses)

1. The effect of particle contact angle to the liquid in foam stabilising was investigated using 10wt% micron sized emulsion type PVC particles (Vestolit B7021, purified using distilled water) suspended in water-ethanol solution with various ethanol content. Through changing the ethanol concentration we could vary the contact angle between PVC and the liquid (0, 33, 55, 78, 90, 96 ethanol vol.% for 83, 46.5, 36, 15, 0, 0° contact angles, respectively). It was shown experimentally that the contact angle has to be in a certain range (36-83°) in order to see the stabilisation effect of PVC particles in water-ethanol solution, using direct gas injection through porous ceramic for foaming. The maximum foam volume was reached in the case of ethanol-free system which corresponds to 83° contact angle for PVC particles. Foams were created using 0.3bar bubbling pressure for 10 seconds.

2. The amount of foams generated from FOCUS Suspension (2wt% SiO_2 nanoparticles, 0.05wt% SDS in distilled water) using fixed air flow rate (0.125l/min) and foaming time (10 seconds) with FOCUS FG-s, depend on the gravity level: higher gravity gives less foam volumes in all measured directions (180°, 90° and 0°, measured to gravity vector).

3. The 'foaming curves' (foam volumes vs. time) of FOCUS Suspension (2wt% SiO_2 nanoparticles, 0.05wt% SDS in distilled water) showed that the largest foam volumes can be reached in microgravity, using FOCUS FG with HFC-245fa as foaming gas. Foams were generated at 0.08, 0.125 and 0.23l/min flow rates for 42, 40 and 37 seconds, respectively.

4. Foam stability in the increased gravity (1-15g) experiments was characterised by the ratio (given in %) of the 3 minutes old and the initial foam volumes. The stability of foams generated from FOCUS suspension (2wt% SiO_2 nanoparticles, 0.05wt% SDS in distilled water) with FOCUS FG, using air as a foaming gas remained between

63 and 85% showing only a slight decrease in the function of gravity level at 180° (Figure 2). Foams were generated at 0.125l/min flow rate for 10 seconds.

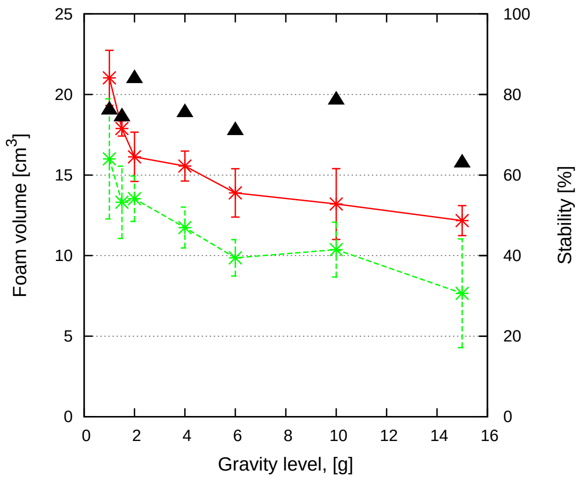

Figure 2: Initial and 3 minutes old foam volumes and calculated foam stabilities in the function of gravity level, 180° foaming direction.

5. The foam lives (i. e. stability) of FOCUS Suspension (2wt% SiO_2 nanoparticles, 0.05wt% SDS in distilled water) did not increase under microgravity environment. Foams were blown using HFC-245fa and FOCUS FG at 0.08, 0.125 and 0.23l/minflow rates for 42, 40 and 37 seconds, respectively. Foam decay in the case of our suspension is therefore not connected with gravity induced drainage.

6. Average cell sizes of FOCUS-suspension foams (2wt% SiO_2 nanoparticles, 0.05wt% SDS in distilled water) did not change markedly with the increasing magnitude of gravity, but the variation of foaming direction (measured to gravity vector) causes significant differences in the foam structure. 0° direction gives much coarser foams, with cca. 3 times less pores per inch value. Foams were generated using FOCUS FG, at 0.125l/min flow rate for 10 seconds with air as a foaming gas.

7. The largest average bubble sizes were reached in microgravity compared to 1g reference measurements using FOCUS suspension (2wt% SiO_2 nanoparticles, 0.05wt% SDS in distilled water) with HFC-245fa foaming gas. The higher is the flow rate, the more significant is the difference in the average bubble size distribution, when comparing 0g experiment with 1g reference experiments, using 0, 90 and 180° foaming directions, respectively. Foams were generated using FOCUS FG at 0.08, 0.125 and 0.23l/min flow rates with 42, 40 and 37 seconds foaming times, respectively.

3 Utilisation

Based on the large number of experimental data development of a numerical model for foam generation using FOCUS FG can be set up, including the effect of gravity vector. Foaming from different directions can be interesting for the metal foam industry in the manufacturing of foamed components with advanced shapes.

Experiences gained using aqueous foams has been already transferred to the aluminium foam domain within the frame of 'AFT' project[6] at ADMATIS, from 2008-2011.

Publications connected to the topic of thesis

Scientific publications

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3. Béla M. Somosvári, Norbert Babcsán, Pál Bárczy, Almuth Berthold, PVC particles stabilized water-ethanol compound foams, Colloids and Surface A: Physicochem. Eng. Aspects 309 (2007) 240-245

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[6] AFT, Shaped Metal Foam Technology, Ányos Jedlik Programme, NKFP-07-A2-METFOAM8

1. Béla M. Somosvári, Pál Bárczy, János Szőke, Investigation of Shelf-Life and Foaming of Water-SiO_2-SDS Compound, poster, Colloids and Materials 2011, Amsterdam, 2011.05.08-11.

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5. Béla M. Somosvári, Pál Bárczy, Péter Szirovicza, János Szőke, Tamás Bárczy, Foaming Experiments under Macrogravity Conditions, presentation, EUROMAT 2007, Nürnberg, 2007. 09.10.

6. Béla M. Somosvári, PVC Particles Stabilizing Water-ethanol Compound Foams, presentation, EUFOAM 2006, Potsdam, 2006. 07. 02-06.

7. Béla M. Somosvári, Pál Bárczy, Stabilization Effect of Particles in Aqueous Suspension Foams, poster, EUFOAM 2006, Potsdam, 2006. 07. 02-06.

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9. Béla M. Somosvári, Foaming of Water-ethanol-PVC System, presentation, Winter School on Fluid Foam Physics: A Model for Complex Systems, Les Houches, 2006. 01. 9-20

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1. Huszár Márton: PUR szivacs habképző képességének összehasonlító vizsgálata. PUR csőszigeteléssel épített melegvíz távvezeték hőveszteségének meghatározása (Comparative investigation of foam generation ability of PUR sponge. Determination of heat loss of hot water line equipped with PUR insulation.), Master Thesis, Dept. of Polymer Eng., 2008, Univ. of Miskolc, consultants: Dr. Bárczy Pál, Dr. Szemmelweisz Tamásné, Somosvári Béla Márton

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1. Pál Bárczy (speaker), János Szőke, Béla M. Somosvári, Péter Szirovicza, Tamás Bárczy, FOCUS Experiment, Joint CSA/ESA/JAXA/NASA Science Symposium, Increment 21-22, 2009. 09. 02-03.

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[3] Arnaud Saint-Jalmes, Sebastien Marze, M. Safouane, and Dominique Langevin. Foam experiments in parabolic flights: Development of an ISS facility and capillary drainage experiments. *Microgravity Sci. Technol.*, 18-1:22–30, 2006.