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Beer Foam as a Multiphase System

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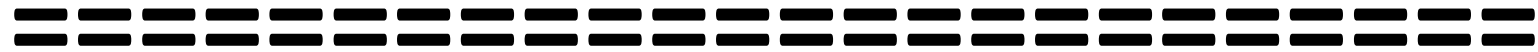
Beer foam as a multiphase system

Marek Růžička

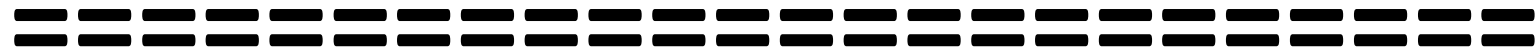
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Contents

- 1. "Multi-Phase"**
- 2. Gushing: prelude**



Part 1. Multi-Phase systems



Basic orientation

I. Definition of Multi-Phase

1. Intuitive

"Multiphase flow is when water flows together with bubbles, drops, and particles."

2. Exact

Phase = macroscopically distinguishable material substance
immiscible with others.

macro - bulk system, continuum,

immiscible - separation, no dissolution.

- a) Continuous phase - fluid phase carrying 'particles' (fluid = gas, liquid),
- b) Discrete phase(s) - dispersed 'particles' (bubbles, drops, solids).

Examples - phases

Three states of matter: gas, liquid, solid
(NOT water + salt: microscopic, true chemical solution)

Two liquids: water + oil (NOT water + ethanol, miscible)

Two gases: NO (miscible, no interface tension!)

Two solids: peas + ashes /hrách + popel/

Ms. Popelka /Cinderella



A multiphase researcher in dry granular media,
system gas-solid-solid, namely phase-separation aspects

II. Multi-Phase abounds

1. Natural systems

Two main continuous phases: air & water (ev. two more fire + ether)

Air (gas)

- aerosols (g-l-s),
- rain (g-l),
- snow (g-s),
- volcano (g-s-f) f - fire /plasma state/
- fires (g-f-s)
- soil, sand, rocks, ... (g-s) granular system /dry or wet/
- people, animals, ... (g-s) /particles, bodies dispersed in air/
- solar, galactic, universal, cosmic systems (s-e) e - ether /'dark matter template'/

Water (liquid)

- sea waters (l-s-g):

g - bubbles of CO₂, CH₄ - carbon cycles,

s - sediments, fish, submarines, icebergs, ...

l - drops of oil,

- fresh waters: ... similar

2. Man-made (artificial) systems

All technologies:

- to contact phases,
- inter-phase transport processes (mass, momentum, energy),
- reaction phenomena (old / new compounds),
- separation steps (wanted / unwanted substances),
- concentrate / dilute,
- use, consume, waste.

Example

Beer *(un-filtered)*

l-g-s double-three phase system

Liquid (golden): water (true solution) + bubbles + yeast ('particles')

Foam (silver): gas (near 100% volume) + liquid films + yeast

"The Golden-Silver One"

Note

Foams = stable bubbles

Liquid film drainage is suppressed by surface gradients of surface tension, produced by surface gradients of surfactant concentration (Marangoni effects).

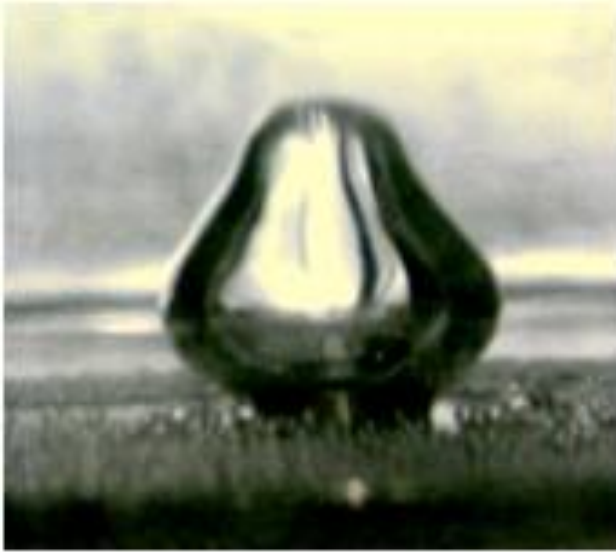
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- g-l bubble columns, aerated systems,
bubble formation, rise, coalescence, breakup
- g-l-s fermenters, flotation,
- s-l sedimentation,
- s-g granular matter (powders - many of !),
- g-l foams.

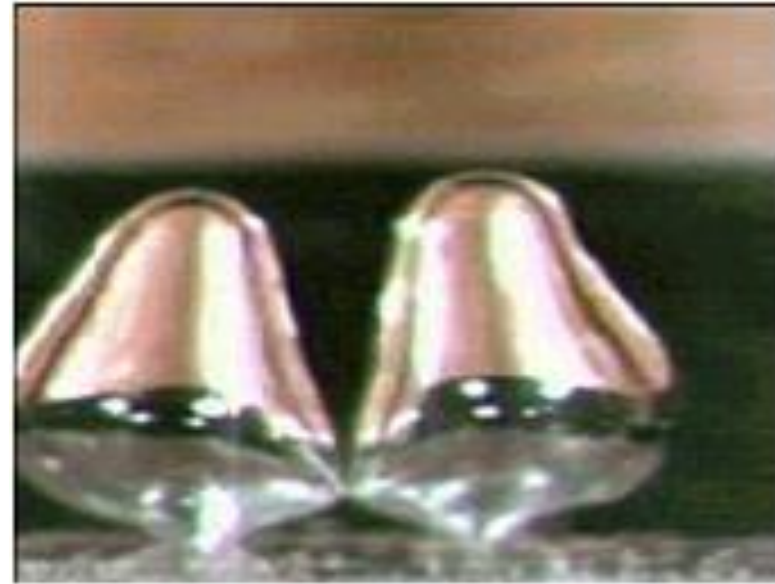
Some pictures on bubbles ...

Bubble formation

Single orifice



Two orifices - close spacing



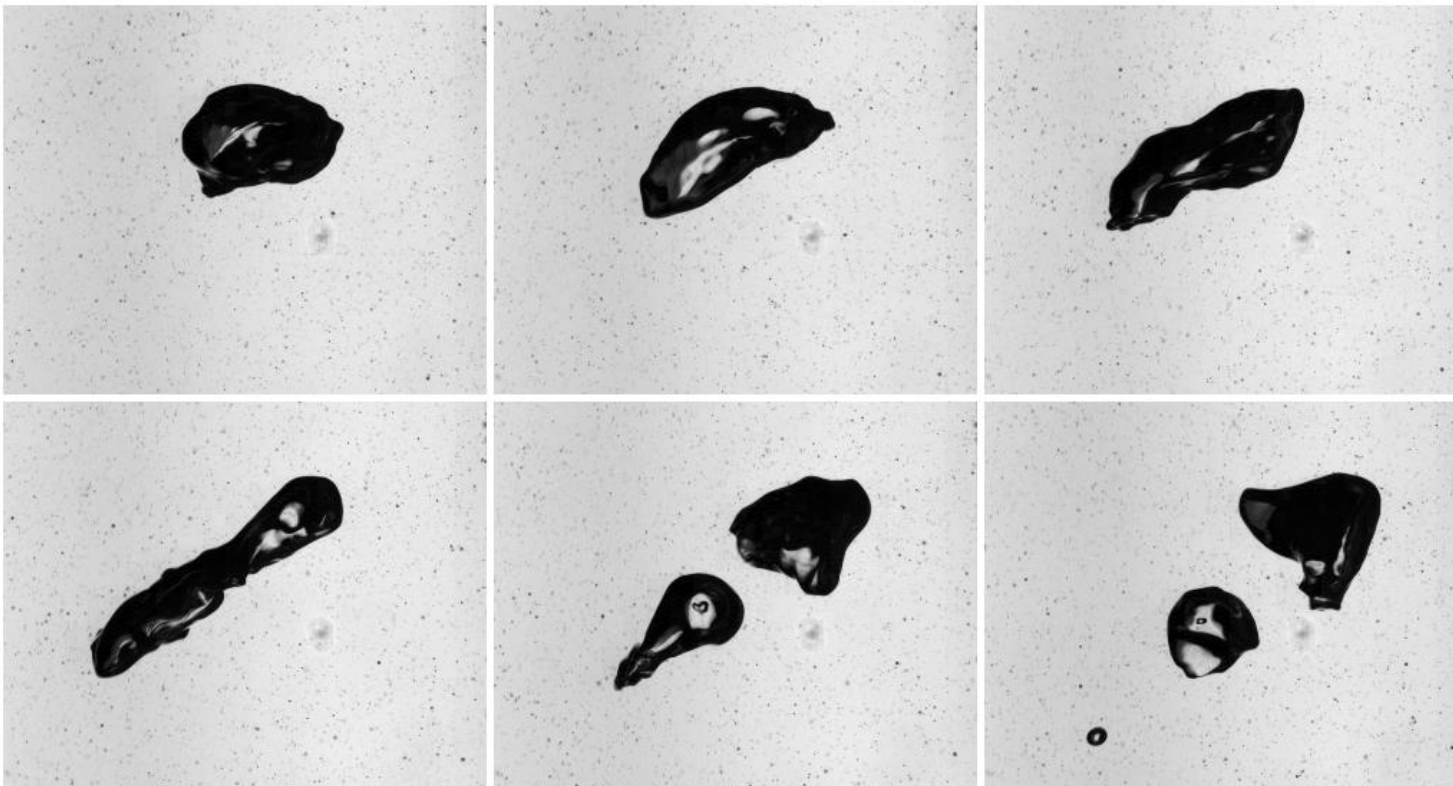
Two orifices - distant spacing



Bubble coalescence

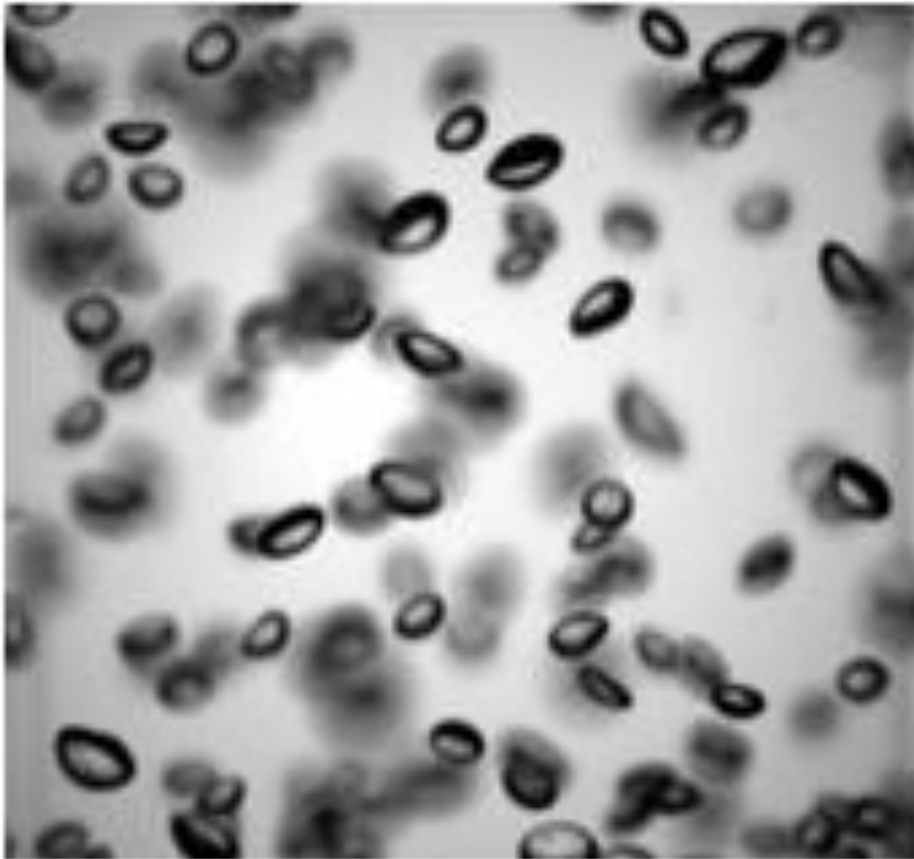


Bubble breakup



Bubble dispersion

Diluted

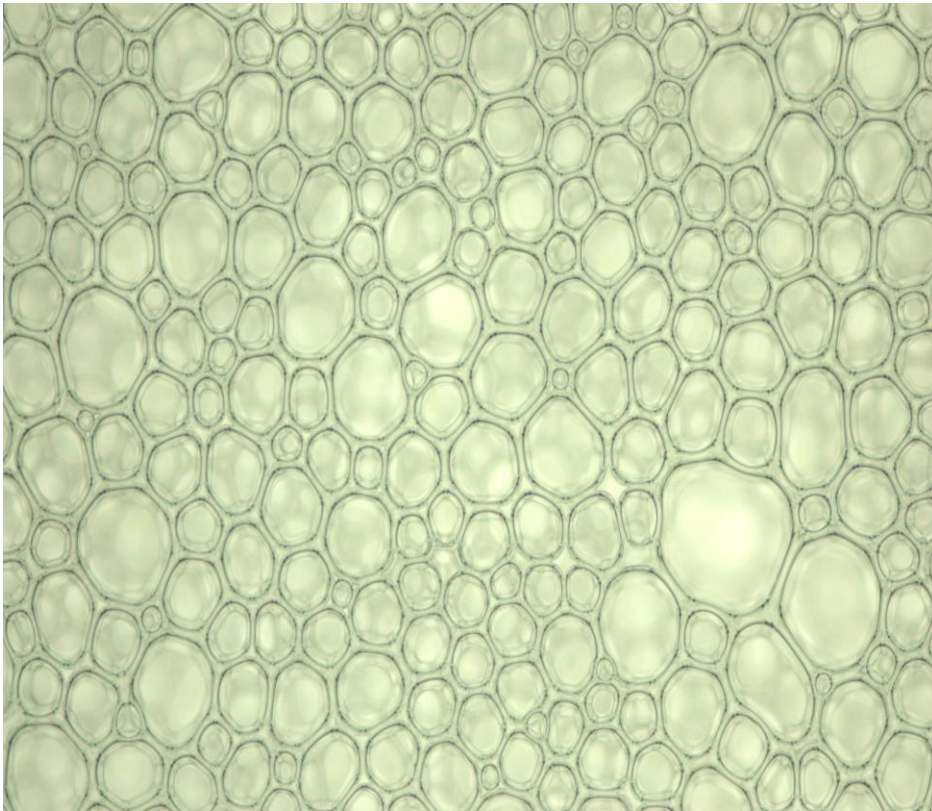


Dense

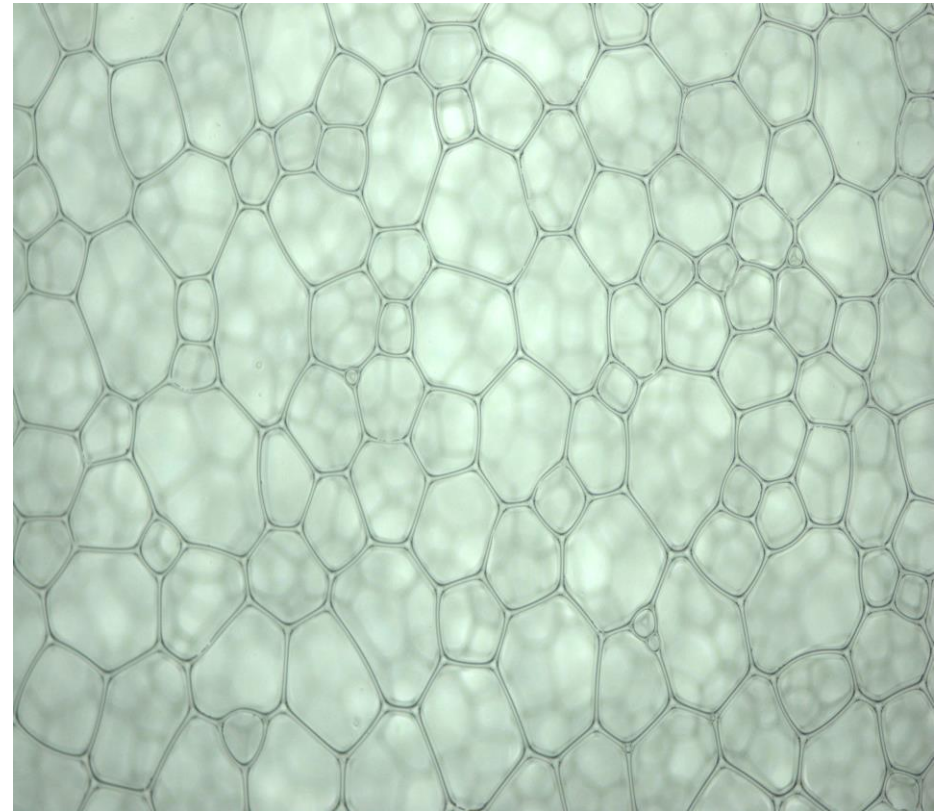


Bubble foam

Wet



Dry

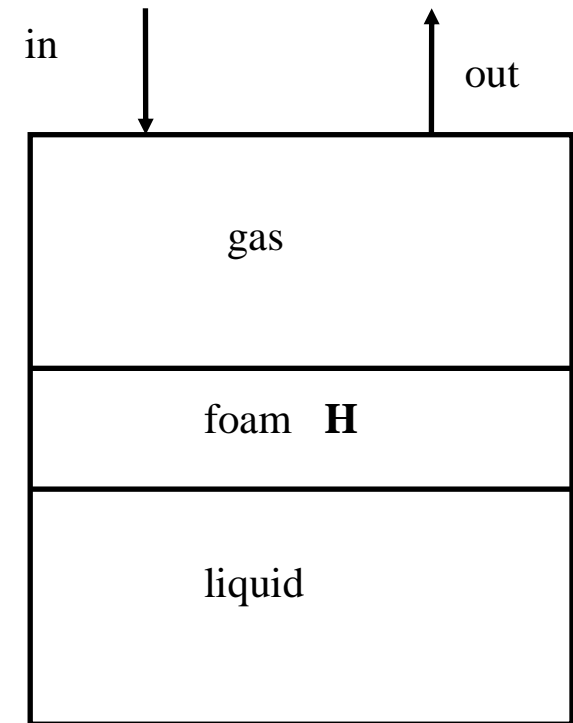


Part 2. Gushing experiments: How to begin ?

Didactical guide - not only for students

Desaturation cell - measuring apparatus

- glass cylinder for low pressures of CO₂ gas (3-10 bars),
- liquid sample (beer) for foam production,
- procedure: liquid saturation and desaturation
(shaking) (cell opening)
- measured data: visual (video) + pressure (transducer),
- results: foam production dynamics, $p(t)$, $h(t)$



→ → → **max foam height H, mean growth rate R**

1. Parameters describing the system

Experimental cell

- shape,
- dimensions,
- working volume,
- sample volume.

Ambient conditions

- temperature, pressure, humidity, light conditions, contaminants, ...

Solutions

- foaming agent (chemical substance),
- producer and type,
- way of storage,
- concentration (relevant units, grams x moles),
- solution preparation (fresh x stored) and conditioning,
- solution use (single x multiple).

Operation parameters

- saturation pressure,
- sample motion (shaking x sloshing, frequency, amplitude),
- saturation time,
- valve opening time (manual x solenoid valve - PC).

2. Definition of "Reference State" [RS]

Sample volume:	$V = 0.5 \text{ l}$,
Ambient conditions:	laboratory,
Foaming agent:	BSA (model substance),
Concentration:	$c = 0.5 \text{ g/l}$,
Solution:	fresh, single use,
Saturation pressure:	$p_0 = 3 \text{ bar}$,
Saturation time:	$T_{AB} = 45 \text{ min}$,
Valve opening:	PC-controlled.

3. Performing experiments

Data acquisition

- pressure signal (sensor - parameters, T-scales, A/D converter),
- video (parameters: resolution, pixel/mm, optical distortion, synchron.),
- precision, sensitivity, errors, reproducibility.

Data treatment

- pressure signals (Volts into Pascals, time series-p, diagrams),
- videos (pixels into mm, time series-h, diagrams),
- errors, statistics, mean values, deviations, function of random variables.

Results

- results: $p(t)$, $h(t)$, H , R ,
- range of validity, reliability, robustness.

4. Basic rules for experiments

Start with "Reference State": test its stability and reproducibility.

Never change more than 1 parameter (in words: 'one').

When in problems, resort to "RS" - the only 'fixed point' in Universe.

5. Basic test measurements

Purpose: mapping the neighbourhood of "RS" in parameter space.

"What would happen, if I make a little error in measurements ?"

But not only !

Test the foaming agent BSA: effect of source, storage, ...

Test the solution: single x multiple use.

Test the mode of saturation: frequency + amplitude of shaking, time period.

Test the mode of cell opening: rate of gas release.

Test the effect of saturation pressure.

6. Planning experiments and 'doing science'

Only now

you may carefully plan

your live 'research' measurements :)

Acknowledgements

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