Fluid-Struktur-Oszillation zur Drainageoptimierung bei der Druckluftfiltration (VibraDrain)

Sitzung des projektbegleitenden Ausschusses

13.12 2022

iuta
forschen.
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anwenden.

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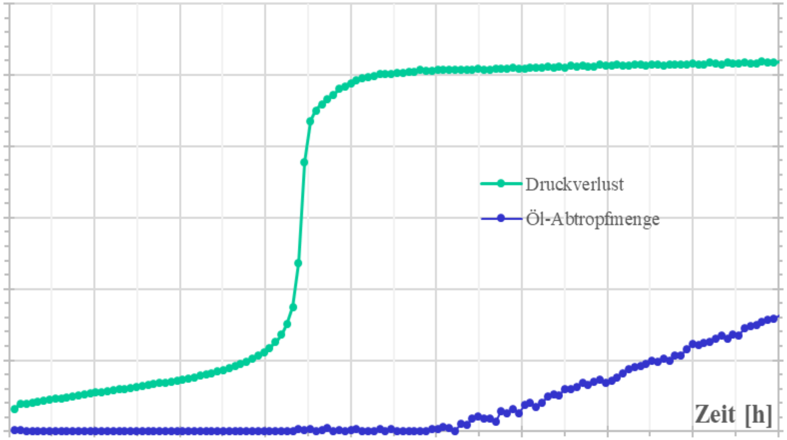
Zielsetzung

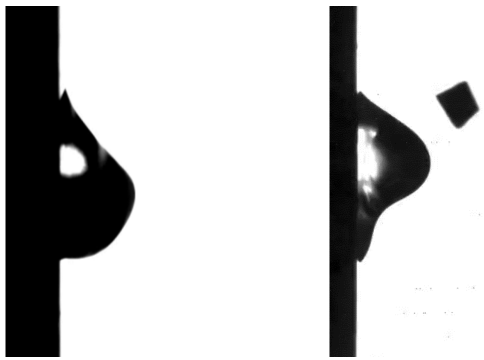
- Entwicklung einer technischen Maßnahme zur Reduktion des Sättigungsniveaus bzw. zur Verringerung der Sättigung über eine
  - Einbringung einer **Oszillation** mit direkter Wirkung auf die Flüssigkeitsansammlung



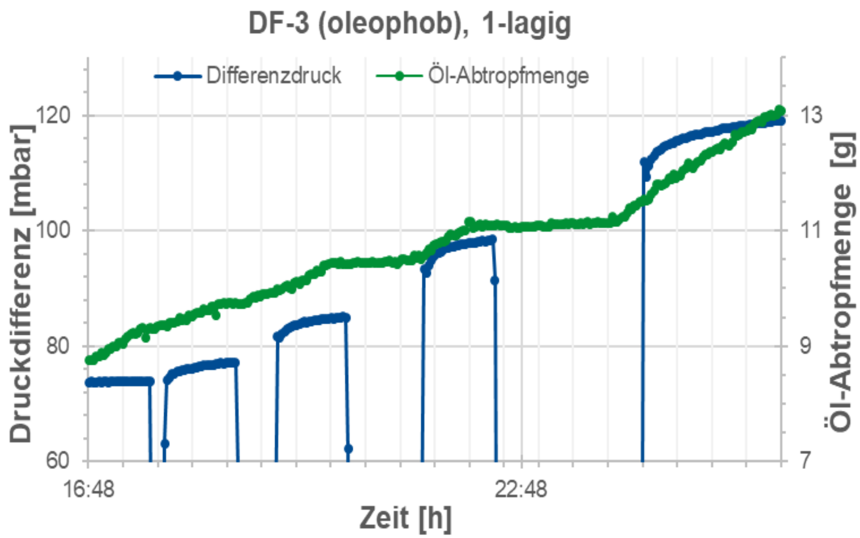
  - **verbesserte Drainage**
  - **Verringerung des Druckverlusts**
  - dadurch Erzielung eines **geringeren Energieverbrauchs** der Drucklufterzeugung in der Gesamtbilanz.

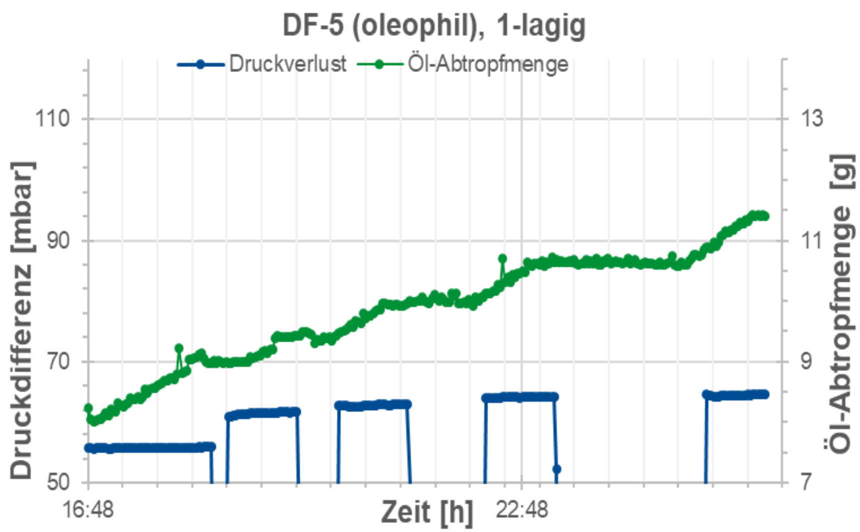
Stand der Forschung

- Bewegung von Flüssigkeits-ansammlungen lässt sich durch Oszillation von Substrat und / oder Strömung beeinflussen und kann eine Reduktion der Haftkräfte bewirken



- Änderungen im Volumenstrom, die als Strömungsschwingung angesehen werden könnten, wirken sich auf die Sättigung von Filtermedien aus





Lösungsweg

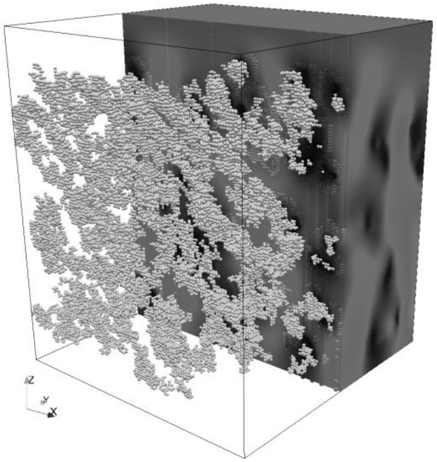
Ansatz: Oszillationen von Struktur und / oder Strömung

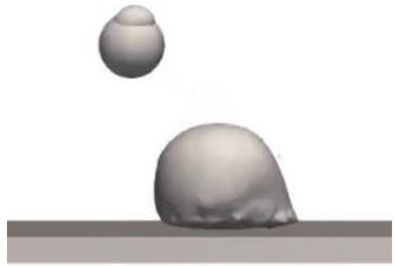
- verbessern die Koaleszenz von abgeschiedenen Öltröpfchen
- erhöhen die Transportgeschwindigkeit durch das Medium
- verringern die Ölsättigung im Medium

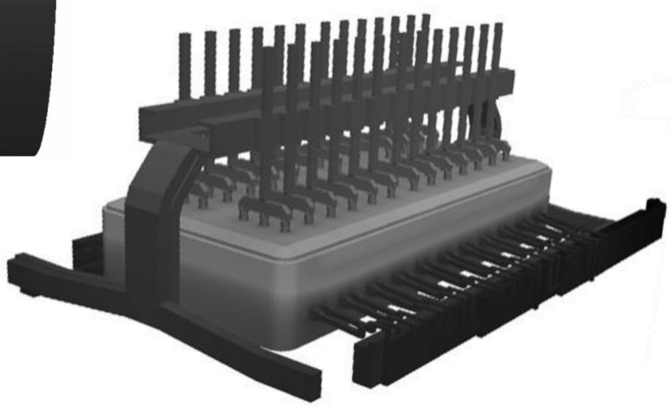
→ Reduktion des sich ausbildenden Differenzdrucks und Reduktion des Energieverbrauchs des Drucklufterzeugungssystems

Lösungsweg:

- Aufbau von Versuchsständen am IUTA und LSM
- Gezielte Untersuchung des Einflusses von Schwingungen auf die Tropfenbewegung sowohl
  - makroskopisch am Filtermedium und Filter als auch
  - mikroskopisch an Ausschnitten von Vliesstoffen.
- Einbringung der Schwingung auf mechanischem Wege und durch Störkörper zur Induktion von Strömungsoszillation.
- Untersuchung an realen Druckluftfiltern mit Unterstützung des PA.







Lehrstuhl Strömungsmechanik

Bergische Universität Wuppertal Fakultät für Maschinenbau und Sicherheitstechnik

Univ. Prof. Dr.-Ing. habil. Uwe Janoske,

Dr.-Ing. Sebastian Burgmann,

Dr.-Ing. Beawer Barwari, Dr.-Ing. Kamil Braschke,

M.Sc. Martin Rohde, M.Sc. Andreas Metzmacher, M.Sc.

Jannik Seybold, M.Sc. Hendrik Gesell. M.Sc. Amin

Zargaran, M.Sc. Florian Freese, M.Sc. Nils Janssen

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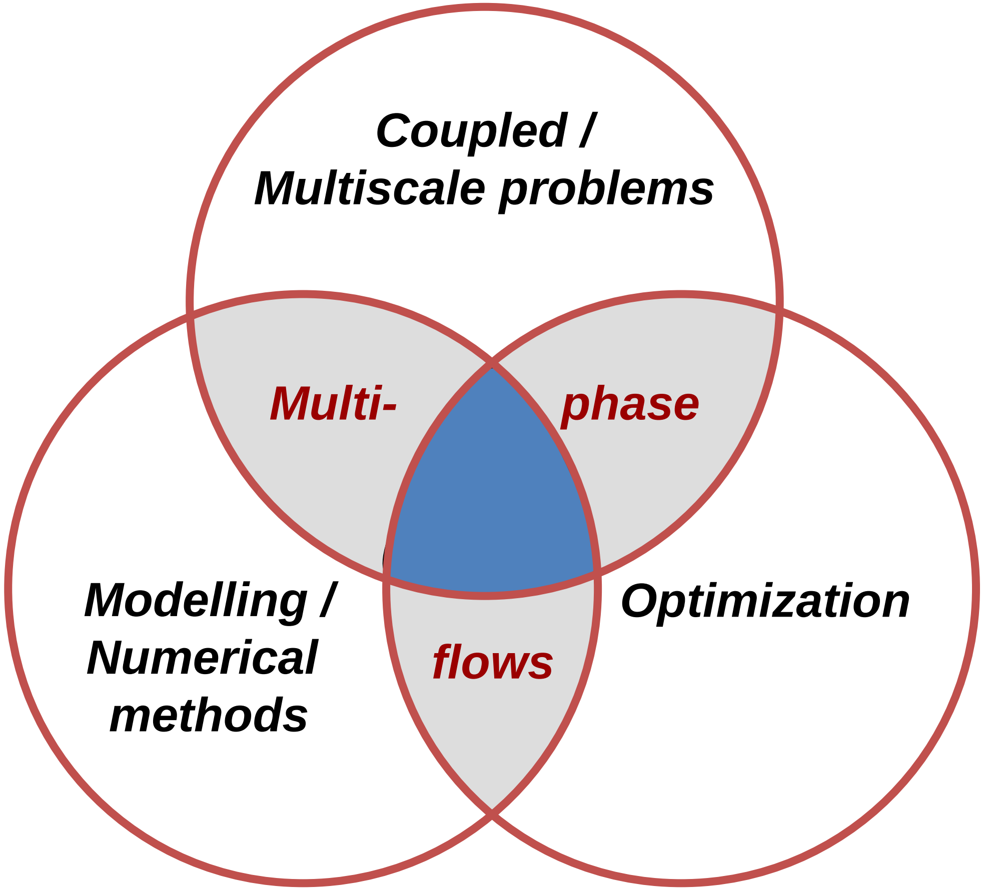
	Bachelor MB	Vertiefung Master	Vertiefung Master
Winter term	Strömungs-mechanik I **(2V+2Ü)**	Modellbildung von Mehrphasenstr. **(3V+1Ü)**	Körperumströmung/ Aerodynamik **(3V+1Ü)**
	Thermodynamik II **(2V+2Ü)**	*Vorlesung mit CSIS im WS*	
		Num. Strömungs-berechnung (CFD) **(3V+1Ü)**	
Summer term	Thermodynamik I **(2V+2Ü)**	Angewandte Strömungsmechanik **(3V+1Ü)**	Strömungsmess-technik **(3V+1Ü)**
	Strömungs-mechanik II **(2V+2Ü)**	Num. Berechnung von Mehrphasenstr. **(2V+2Ü)**	



Virtual Process Engineering

Multiscale modelling of processes and their experimental validation

Strategy - Applications

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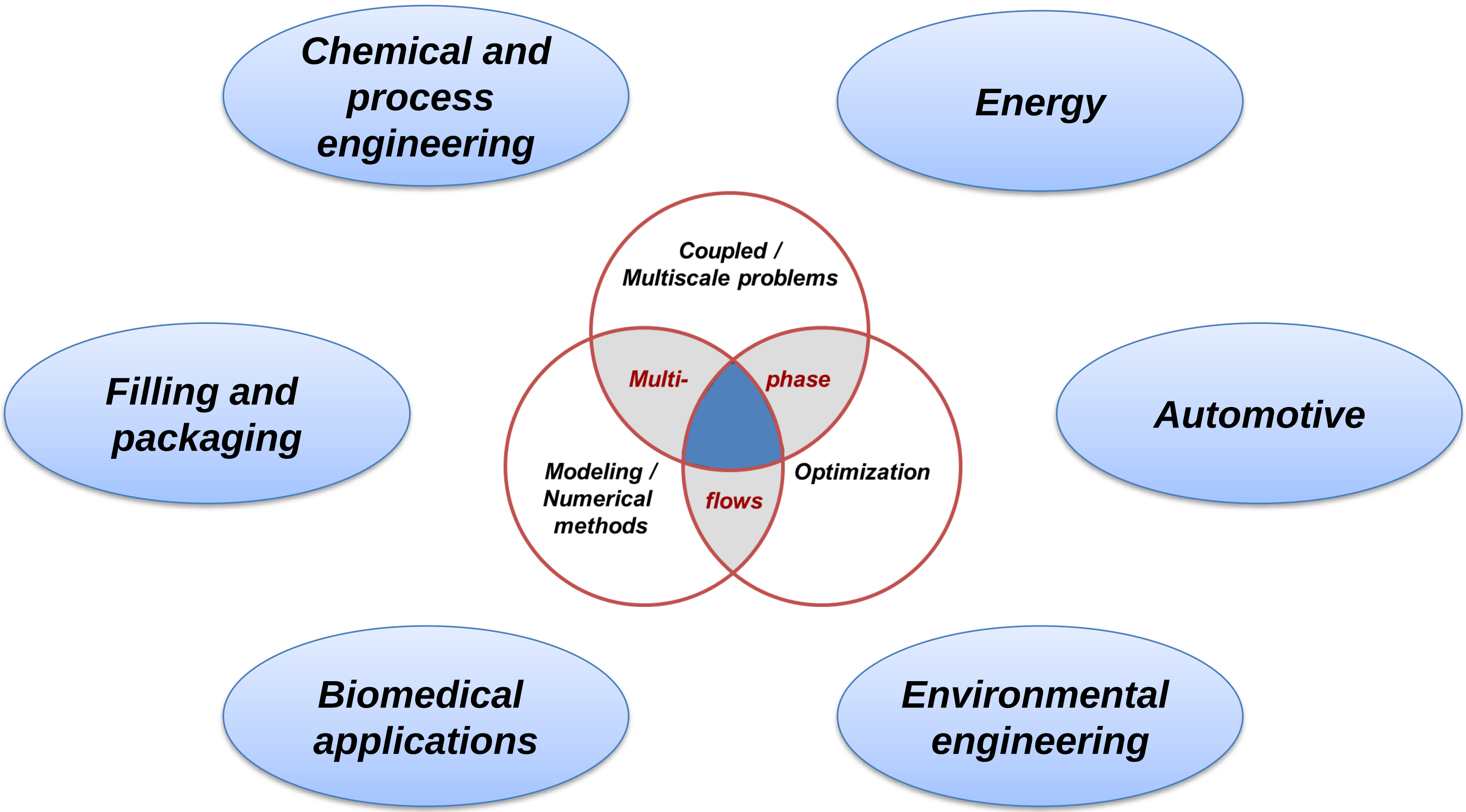
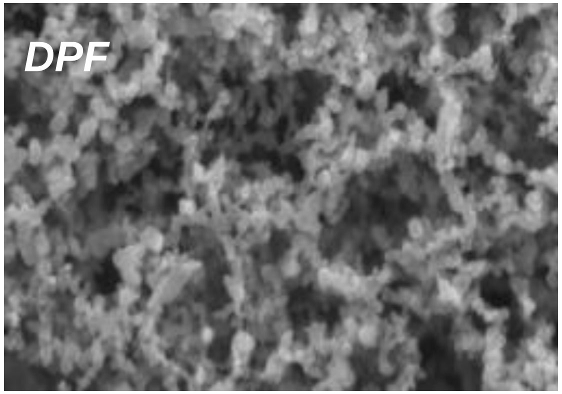


Motivation

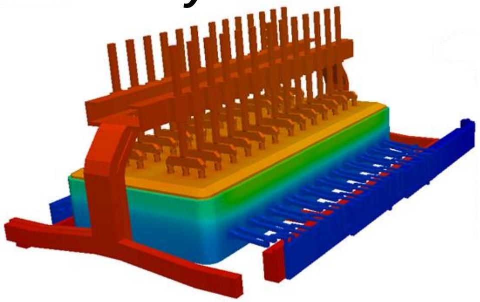
- Multiphase flows can be found in various applications
- Modelling and simulation required for virtual product development
- Complexity of simulations always increasing
    - Coupling of different physical phenomena
    - Problems of different spatial and temporal scales
    - ….
- Reliable (and fast) models as well as suitable algorithms and workflows for industrial applications necessary
- Development of models and workflows still requires work on
    - Fundamental problems
    - Numerical methods
    - Applications

↳ Overview of selected research projects in these fields



Bürger, M., PhD-thesis 2019

Al-electrolysis



Gutt, R. et al., Internal report 2019

Cleaning

Kumar, M. K, PhD-thesis 2019

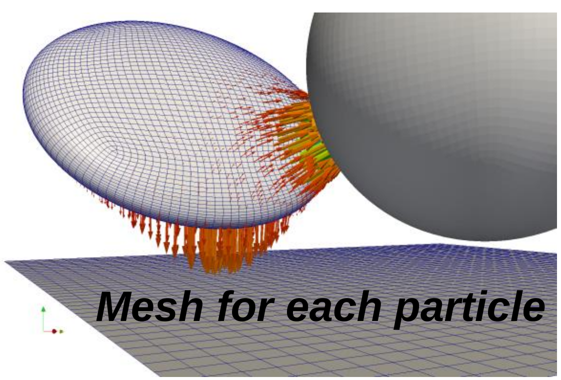
Motivation – Selected projects

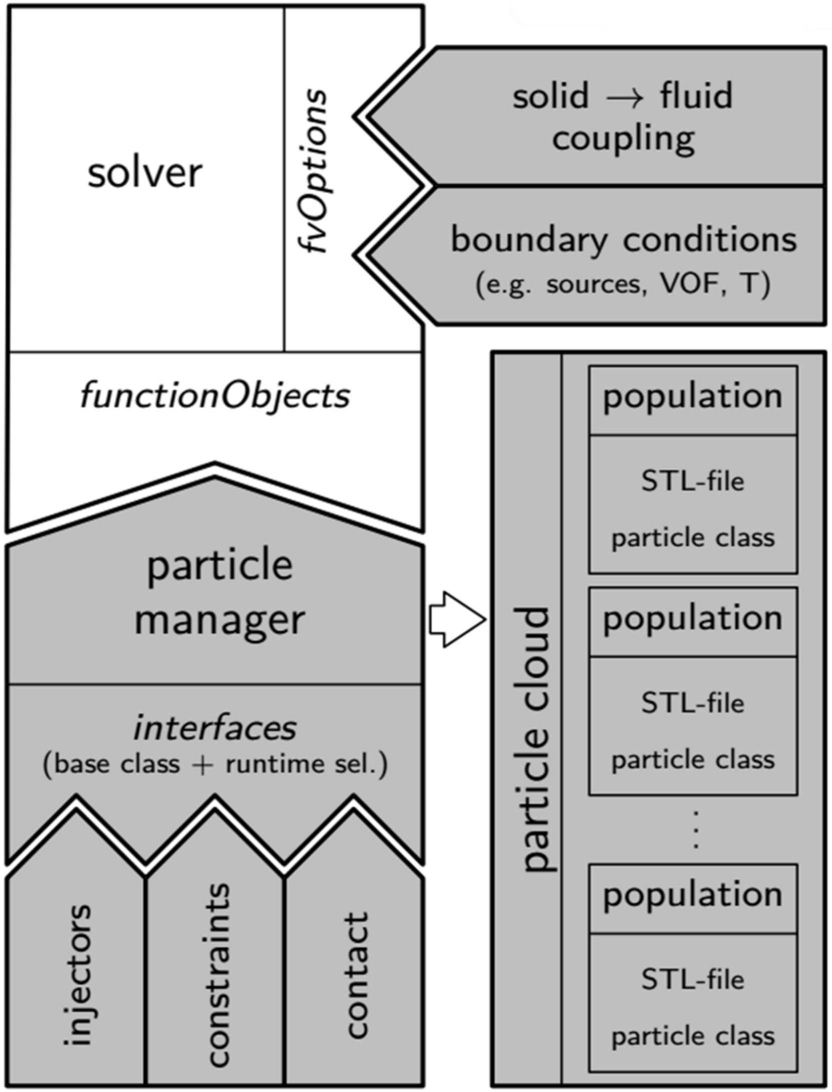
	Dispersed flows	*Separated flows*
Fundamental studies	▪ Movement of irregularly shaped particles Immersed Boundary Method for arbitrarily shaped particles ▪ Dewatering of sludge Coupled FSI with multiphase models	▪ Droplet movement due to flow and mechanical vibrations VoF model including contact angle hysteresis models ▪ Film flows on surfaces Smooth particle hydrodynamics for shallow water flows
Applications	▪ Filtration and regeneration processes, e.g. in soot particle filters Immersed Boundary Method for arbitrarily shaped particles ▪ Separation processes in disk-stack centrifuges Immersed Boundary Method for arbitrarily shaped particles	▪ Coupled multiphase flows in aluminium electrolysis Coupled multiphase methods with MHD ▪ Cleaning of surfaces (fluid films and particulate matter) Coupling of wall film and VoF models

Modelling approach:

- Immersed boundary approach based on OpenFOAM® (new implementation as library) including interfaces for
  - potential forces
  - contact models
  - boundary conditions
  - source terms
  - injectors
  - constraints

- Arbitrary bodies can be implemented as STL-file including adaptive mesh refinement
- All forces (potential, fluid forces, etc.) are calculated based on irregular geometry

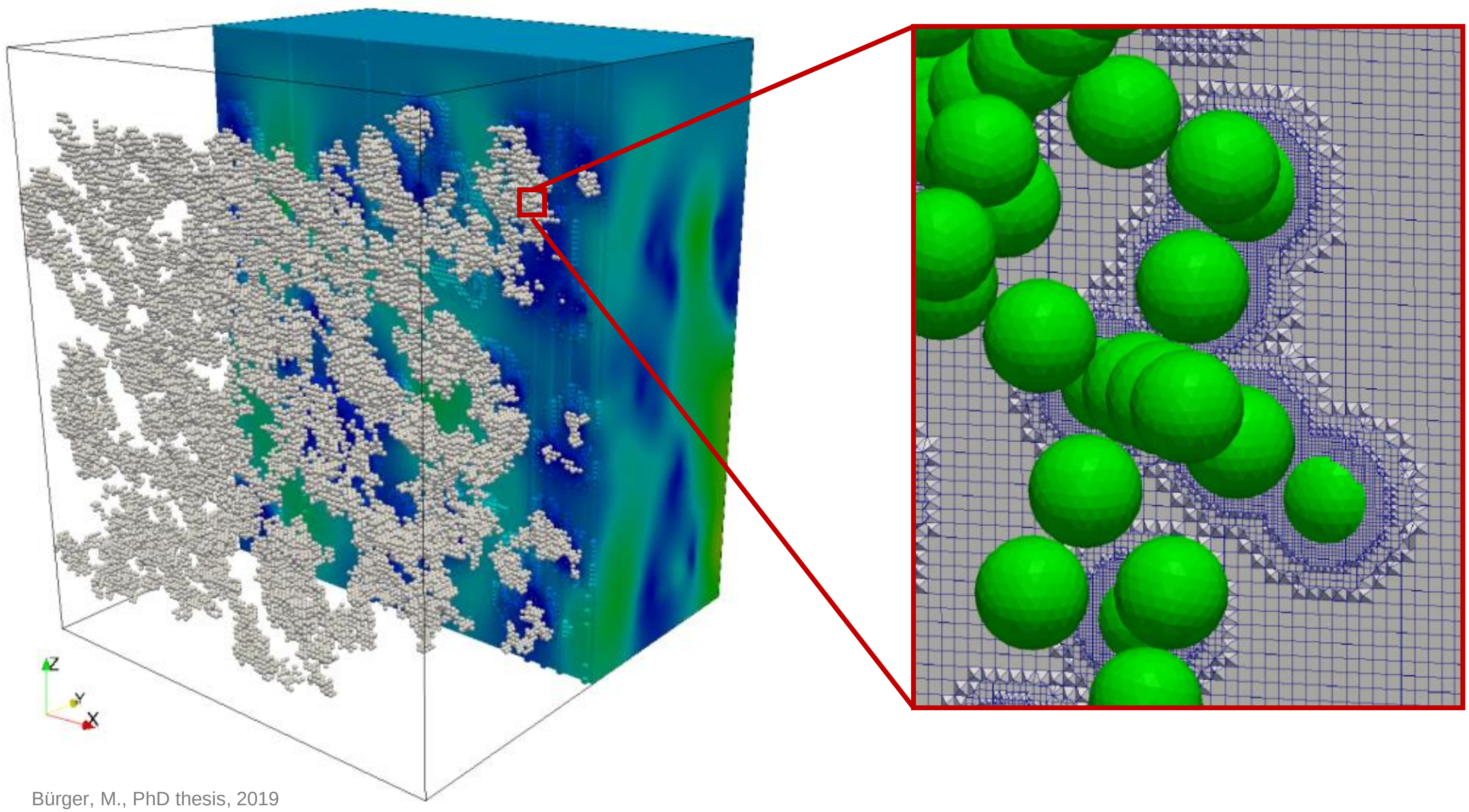




Example - Modelling of soot particle filters:

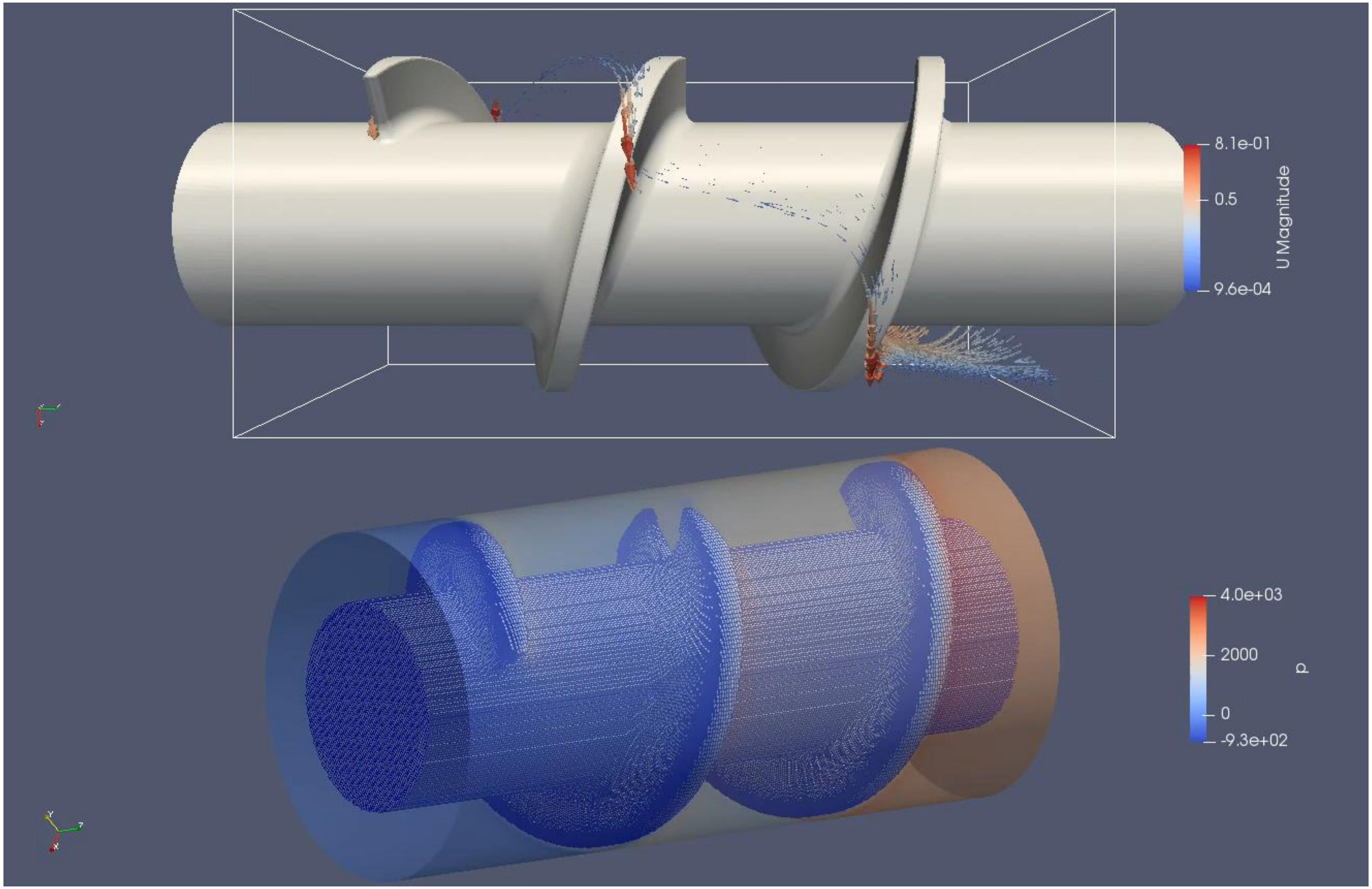
- Flow and species distribution for 50.000 volumetrically resolved particles
- CFD model with approx. 120 Mio. CV

↳ Local information for regeneration conditions (temperature, species) available



Bürger, M., PhD thesis, 2019

Example - Modelling of rotor-stator systems:



Introduction:

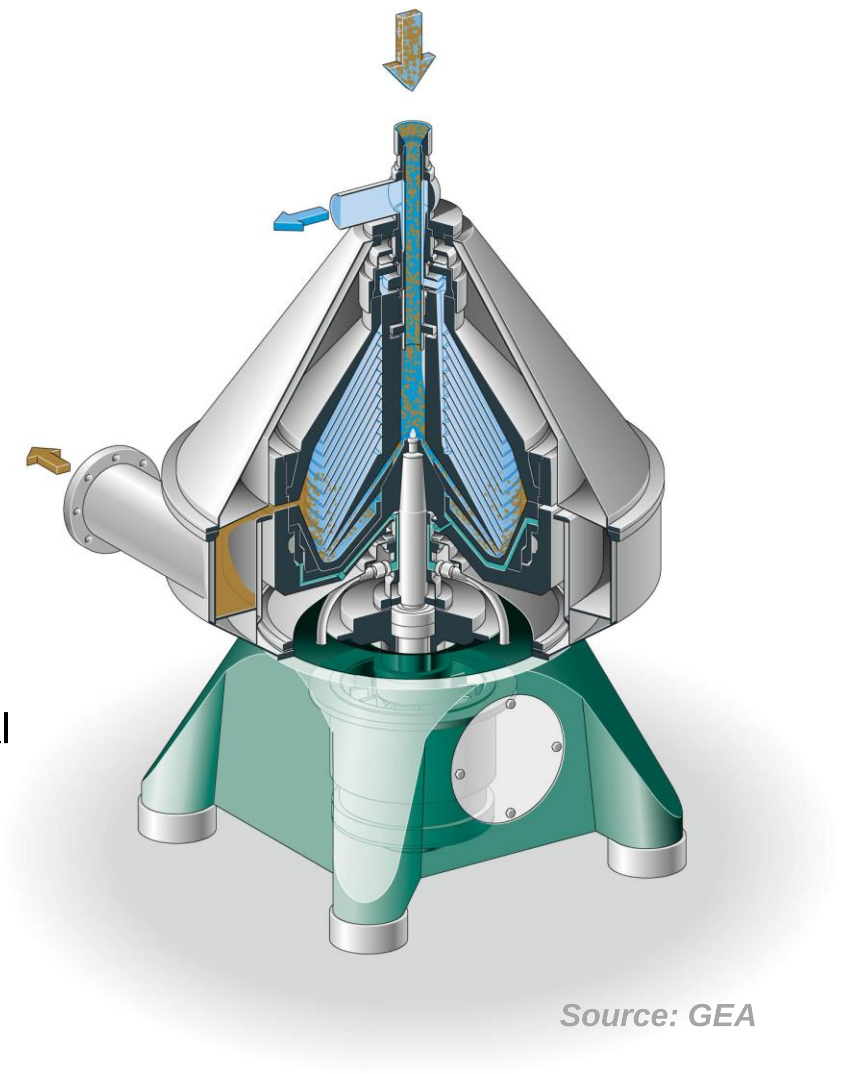
- **Basic principles known** since the patent of Bechtolsheim in 1888

- Used in process lines of **numerous different applications** for
  - liquid-liquid
  - solid-liquid
  - liquid-liquid-solid separation

- Various common designs but focus on batch-operated, **solid-liquid separators with radial rips** (caulks)

- Design often based on semi-empirical, analytical equations (Σ equation)

➯ ***Influence of non-spherical particles and depositions on separation efficiency?***

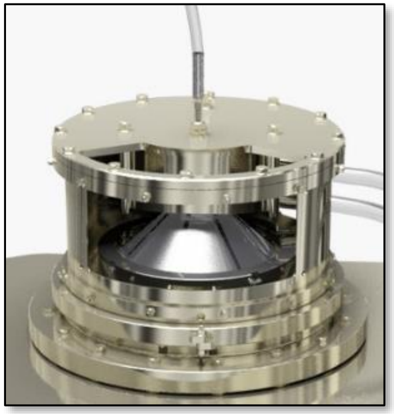


Source: GEA

Deposits in centrifuges

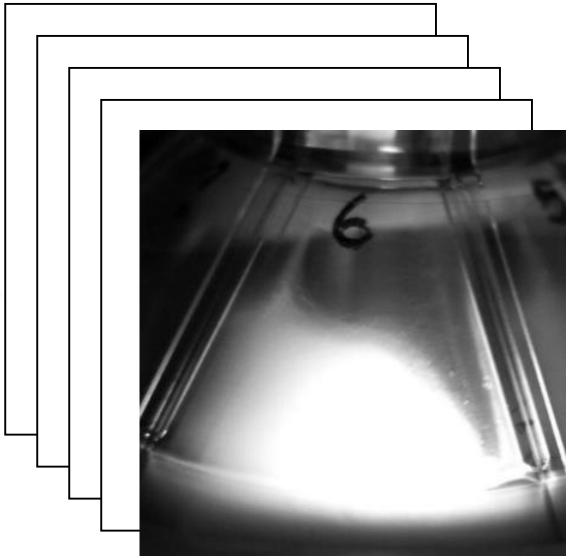
Experimental setup and image processing:

Cube7 High Speed Camera

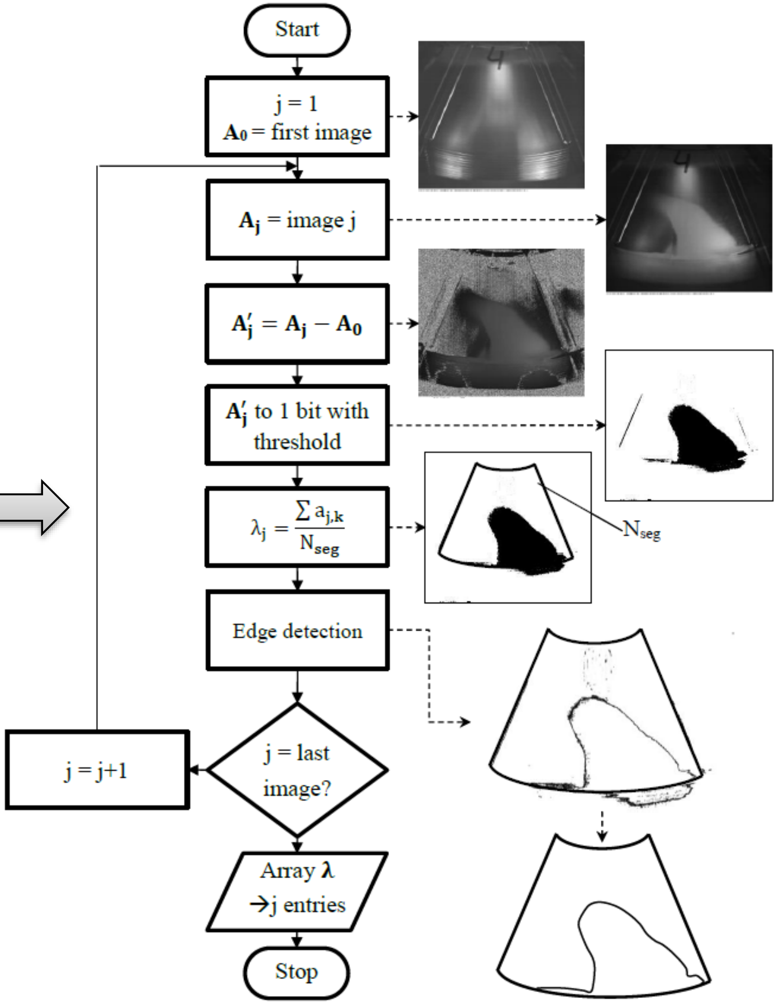


Transparent bowl lid

Up to 1 picture per revolution



$$\mathbf{A_j} = \begin{bmatrix} 0-255 & \cdots & 0-255 \\ \vdots & \ddots & \vdots \\ 0-255 & \cdots & 0-255 \end{bmatrix}$$

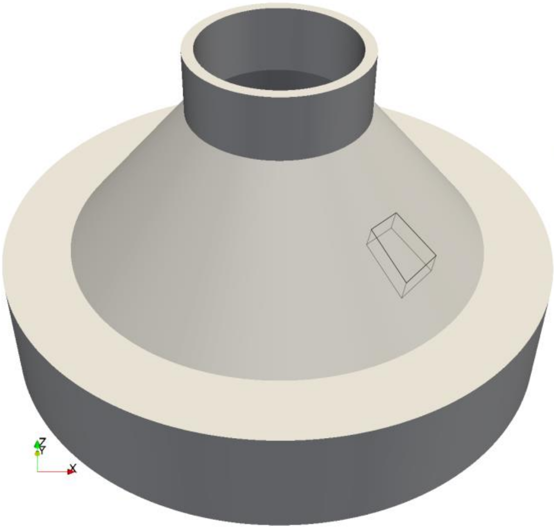


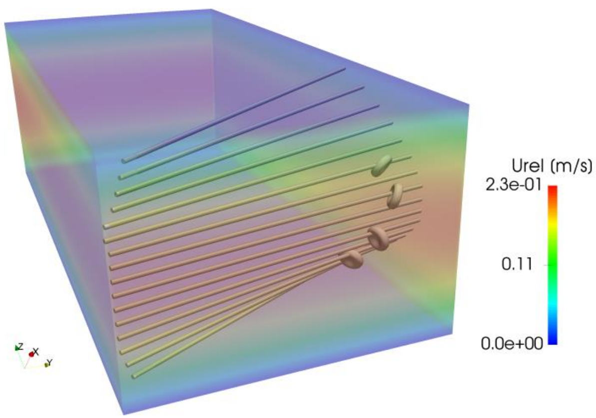
König, J., PhD thesis, 2018

Influence of non-spherical particles on deposition

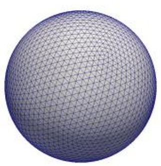
- Influence of different particle shapes and orientations on deposition with ABSFoam

Setup of model

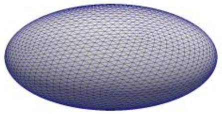




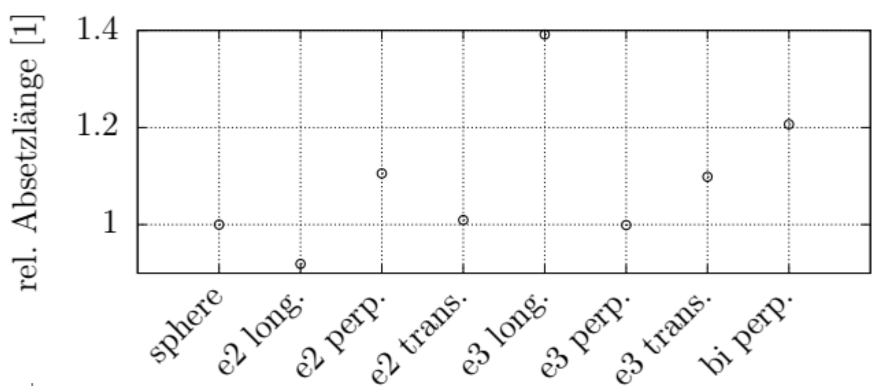
Results



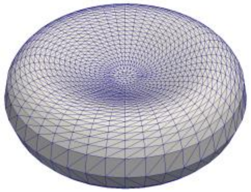
sphere



e2



e3



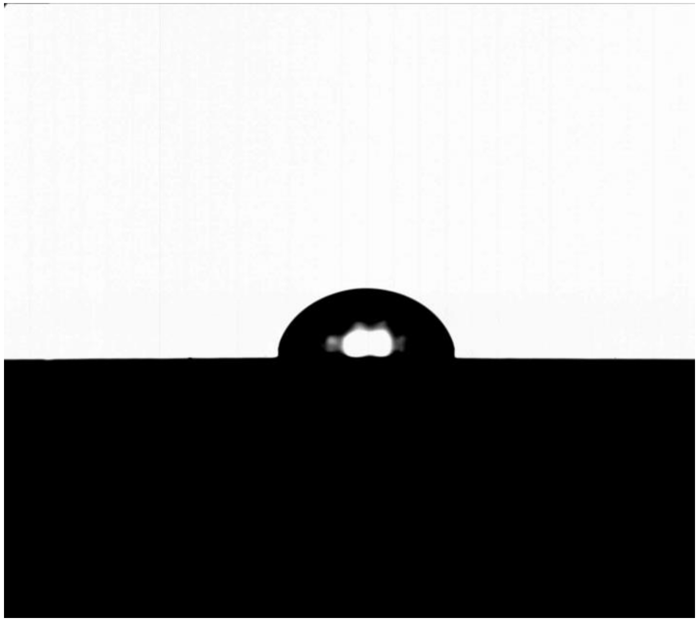
bi (-concav)

Bürger, M., ASME Proceedings | 17th International Symposium on Numerical Methods for Multiphase Flow, 2017

Introduction:

- Wetting of surfaces dependent on various factors
- Behaviour of droplet movement, e.g. on an inclined plate determined by Contact Angle Hysteresis (CAH)
- Phenomena difficult to describe in CFD codes, resp. has not been implemented at all

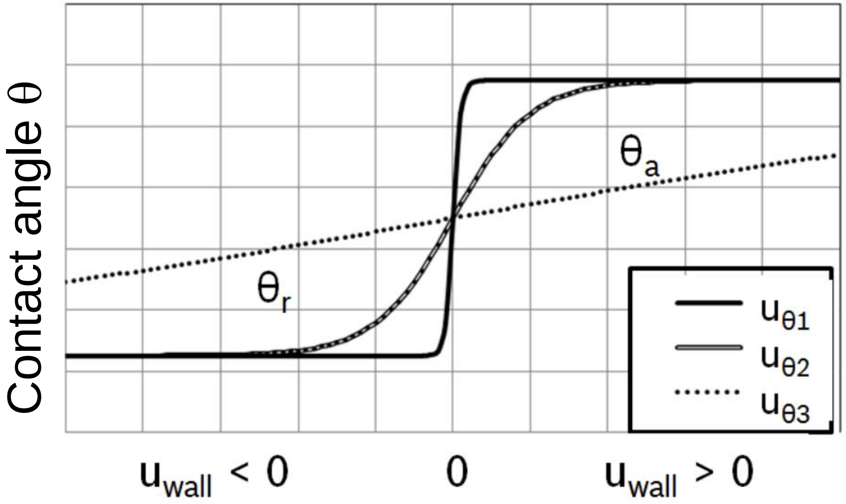
➯ **How to model effects of adhering and sessile droplets?**



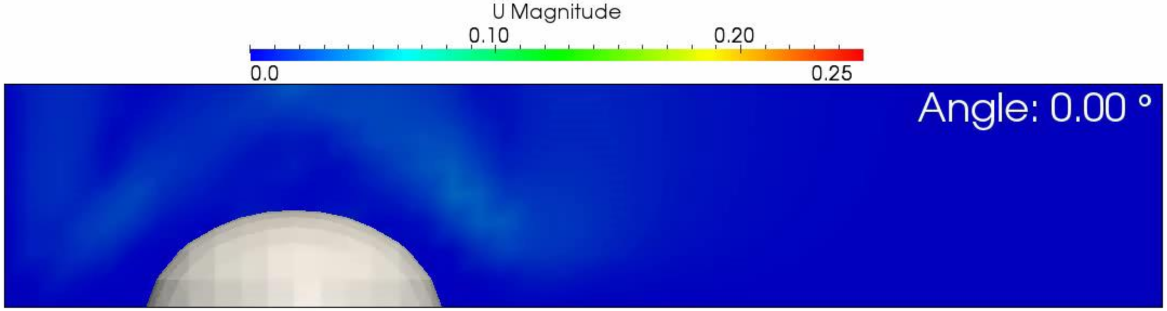
Mauer, T., PhD thesis 2016

Modelling approach:

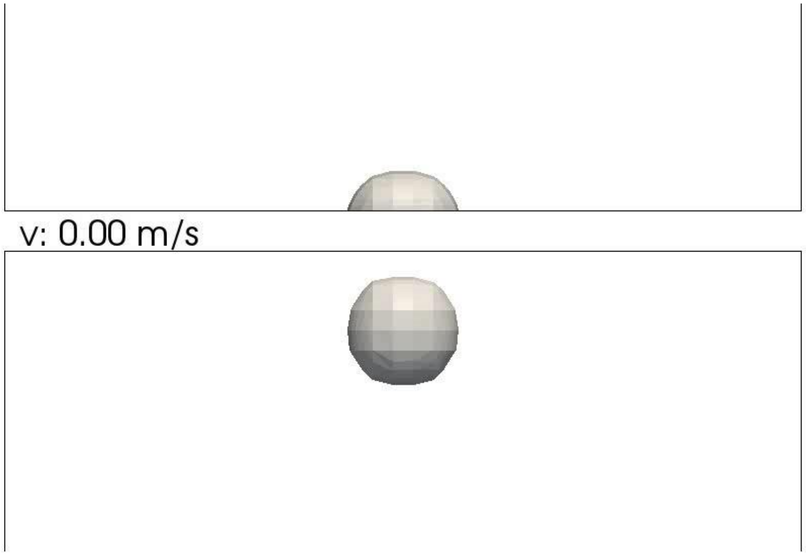
- Volume of Fluid model
- Implementing Contact Angle Hysteresis based on approach of Park and Kang (Physics of Fluids, Bd. 24(4), 2012)

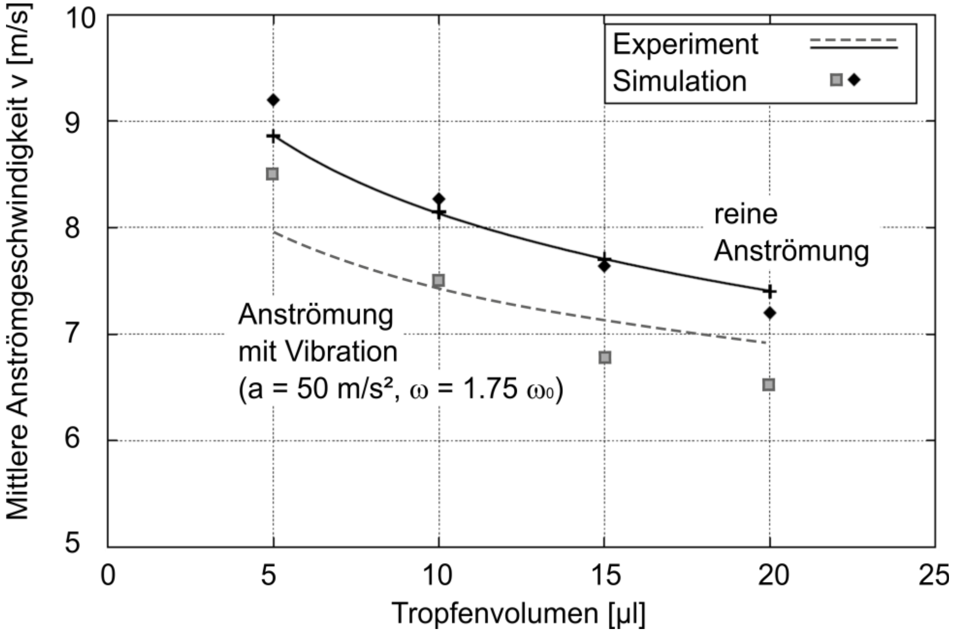


Example – droplet on inclined surface:

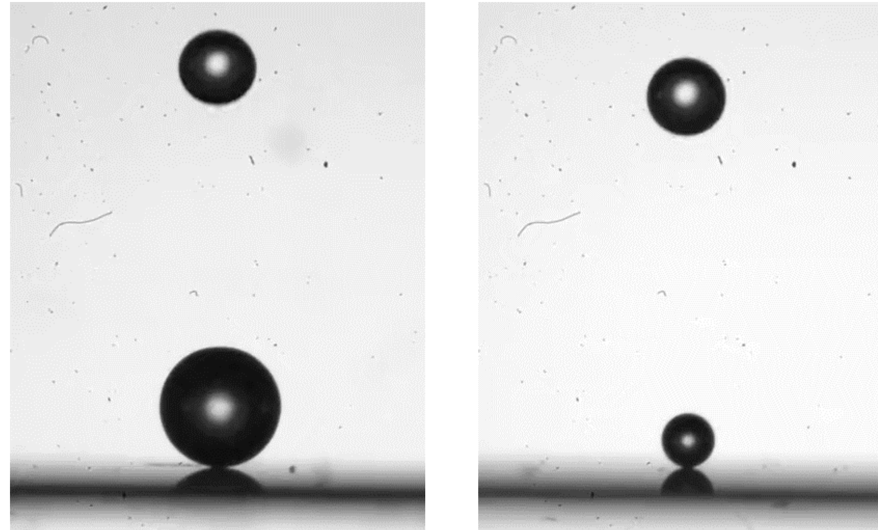


Example – influence of vibration on critical flow velocity

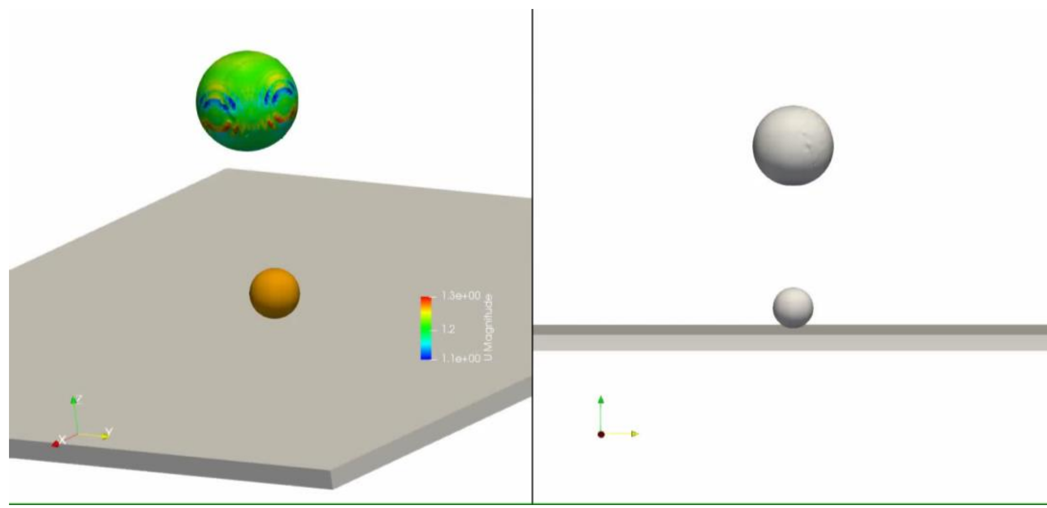




Example – Particle – Droplet (< 2 m/s) – Substrate – Interaction:

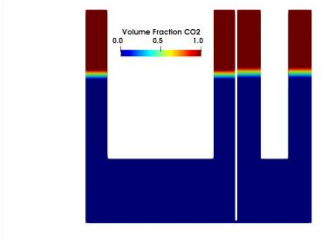


- Cleaning is a complex process
- For a detailed understanding basic experiments for the cleaning of a single particle with droplets are considered
- Combination of experimental and numerical methods (Coupling of wall film and VoF models)

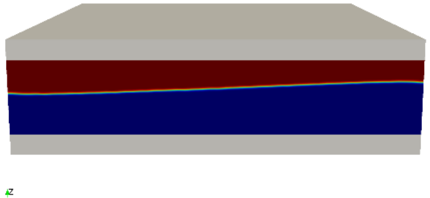


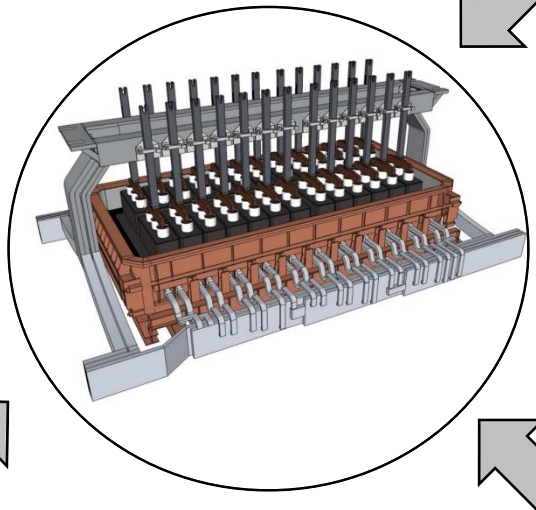
- Aluminium electrolysis is a well-known process for years but is dependent on constant values for the electric current
- This leads to problems bringing in flexible regenerative energy in the process
- New development of a flexible aluminium electrolysis cell “virtual battery” poses new problems

Bubble dynamics

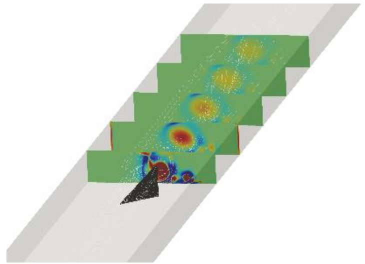


Magnetohydrodynamics

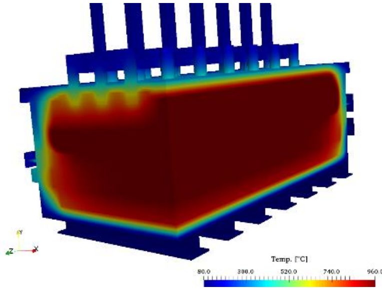




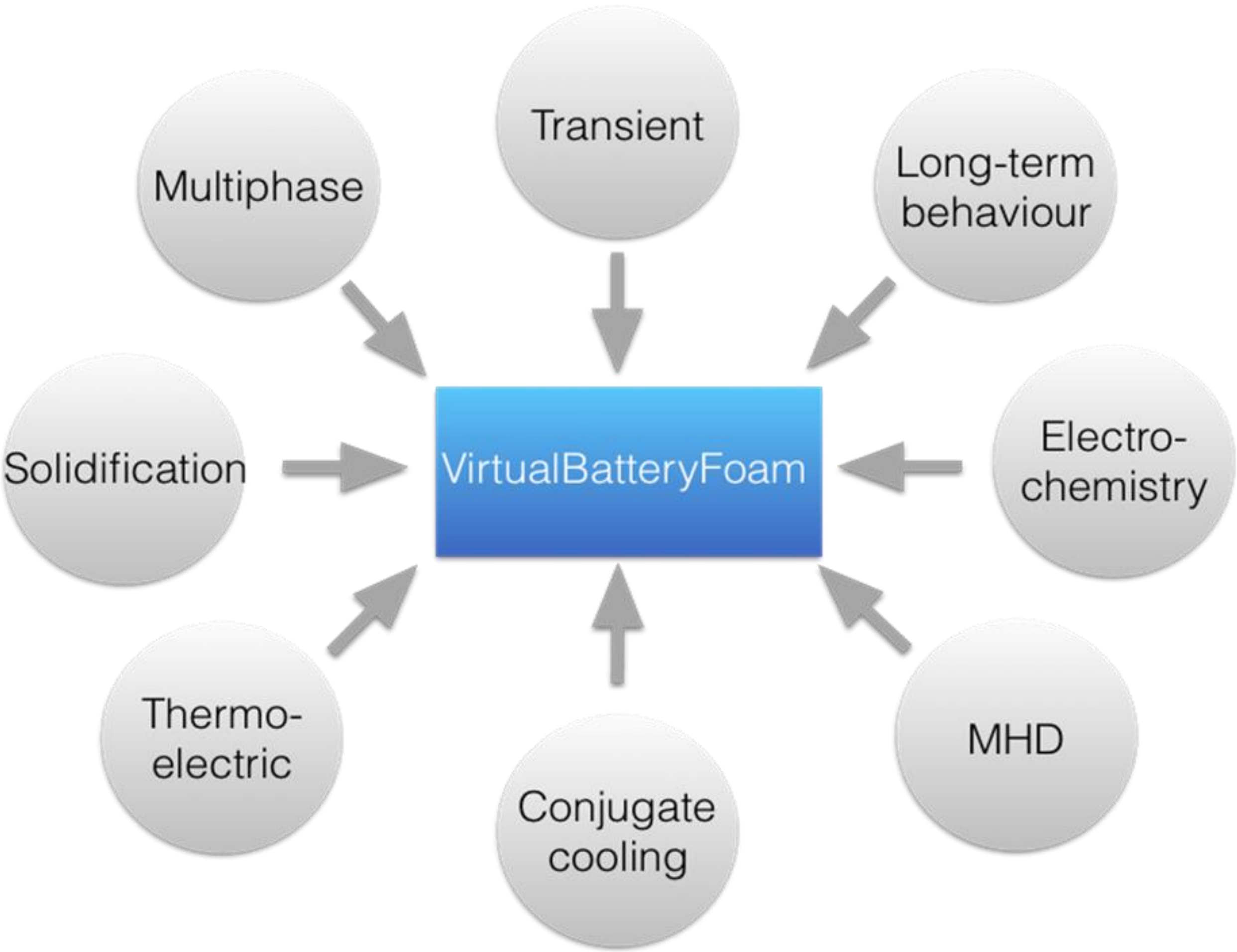
Turbulent heat transfer



Thermoelectric

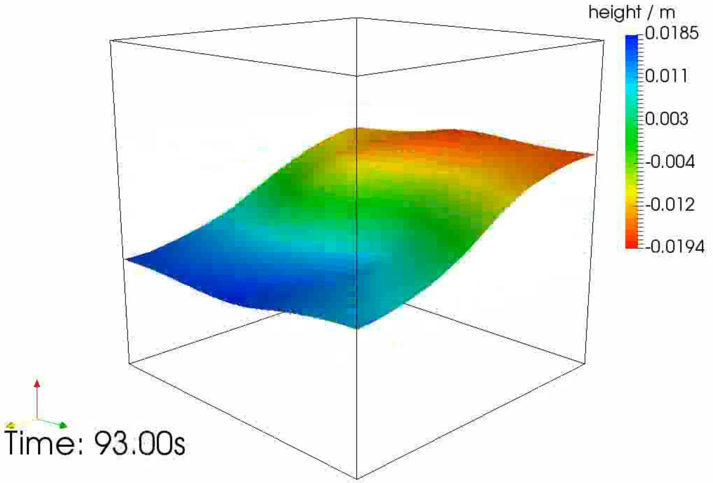


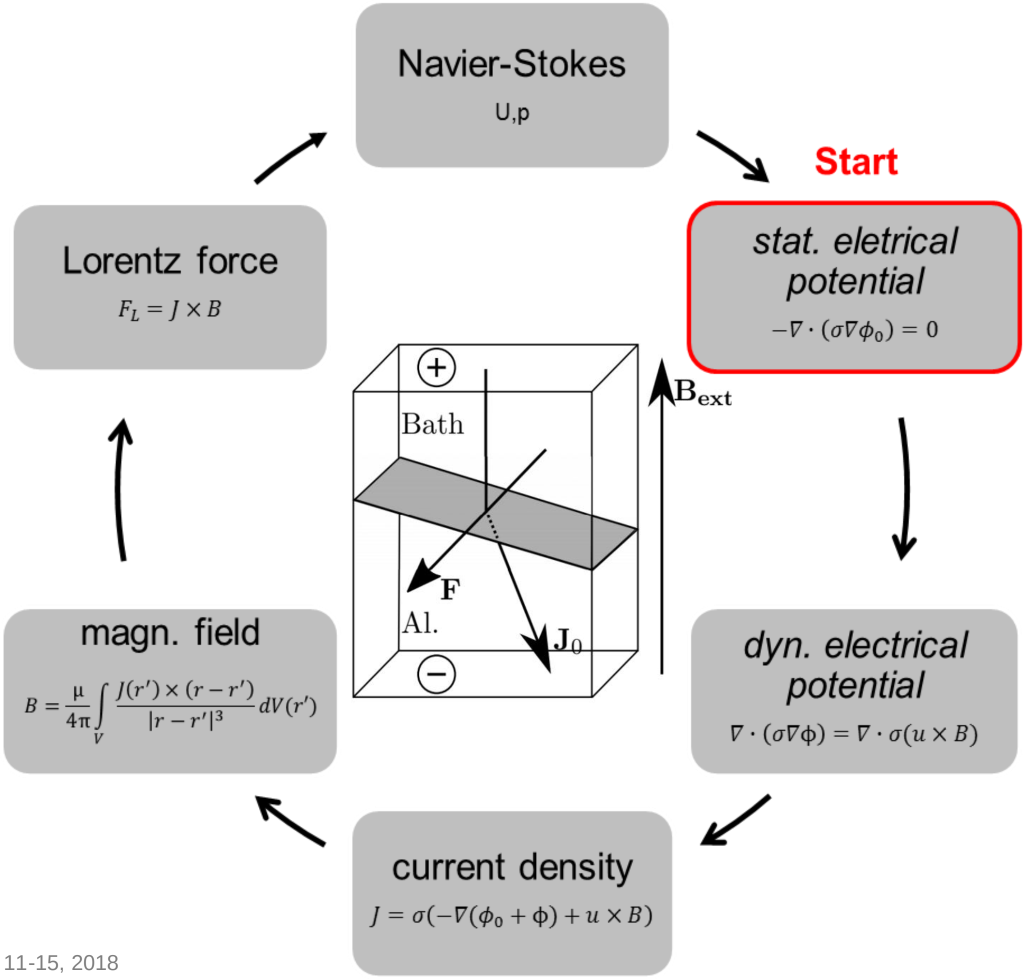
- Development of a new solver framework based on the open source CFD code OpenFOAM®
- Various physical processes are combined in one solver



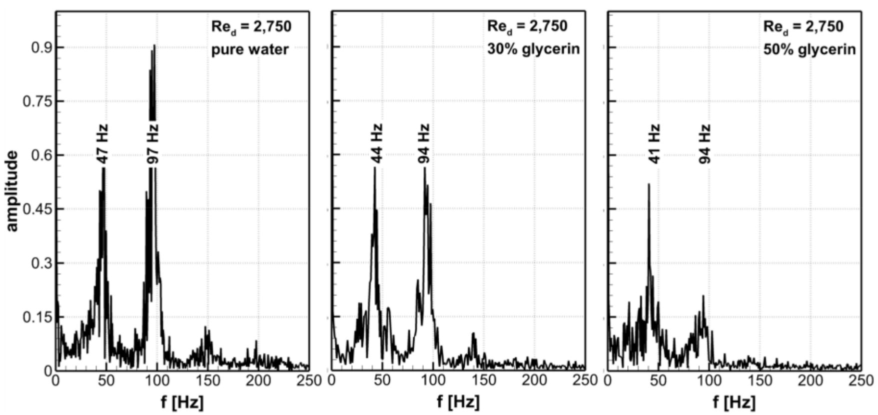
Nandana V. et al., ISCOBA, Belem, 29 October – 1 November 2018

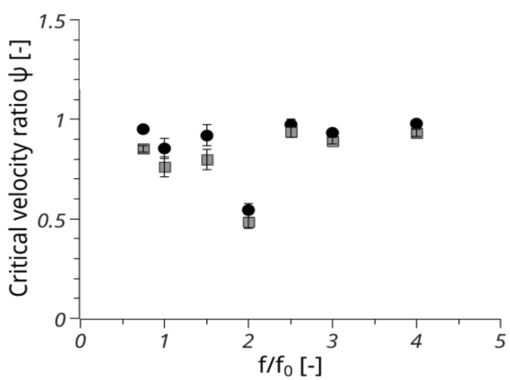
- Lorentz forces induced by the current density and the magnetic field lead to a rolling of the metal
- ↳ Critical condition if a short circuit between anode and cathode happens





Gutt R. et al. 6th European Conference on Computational Mechanics, Glasgow, June 11-15, 2018





Tropfen in Anströmung und mit Vibrationsanregung

Vorarbeiten
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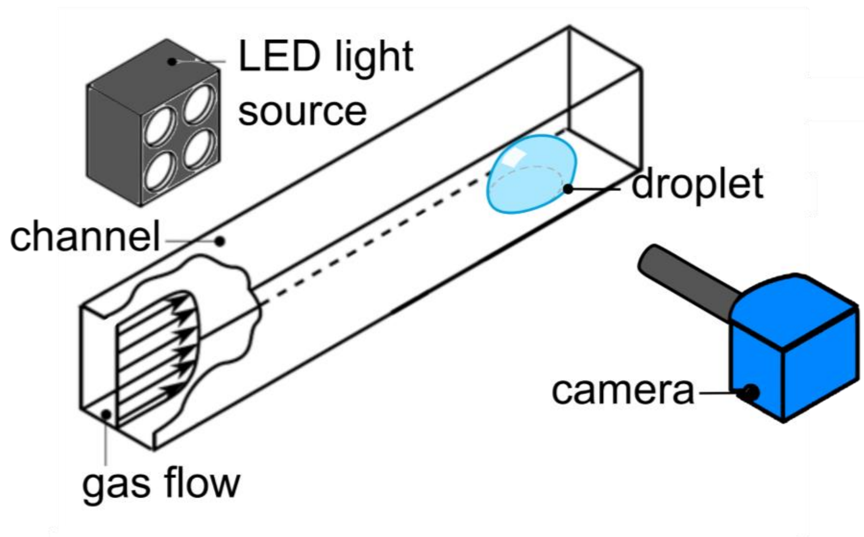
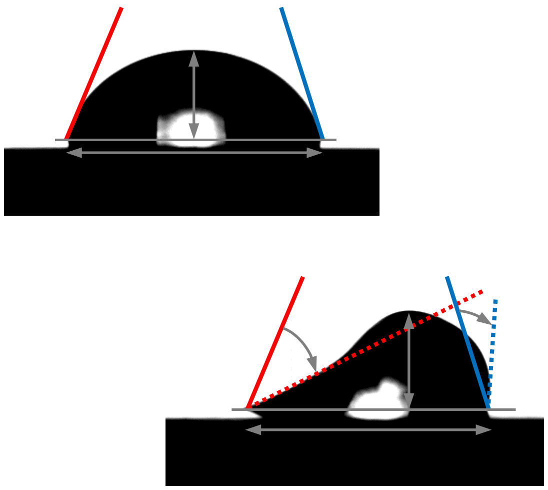
Investigation of sessile drops in a channel flow:

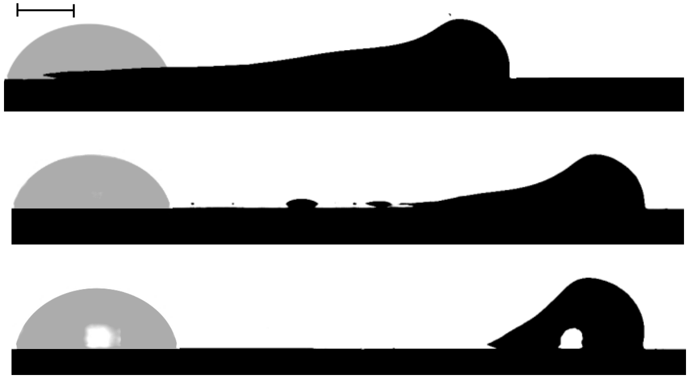




- Single drop is placed in measurement region, drop volume and drop fluid is varied
- Air volume flow rate is linearly increased

→ Shadowgraph-technique allows for contour detection and analysis of temporal behaviour of the drop, i.e. oscillation and onset of movement

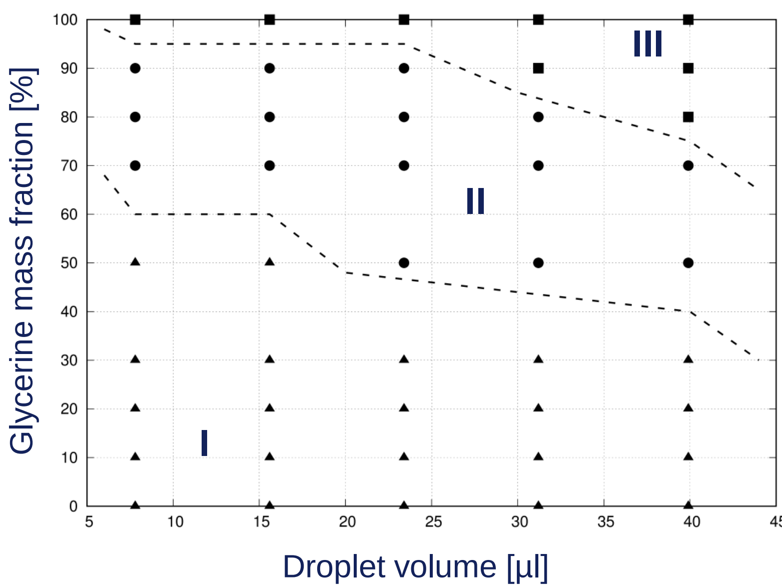
Drop-deformation and movement:



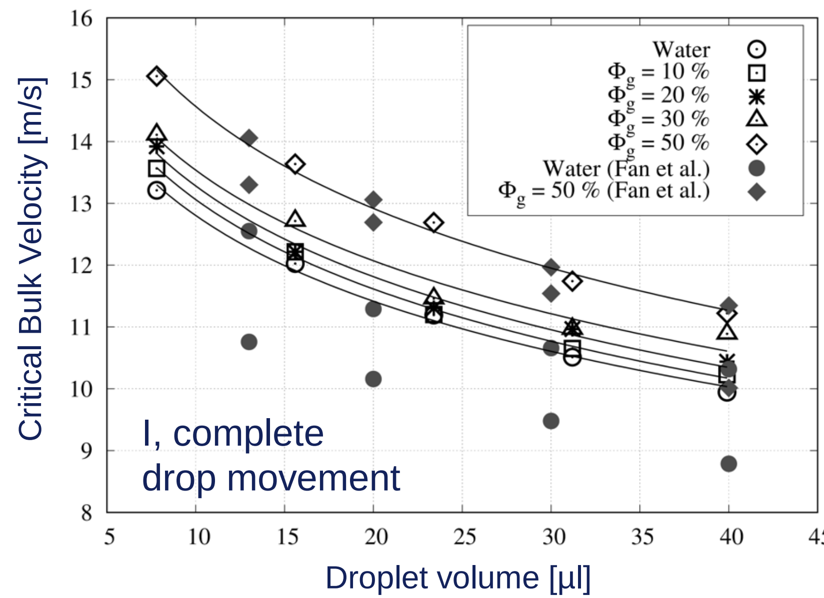
III, rivulet formation

II, tail with sup-drops

I, complete drop movement



→ Analysis of critical velocity for pattern I



Barwari B., Burgmann S., Janoske U. (2019) Chem. Ing. Tech. 91 (1), pp. 991-1000

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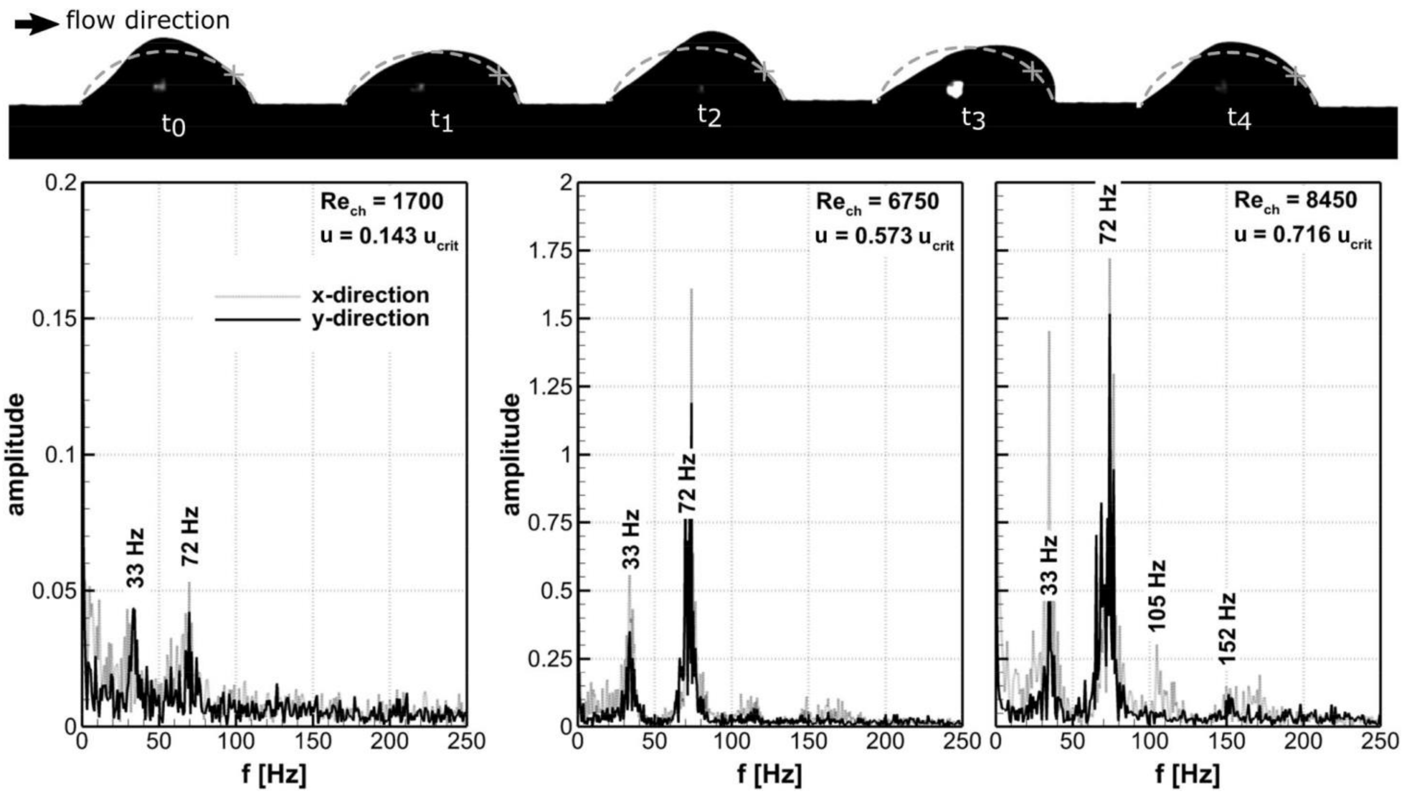
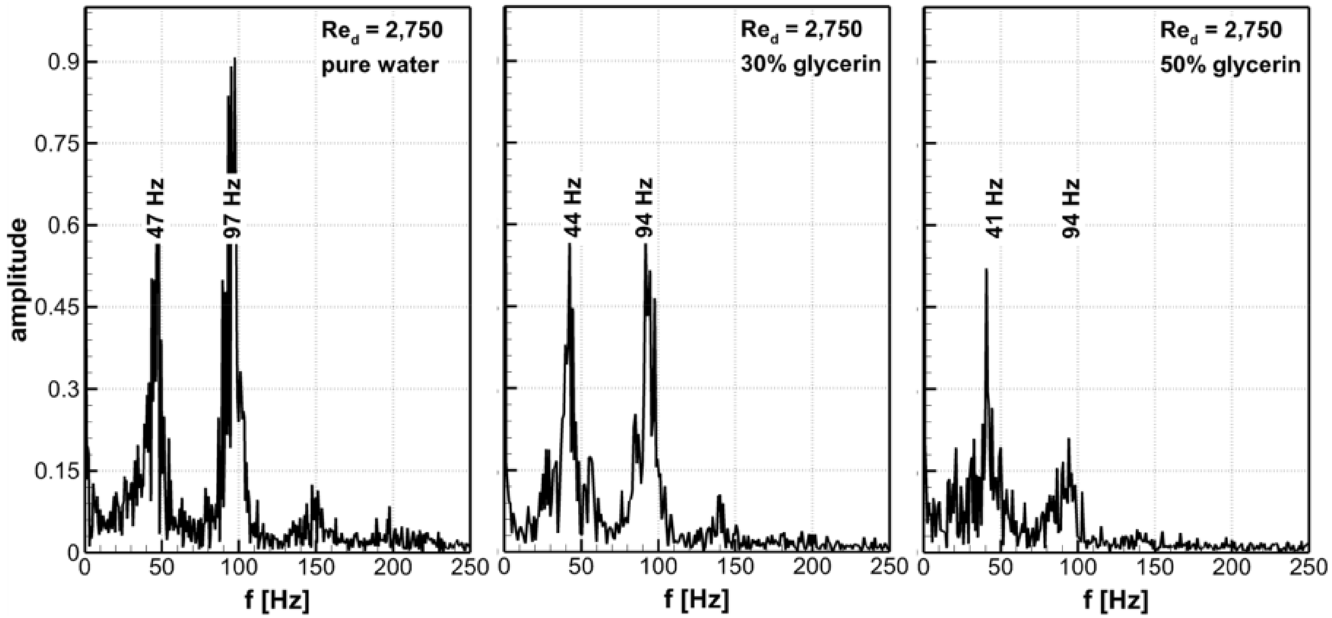
Oscillation Characteristics of Drops in Shear Flow:



→ “rocking” motion: mainly a back-and-forth (first frequency peak) and an up-and-down movement (second frequency peak); EF agree with Sharp et al. (2011)

Burgmann S., Dues M., Barwari B., Steinbock J., Büttner L., Czarske J., Janoske U. (2021) Experiments in Fluids, 62:47

Oscillation Characteristics of Drops in Shear Flow:

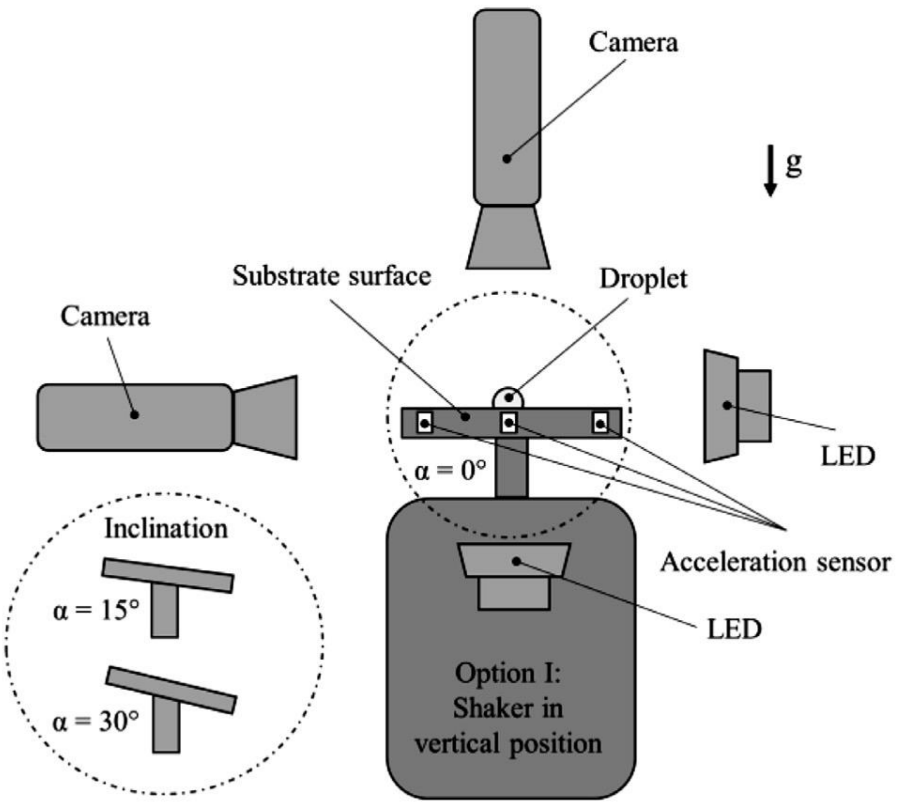


→ increase in the viscosity by increasing the amount of glycerin leads to a damping of the oscillation

→ corresponds to an increase in the critical velocity, that is needed to move the drop

Burgmann S., Dues M., Barwari B., Steinbock J., Büttner L., Czarske J., Janoske U. (2021) Experiments in Fluids, 62:47

Method:



- Change of:
  - acceleration,
  - frequency,
  - drop-volume,
  - and inclination

→ Shadowgraph-technique allows for contour detection and analysis of temporal behaviour of the drop, i.e. oscillation characteristics and onset of movement

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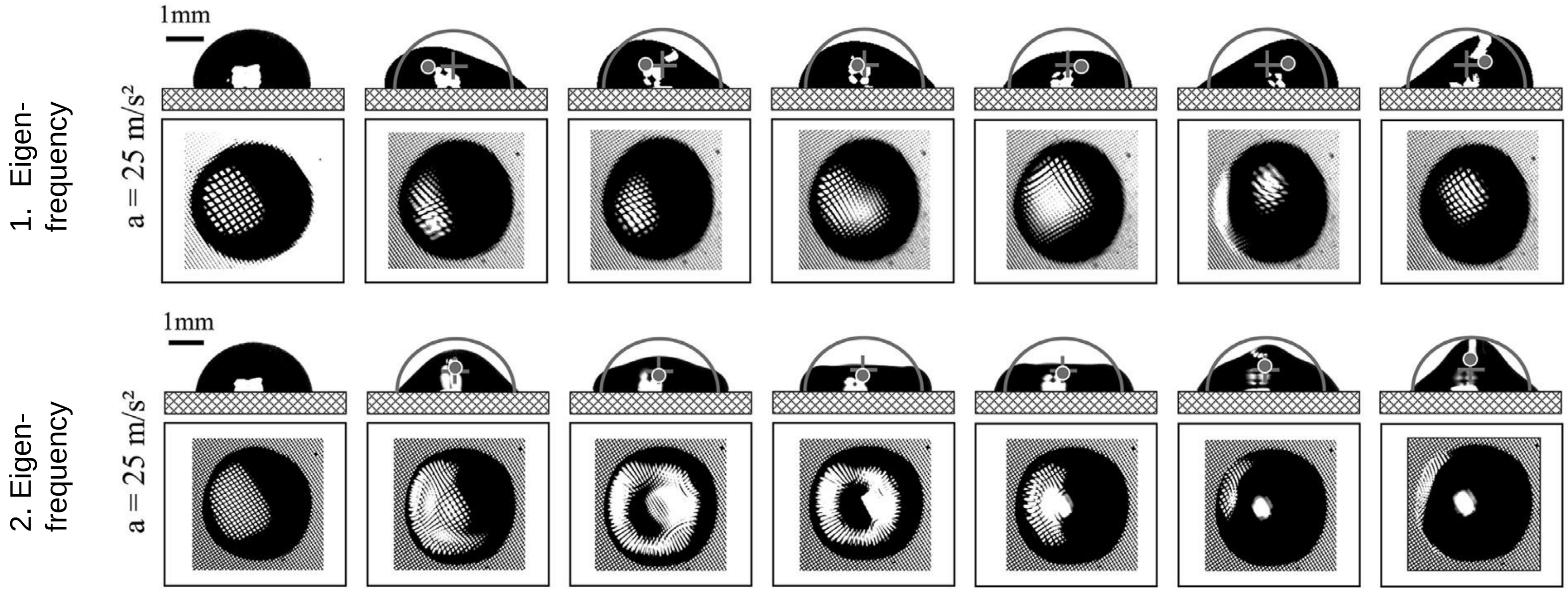
Investigation of vertical surface vibration:

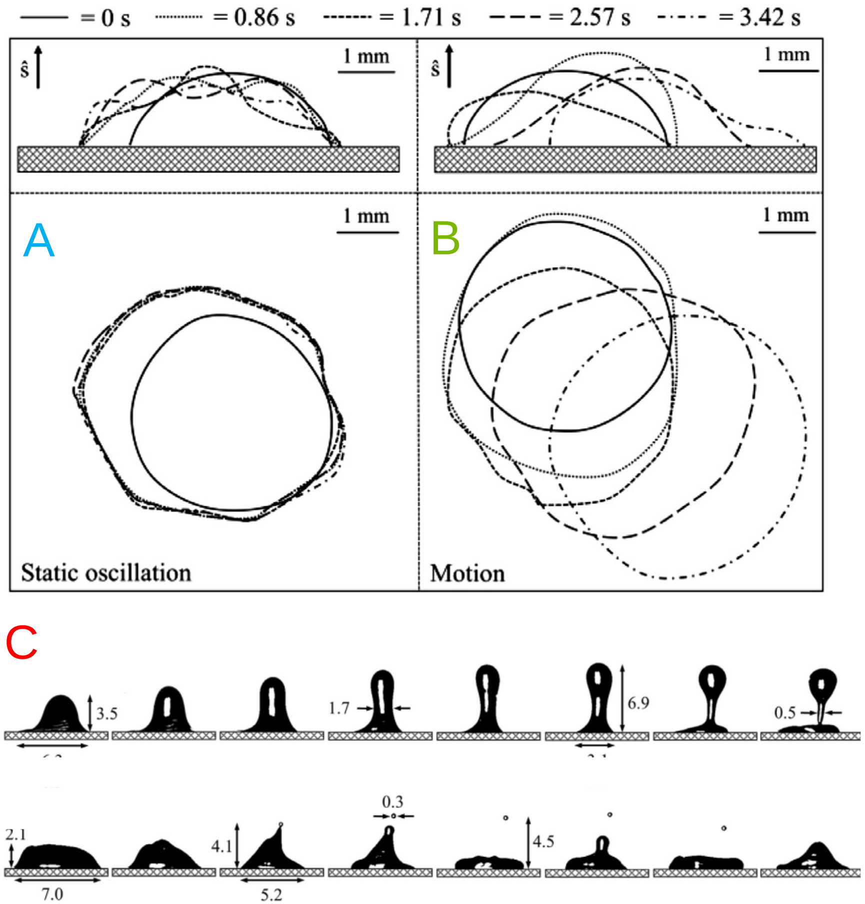


- Tumbling “back-and-forth” motion at excitation at 1. Eigenfrequency
- Up-and-down motion at excitation at 2. Eigenfrequency

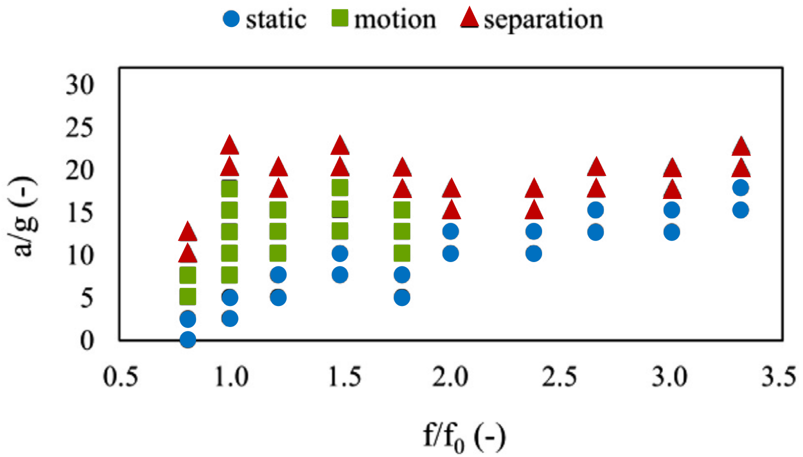
→ Corresponds to findings for drop in shear flow

Barwari B., Rohde M., Wladarz O., Burgmann S., Janoske U. (2021) International Journal of Multiphase Flow, 135, 103537

Investigation of vertical surface vibration:



- Resting, motion and formation of satellite drops depending on acceleration and frequency



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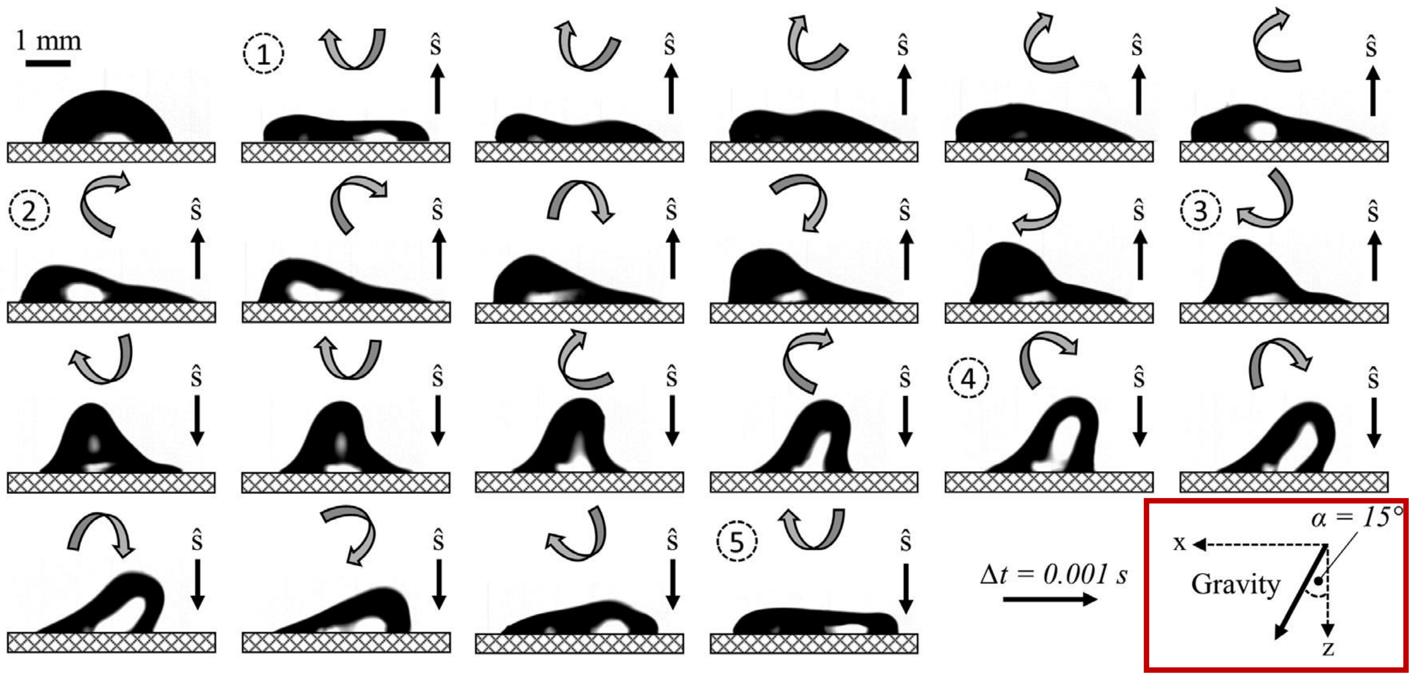
Investigation of vertical surface vibration:



- tumbling "back-and-forth"-motion leads to periodic shift of center of volume forces (gravity and acceleration) and therefore a periodic moment that affects contact lines

  → climbing of drop on inclined surface

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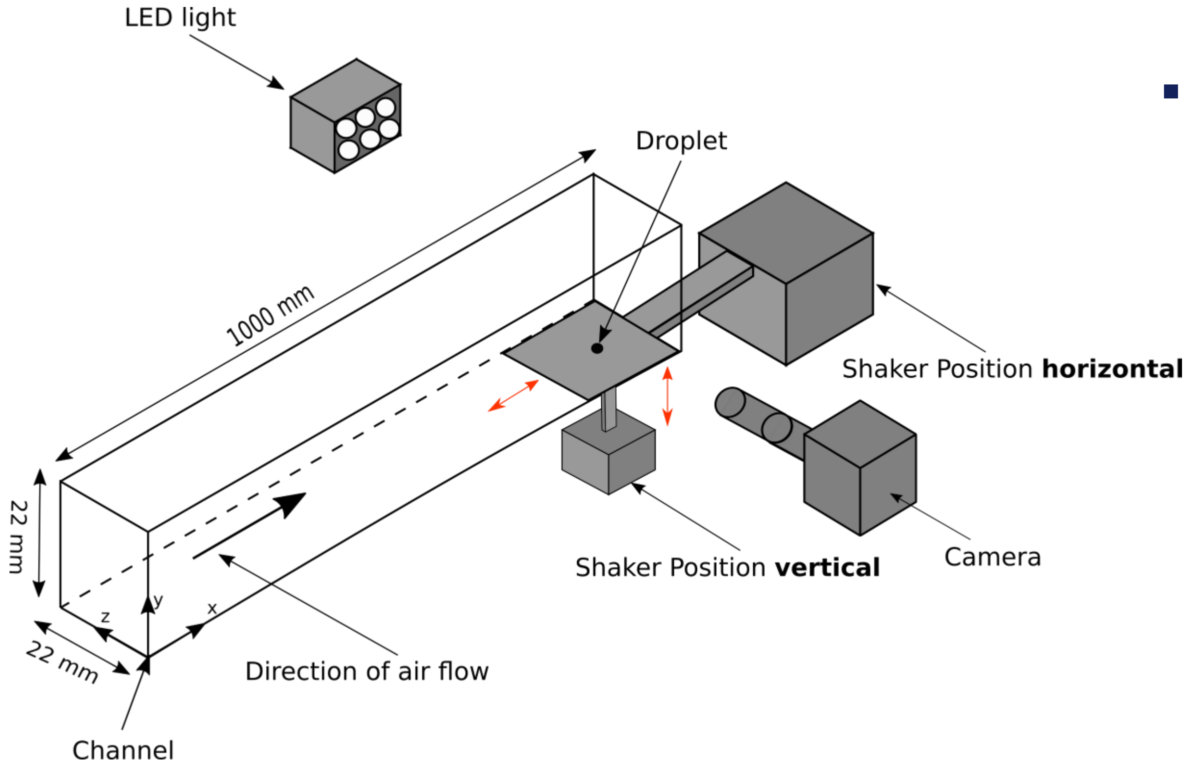
Method – Superposition of vibration with shear flow :



- Change of:
  - Excitation direction (vertical / horizontal)
  - acceleration
  - frequency
  - drop-volume
  - and air speed

→ Shadowgraph-technique allows for contour detection and analysis of temporal behaviour of the drop, i.e. oscillation characteristics and onset of movement

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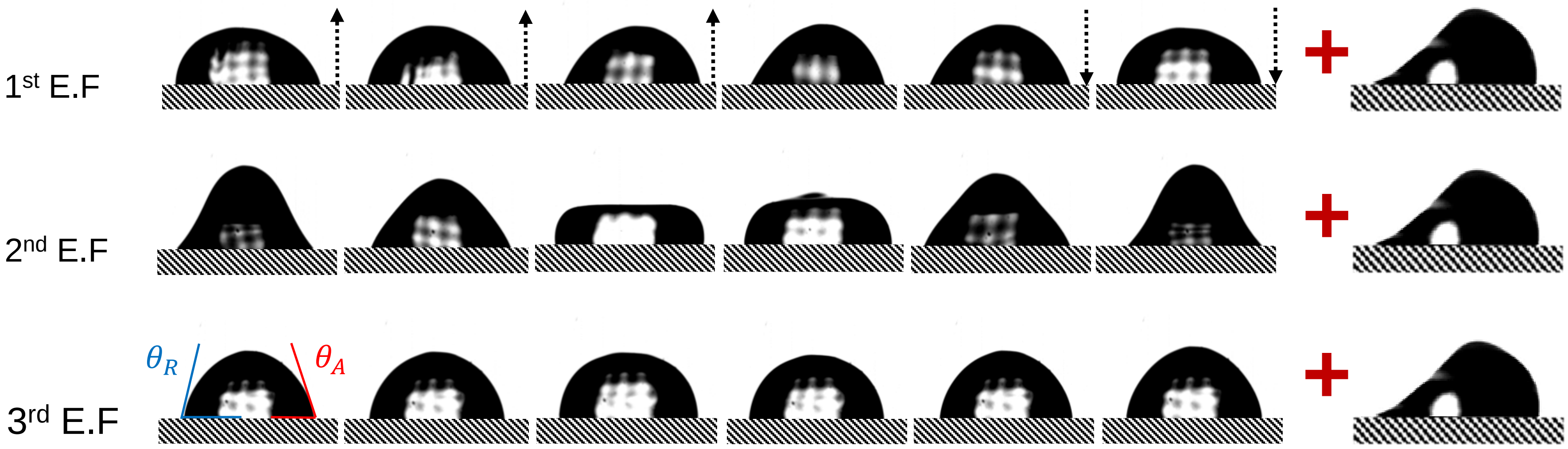
Vertical surface vibration with shear flow:



Note:

- significant oscillation amplitude of the drop only at excitation with 2nd E.F.
- Sessile drop in shear flow shows significant oscillation with 2nd E.F.
- Flow in the wake of the drop shows oscillation with 2nd E.F.

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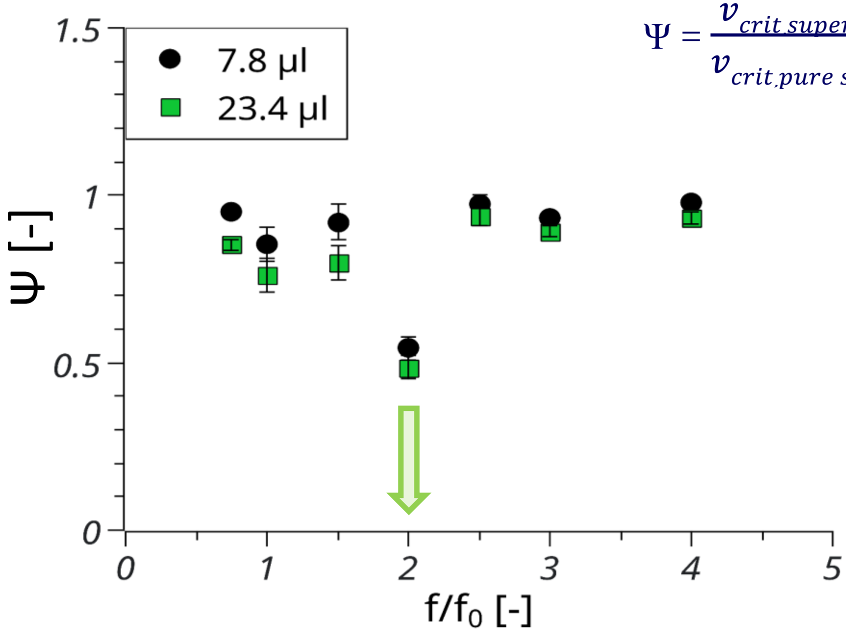
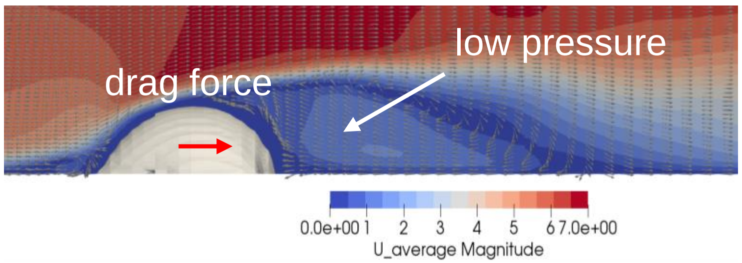
Vertical surface vibration with shear flow:



$$\Psi = \frac{v_{crit\,superpos}}{v_{crit,pure\,shear}}$$

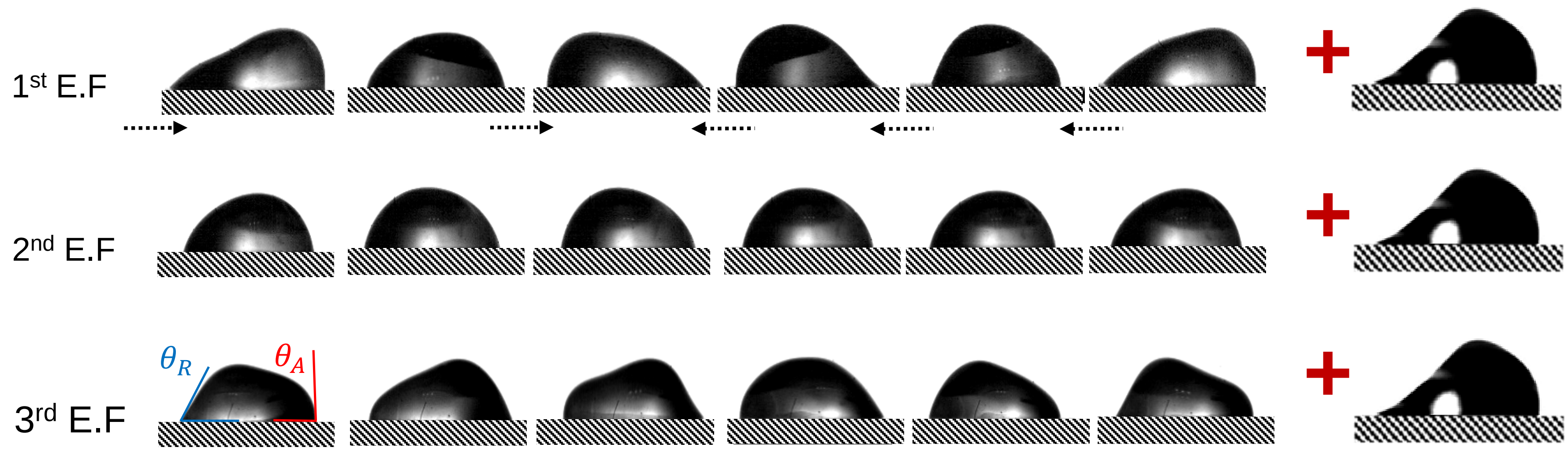


- Only minor reduction of the critical velocity by superposing vertical vibration except for excitation with 2nd E.F.

→ **Hypothesis:** increase of flow oscillation leads to flow separation at lower velocities; pressure field changes, drag force increases

Rohde M., Barwari B., Burgmann S., Janoske U. (2022) International Journal of Multiphase Flow, 155, 104163

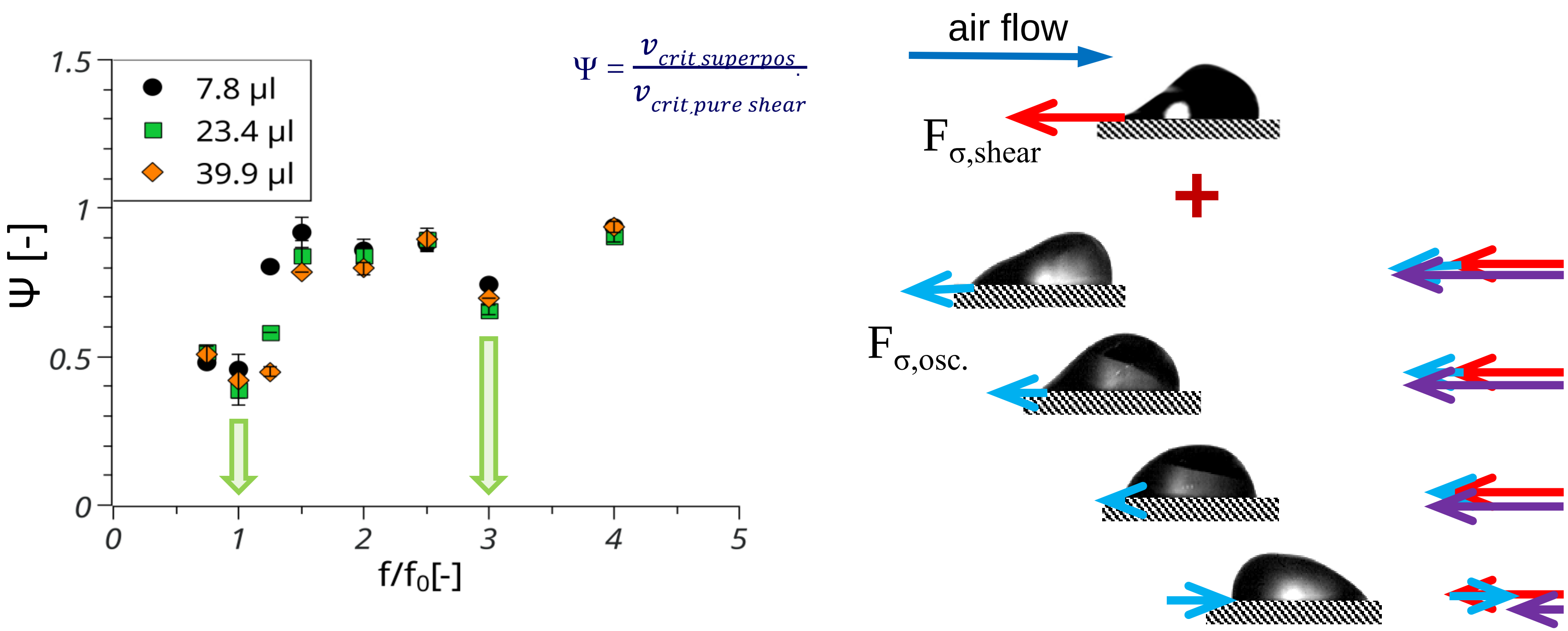
Horizontal surface vibration with shear flow:



Note:

- significant oscillation amplitude of the drop only at excitation with 1st and 3rd E.F.
- Sessile drop in shear flow shows minor oscillation with 1st E.F. but strong deflection in streamwise direction

Horizontal surface vibration with shear flow:



- Only minor reduction of the critical velocity by superposing horizontal vibration <u>except for</u> excitation with <u>1st and 3rd E.F.</u>

→ **Hypothesis:** temporal decrease of the the effective hysteresis-force until drag force overcomes adhersive forces

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LEHRSTUHL STRÖMUNGSMECHANIK

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Thank you for your interest!

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