Numerische Simulation zur Herrstellung monodisperser Tropfen in pneumatischen Ziehdüsen

DFG – SPP 1423 „Prozess-Spray“

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Goals of the first period

1) **Implementation** of a high order mass conservative ALE-based Level Set code

   - Distance
   - Surf. tens.
   - Pressure

   CSF – surface tension treatment
   PDE-based reinitialisation

2) **Numerical simulation** of droplet generation in dripping and jetting regimes

3) **Systematic validation** and benchmarking (CFX, Comsol, FLUENT, OpenFOAM)
Goals of the second period

1) **Jetting mode simulations.**
   - Extraction of operation envelopes

2) **Modulation analysis.**
   - Multi-dimensional process diagrams

3) **Non-Newtonian fluids.**
   - Dripping mode validation
   - Jetting simulations
   - Multi-dimensional process diagrams

Chhabra: "Bubbles, Drops and Particles in Non-Newtonian Fluids"
Goals of the second period

1) Jetting mode simulations.
   • Extraction of operation envelopes

2) Modulation analysis.
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Chhabra: "Bubbles, Drops and Particles in Non-Newtonian Fluids"
Validation of the dripping mode

Validation parameters:
• frequency of droplet generation
• droplet size
• stream length

Continuous phase:
Glucose-Water mixture
\[ \mu_D = 500 \text{ mPa s} \]
\[ \rho_D = 972 \text{ kg m}^{-3} \]
\[ \dot{V}_D = 3.64 \text{ ml min}^{-1} \]
\[ \sigma_{CD} = 0.034 \text{ N m}^{-1} \]

Silicon oil
\[ \mu_C = 500 \text{ mPa s} \]
\[ \rho_C = 1340 \text{ kg m}^{-3} \]
\[ \dot{V}_C = 99.04 \text{ ml min}^{-1} \]

Dispersed phase:

Experimental Set-up with AG Walzel (BCI/Dortmund)
Evaluation of the jetting mode

Volumetric flow rate [ml/min]

Frequency [Hz]

Stream length [dm]

3,64 ml/min
4,17 ml/min
4,70 ml/min
5,23 ml/min
5,75 ml/min
Monodisperse droplet generation in nozzles

In case of monodisperse droplets: $\dot{V}_D = f \dot{V}_{\text{droplet}}$

With regulation

$\dot{V}_{D,\text{mean}} = \dot{V}_{STD}$

With regulation

$\dot{V}_{D,\text{mean}} = 1.5 \dot{V}_{STD}$

No regulation

$\dot{V}_D = \dot{V}_{STD}$

$d_{\text{drop}} = 5.0 \text{ mm}$

$d_{\text{drop}} = 5.7 \text{ mm}$

$d_{\text{drop}} = 5.2 \text{ mm}$

Regulation ranges?

Flow rate ranges?

Resulting droplet ranges?
Monodisperse droplet generation in nozzles

**In case of monodisperse droplets:**  \( \dot{V}_D = f\dot{V}_{\text{droplet}} \)

Small capillary

\[ \dot{V}_{D,\text{mean}} = 0.75\dot{V}_{\text{STD}} \]

Smaller capillary

\[ \dot{V}_{D,\text{mean}} = 0.75\dot{V}_{\text{STD}} \]

Geometrical changes:
- Capillary size
- Contraction angle
- Contraction ratio

Resulting operation envelope:
- Size: 4.5 mm – 5.7 mm
- Volume: 0.38 cm\(^3\) – 0.77 cm\(^3\)

Not monodisperse

**Regulation ranges?**  **Flow rate ranges?**  **Resulting droplet ranges?**
## Future tasks

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<th>Development</th>
<th>Process engineering</th>
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<td>• CFD solver improvement w.r.t.:</td>
<td>• Jetting simulations</td>
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<td>- More realistic physical properties</td>
<td>• Multidimensional process diagrams</td>
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<td>- Adaptivity</td>
<td>• „Rules“ towards optimization</td>
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<td>- HPC (GPU) parallelization</td>
<td>• Droplet-droplet interactions</td>
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<td>• Non-Newtonian fluids</td>
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Validated prediction tool for tailor-made droplet generation

Comparisons, validation, benchmarking
Relevant literature:


**Goals & Deliverables**

1. Benchmarking of the block-structured, multiblock approach to jetting regime.
2. Validation of the block-structured, multi-block approach for two-phase flows.
3. Validation of the block-structured, multi-block approach for shear-dependent models.

**Tasks**

- **Solver**
  - GF-DG semi-explicit scheme
  - More realistic physical model
  - Implementation of Urgo Delorme Technique
  - Acceleration by GPU parallelization

- **Application**
  - Validation within the jetting regime
  - Process modulation
  - Construction of multidimensional process diagrams for the involved parameters
  - Investigation of downstream coalescence effects on the properties of droplets

**Validation & Benchmarking**

- **Dripping mode**
  - Glucose-water mixture
  - Continuous phase
  - Dispersed phase

- **Jetting mode**
  - Air-water mixture
  - Continuous phase
  - Dispersed phase

**Recent Modulation Results**

- High frequency
  - Flow regimes: Diffusion, Shear, Coalescence
  - Modulation and dispersion of droplets

**Guidelines, References**

- Use of modulation with constant frequency
- Targeted coalescence of generated droplets
- Introduction of disturbances with constant frequency
- Validity of regulation in ranges of the parameters
- Droplets can be mixed with different diameters

**Cooperation**

- Experimental measurements supported by group and facilities of AI Water
- Access to compute power supported by the Linux Cluster LIDO
- Simulation cooperation partners: AIF Bielefeld, AIF Sonnenfeld, AIF Schweins