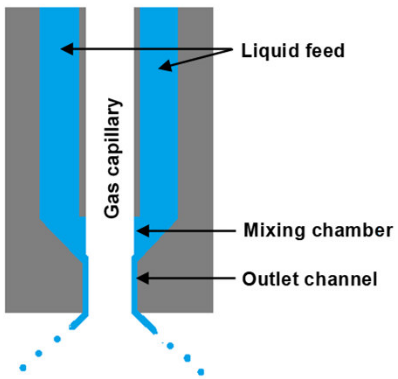
Karlsruher Institut für Technologie

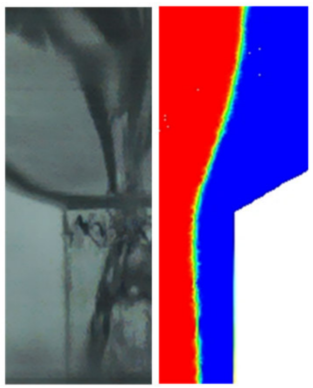
Max Rubner-Institut

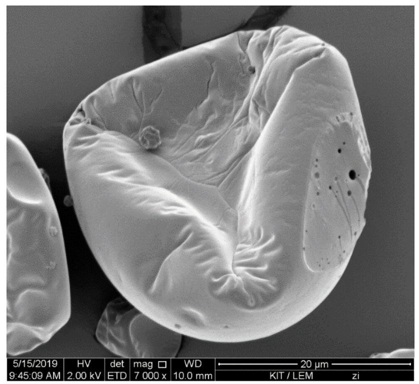
Spray-Drying of Pastes with ACLR-Nozzle for Process Intensification

Volker Gaukel, Sebastian Höhne, Miguel Ballesteros

2025 IFPRI Annual Meeting







Higher feed concentration complicates atomization

Reduction of water content

0. Concentration / dissolve powder

1. Atomization

2. Drying

Feed solids **+ 1.0 %**

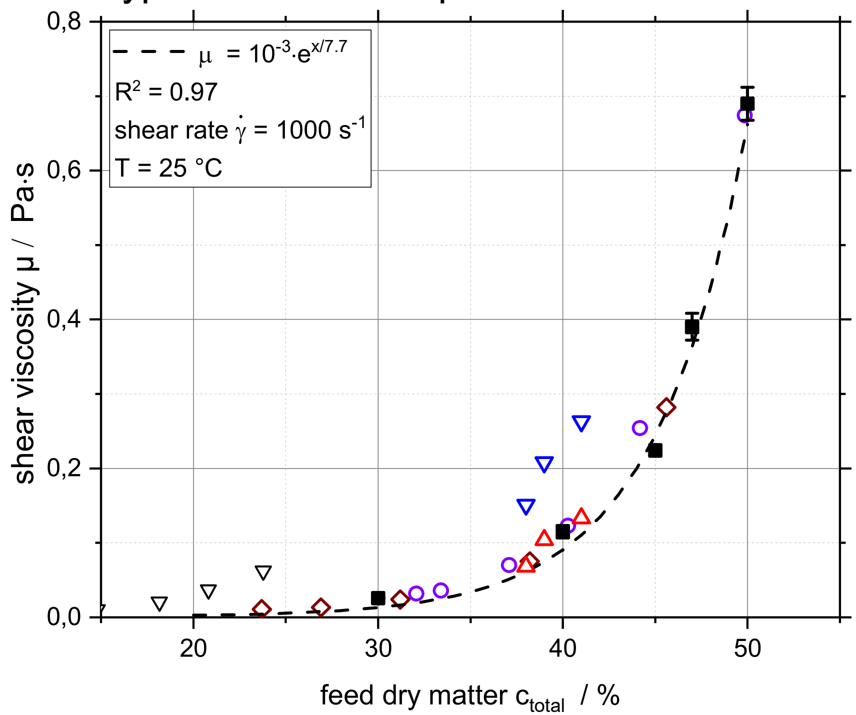
Energy consumption **- 2.5 %**

or

Capacity **+ 4.5 %**

acc. to Fox et al., 2010

Typical milk based products



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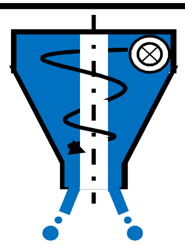
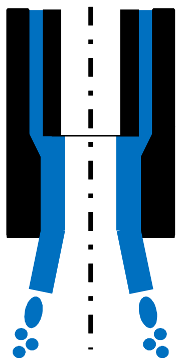
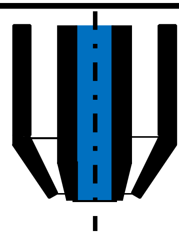
The Air-Core-Liquid-Ring-atomizer is a promising concept



Enforced annular flow inside the exit orifice

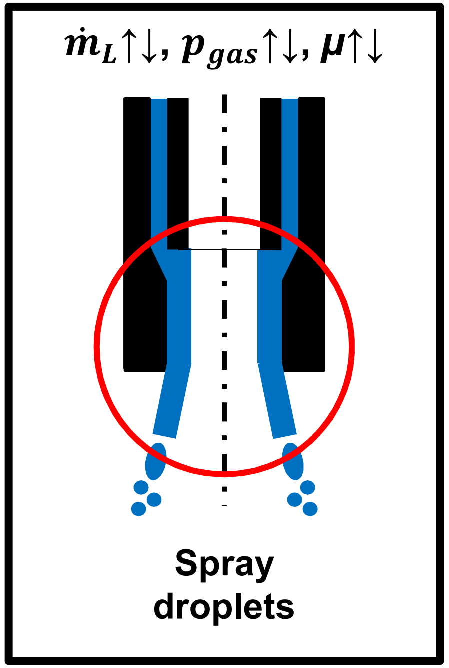




[Stähle, P; Gaukel, V; Schuchmann, HP (2017): *J. of Food Process Eng.* 40, 1-9]

[Stähle, P; Schuchmann, HP; Gaukel, V (2017): *J. of Food Process Eng.* 40, 1-12]

Starting point: Known principles of ACLR nozzle



The liquid film thickness determines the performance of ACLR atomization

Thinner liquid films lead to smaller spray droplet sizes

Increasing stability of liquid film thickness leads to more stable spray droplet size distributions

Feed with 220 mPa s spray dryed with possible energy savings of 30 %

[Wittner, M.O.; Ballesteros, M.A.; Link, F.; Karbstein, H.P.; Gaukel, V. (2019): processes 7, 616]

Project goals

Atomization and drying of feeds with higher viscosity (pastes)

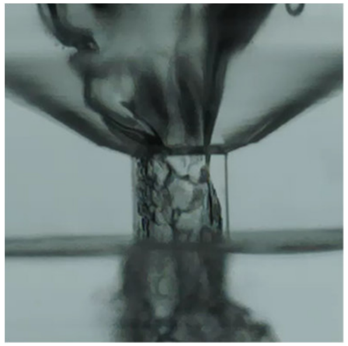
- **Further improve the spray stability of the ACLR-nozzle by:**
  - Geometrical optimizations
  - Process paramater adaptions
- **Further Development of scale up concepts**
- **Investigation of the drying performance of pastes for adapted process conditions**

By means of validated CFD

By single droplet drying

WP 1: Atomization with the ACLR nozzle

Experimental



- The ACLR can achieve stable atomizatic… ith feed viscosities as high as 3 Pa·s, at relat… w pressures (7 bar) and low air-to-liquid ratio…
- The internal flow and the … spray instabilities are directly correlated wit… other.

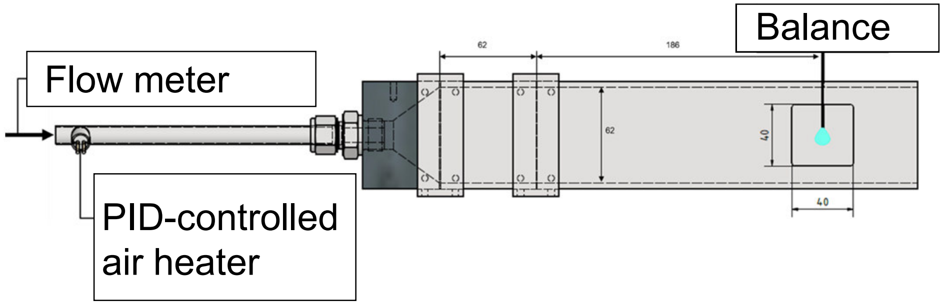
This WP was completed in 2024

CFD

- A CFD m… adapted to predict the multiphase flow i… e ACLR nozzle with non-Newtonian fluids.
- The …LR and resulting liquid lamella thickness inside the nozzle follows the same trend in simulations and experiment.

WP 2: Evaluation of the impact of composition and morphology on drying kinetics

- A method for the analysis of the mass data and calculation of the drying kinetics was developed.

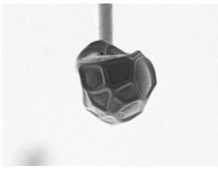


- Experiments were conducted to evaluate the impact of initial solids concentrations of up to 45 wt%. The results for the particle size, mass and drying kinetics showed good agreement with theoretical considerations.
- **Todo:**
  - investigate high initial-solid-concentrations
  - improve the data analysis
  - include a sphericity weighted factor in the surface area calculation

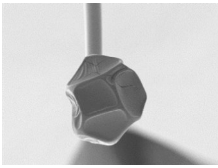
Higher droplet temperatures lead to more spherical and smooth droplet morphologies

25 wt%

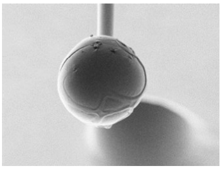
85 °C



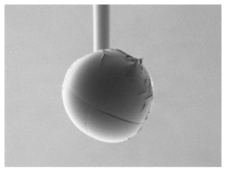
100 °C



115 °C



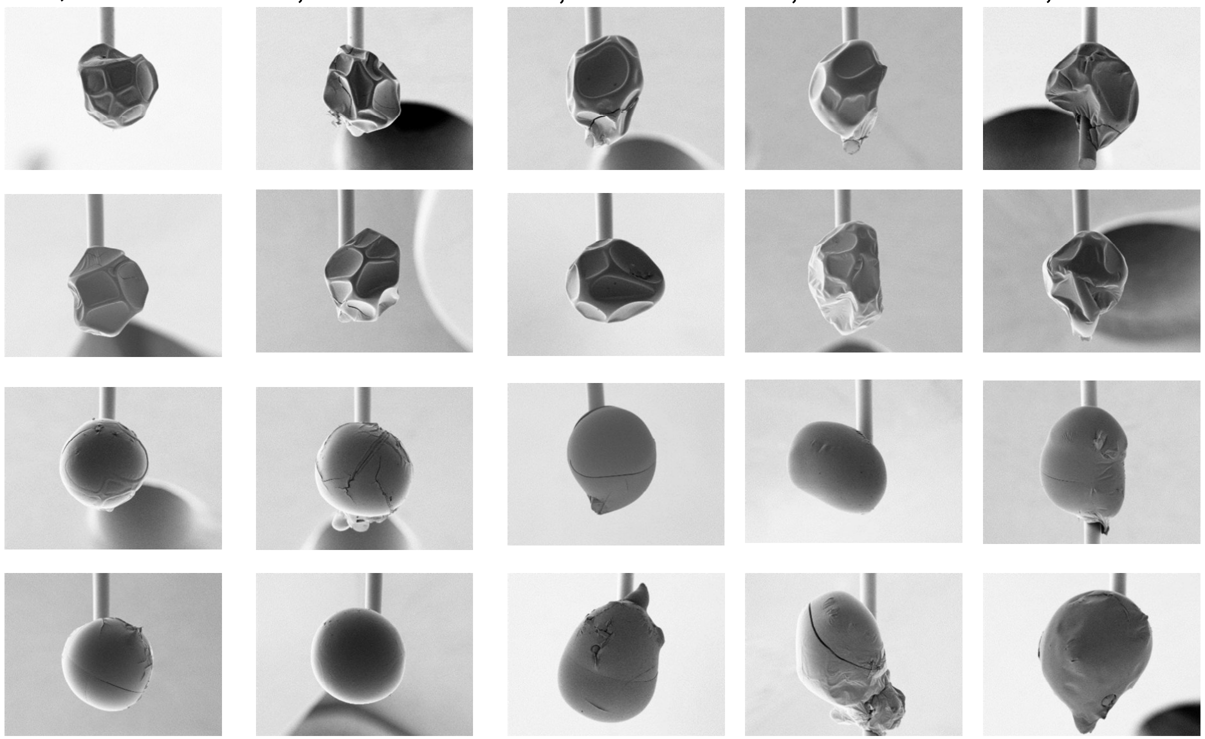
130 °C



- Dried particles are smoother and rounder at temperatures of 130 °C and 115 °C compared to 85 °C and 115 °C

for higher dry matter contents…

	25 wt% 0,01 Pa·s	35 wt% 0,05 Pa·s	45 wt% 0,24 Pa·s	50 wt% 0,63 Pa·s	53 wt% 1,2 Pa·s
85 °C					
100 °C					
115 °C					
130 °C					

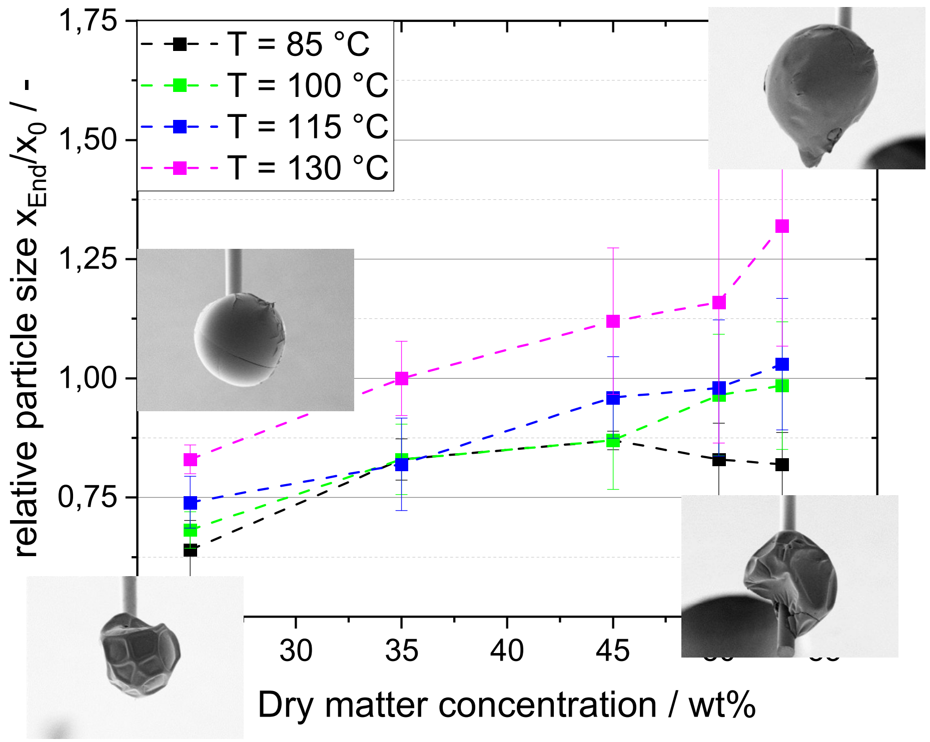


1 mm

still wrinkled at lower temperatures

still smooth but not spherical at higher temperatures

Relative particle size at end of drying increases with increasing dry matter concentration



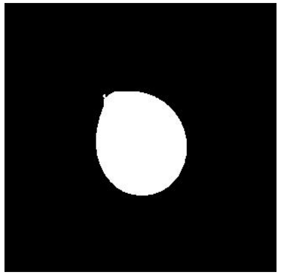
- $T \uparrow \rightarrow x_{End} \uparrow$
- Increase in relative particle size indicates either an earlier locking point or droplet inflation

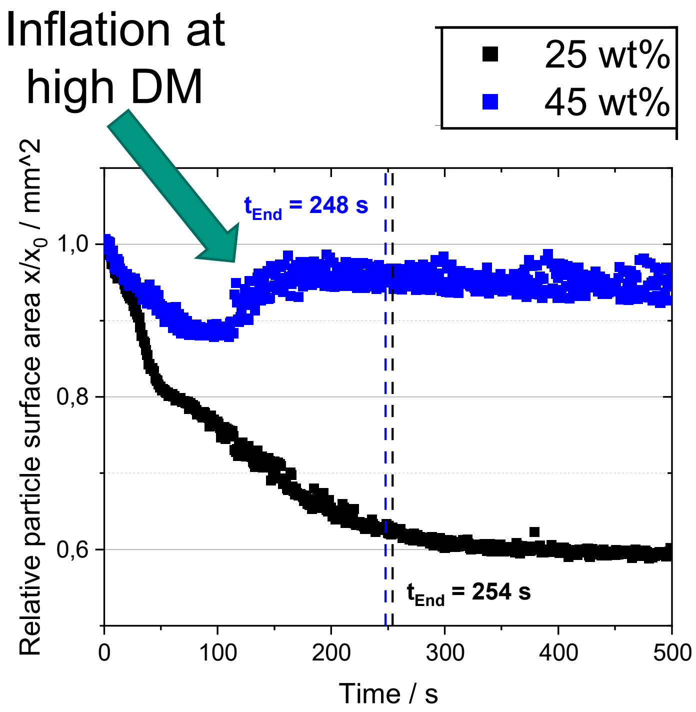
Surveillance of droplet size during drying

Original Picture

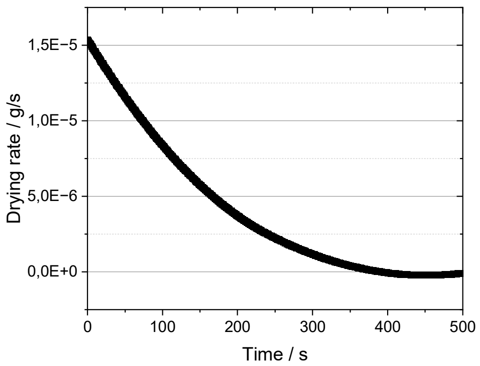
Colored with TiO_2

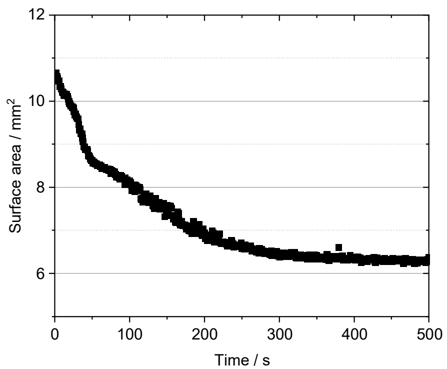
Black & white picture

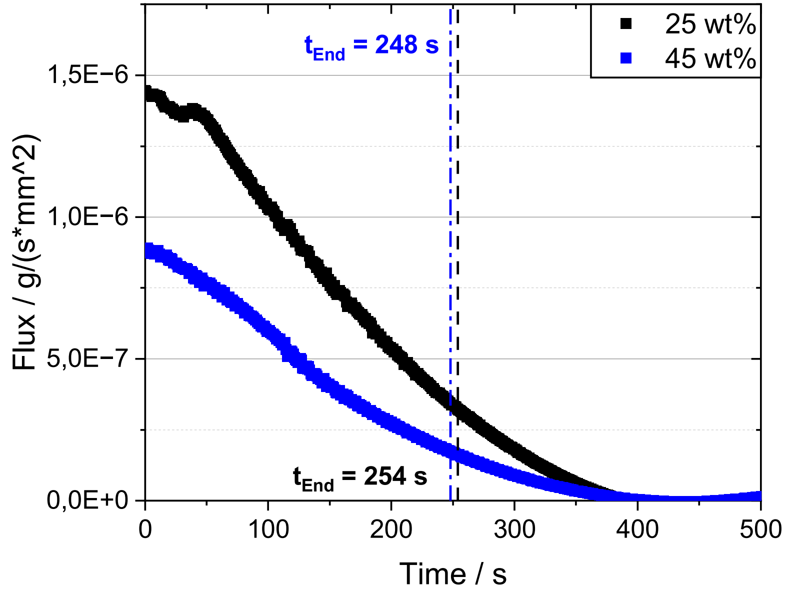




Surface specific water flux during drying





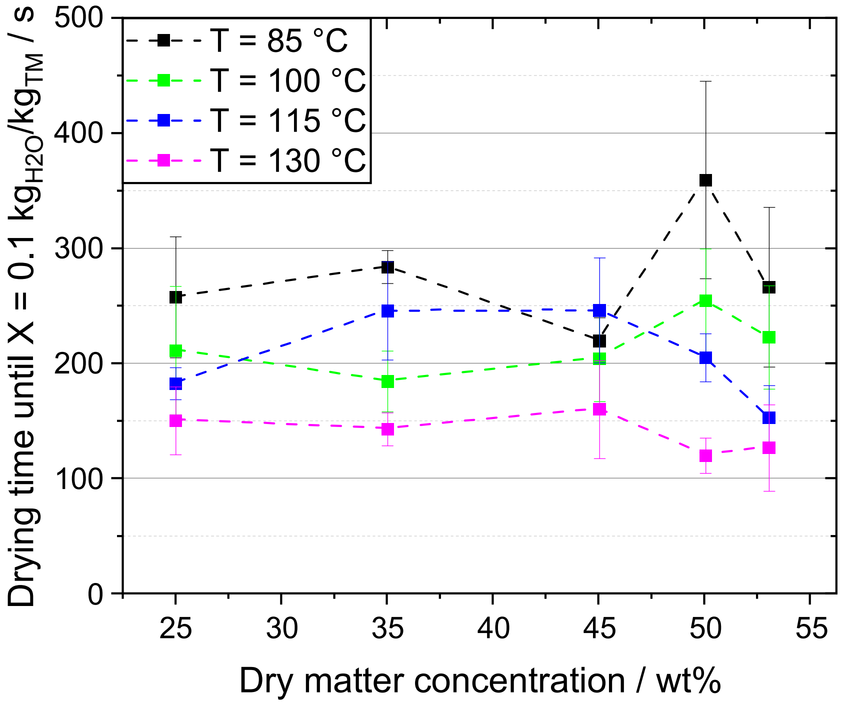


Higher solid content:

- Water flux is decreasing
- t_{End} approx. constant

⇒ lower water content and lower water flux seem to level out

There is no clear dependency of dry matter concentration on drying time



⇒ drying time decreases with increasing air temperature

⇒ no clear dependency for DM concentration

Time until **locking point** is reached, significantly decreases with increasing dry matter concentration

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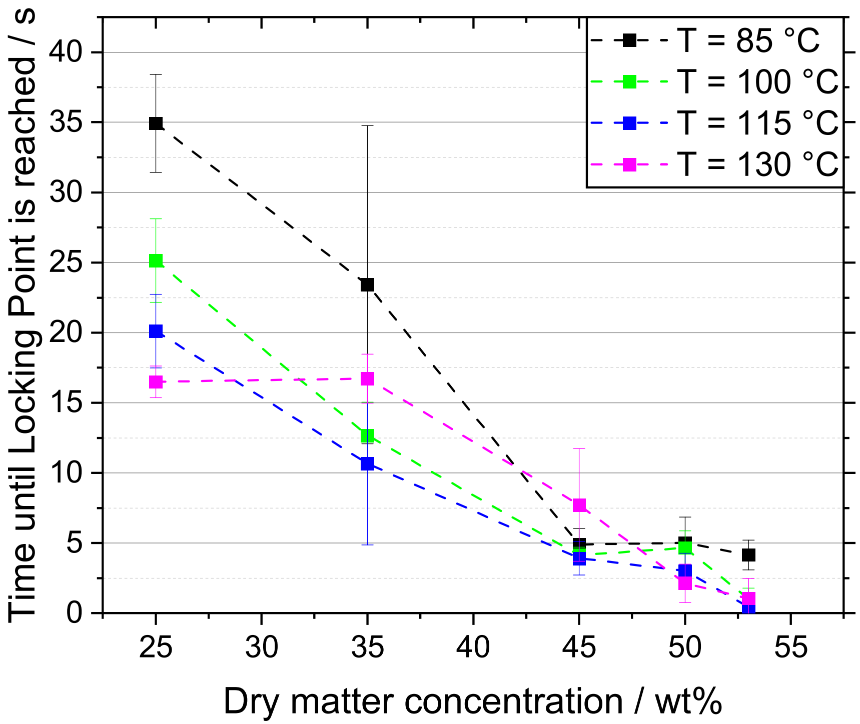
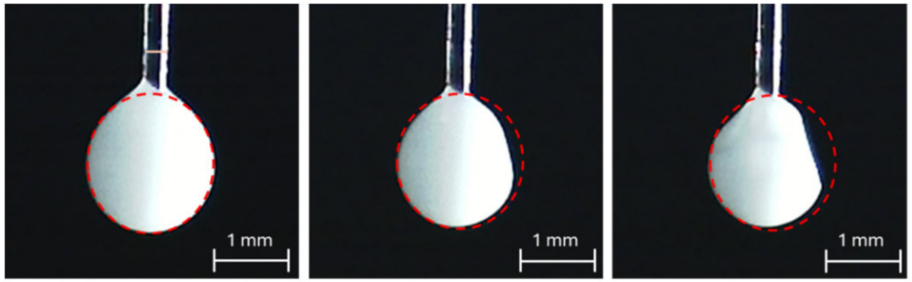




0 s 37 s 62 s

Locking Point = no change in structure

- T ↑ → $t_{Locking\ Point}$ ↓
- Shorter first drying step (constant falling rate period) with higher dry matter concentration

WP 3: Industrial applicability of the ACLR nozzle for spray-drying

Todo:

- Application of results from WP 1 and WP 2 on a spray-drying process
- Geometrical optimization of ACLR-nozzle to achieve highest possible viscosity at acceptable spray droplet sizes
- Investigation of other model liquids like starch solutions („paste“)
- Morphological characterization of spray-dried powders

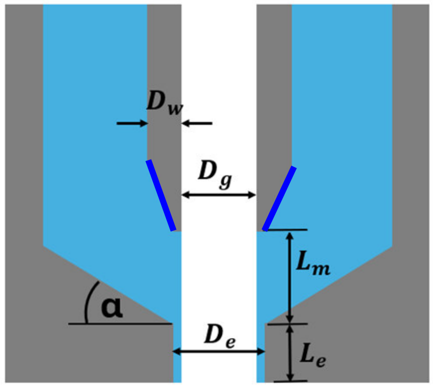
T_{in} = 160-220 °C
T_{out} = 65-95 °C
Water evaporation capacity = 20 l/h

WP 3: Industrial applicability of the ACLR nozzle for spray-drying: Geometrical optimization

Simulation plan

Geometry parameter	1	2	3
Outlet channel diameter D_e [mm]	0.8	1.2	1.5
Outlet channel length L_e [mm]	0.8	1.2	1.5
Angle of capillary edge Mixing chamber inclination α [-]	0° 31°	45° 45°	60° 60°
Capillary wall thickness D_w [mm]	0.9	1.2	1.5
Rounding of edges R [mm]	0.5	1	4

constant:
$D_g = 1.5mm$
$L_m = 2.4mm$



All simulations with η = 0.7 Pa·s

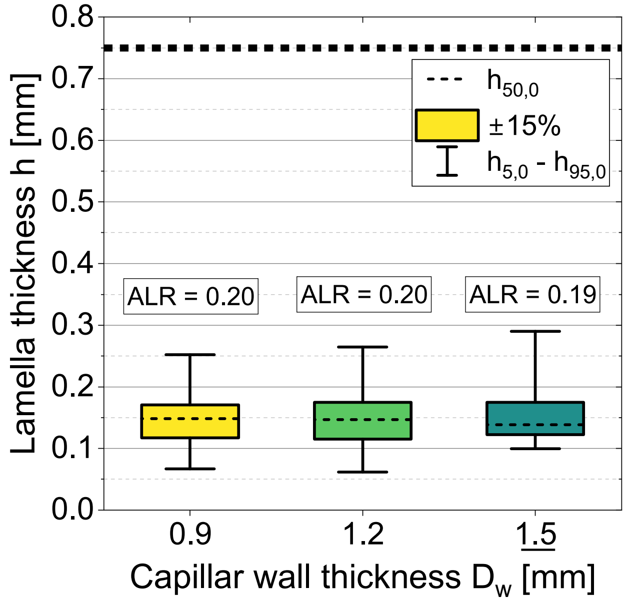
Objective: reduce lamella thickness => leads to smaller droplets

11 simulation with same air pressure, p = 0.7 MPa

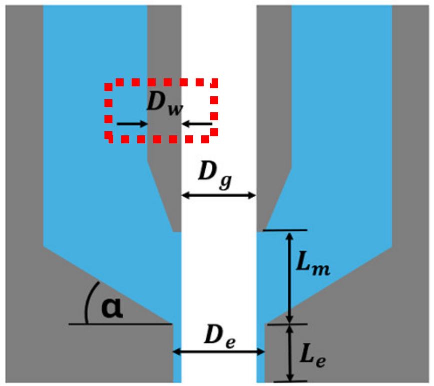
Some parameters affect the ALR, which needs to be considered: D_e, L_e

+ 4-6 Simulations

Mixing chamber: no change for capillary wall thickness

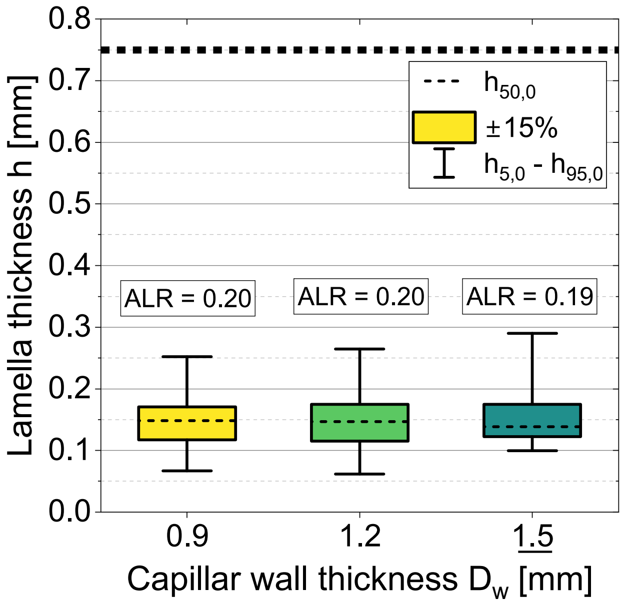


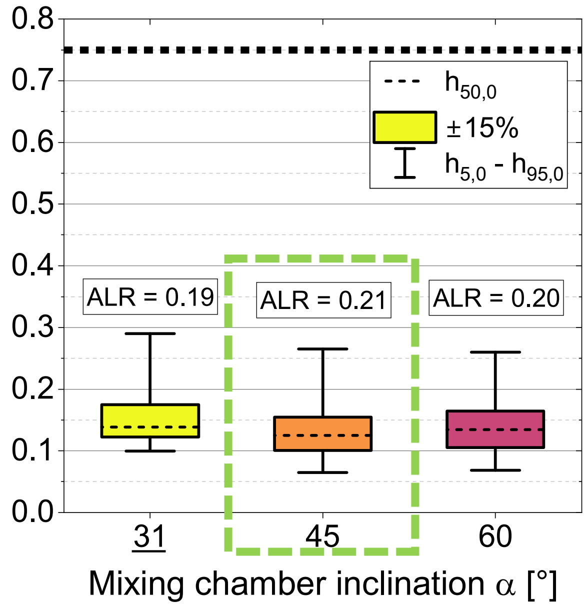
Reducing D_w decreases $h_{95,0}$ but increases $h_{50,0}$

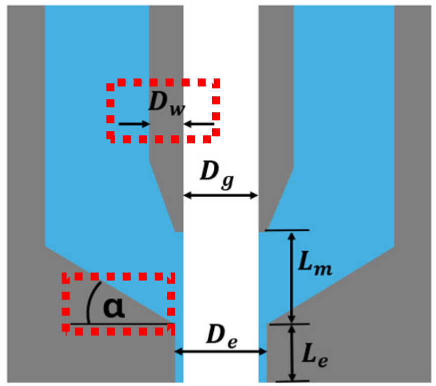


SIM

Mixing chamber: no change for capillary wall thickness but enhancement for inclination at 45°







Reducing D_w decreases $h_{95,0}$ but increases $h_{50,0}$

$\alpha=45°$ has smallest $h_{50,0}$

SIM

The geometrical variations that provided smallest $h_{95,0}$ and $h_{50,0}$ were combined in the optimized nozzle

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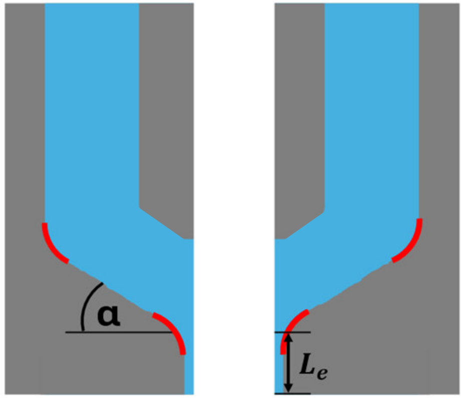
Original design

Optimized design

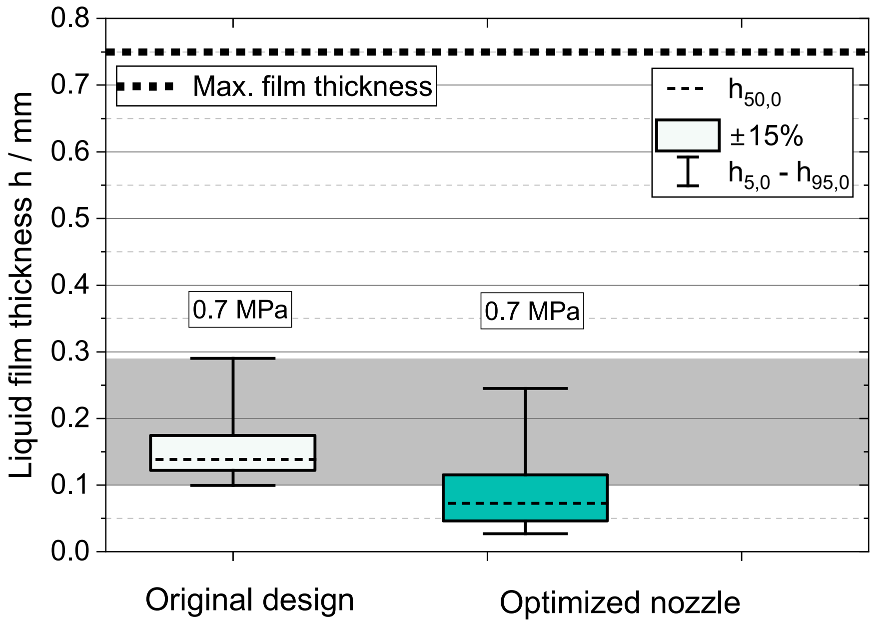


1. ↑ Chamber inclination (α)
2. ↓ Outlet length (L_e)
3. Edge rounding

Optimized design or spray trials

EXP SIM

The optimized design favors the formation of thinner liquid films



Design	Pressure [MPa]	ALR [–]
Original	**0.7**	**0.19**
Optimized	0.7	0.25

=> Reduction of $h_{95,0}$ and $h_{50,0}$ of the liquid film thickness

SIM

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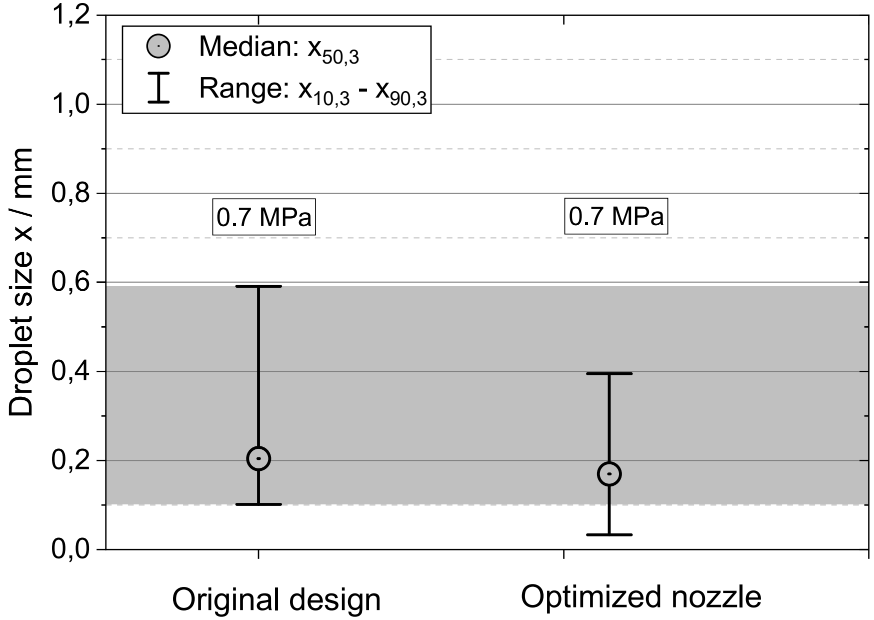
The optimized design results in smaller droplet sizes at same pressure conditions



Design	Pressure [MPa]	ALR [–]
Original	**0.7**	**0.19**
Optimized	0.7	0.25

$x_{90,3}$ reduced from 600 µm to 400 µm

ALR can still be increased

EXP

Conclusion

- Drying higher MD concentrations/viscosities…
  - … drying time: lower water content and lower water flux seem to level out at constant droplet size.
  - … but the locking point is reached much earlier
- Optimized ACLR nozzle design leads to 33 % smaller spray droplets

⇒ The results indicate that even when higher viscosities result in powders with higher residual moisture due to larger droplet sizes, the earlier locking point reduces the risk of powder stickiness

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Thank you for your attention!

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iGF Industrielle Gemeinschaftsforschung

Bundesministerium für Wirtschaft und Energie
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AiF Forschungsnetzwerk Mittelstand

FEI FORSCHUNGSKREIS DER ERNÄHRUNGSINDUSTRIE E.V.

IFPRI International Fine Particle Research Institute

DAAD Deutscher Akademischer Austauschdienst German Academic Exchange Service

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