Spray Characterization at Industrially Relevant Conditions

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1. Background and Introduction

Spray drying is a process used in the production of powdered products such as pharmaceuticals. Pilot scale experiments are used to determine the optimal operating conditions of the sprays and correlations are used to extrapolate to the production scale. Current correlations lack validation across a wide range of nozzle sizes and for fluids relevant to the pharmaceutical industry. This study aims to develop these correlations for a wide range of nozzle sizes and fluid viscosities by focusing on understanding and mechanistically modelling the near-nozzle breakup behaviour.

2. Objectives

1. Develop a benchmark data set for near-nozzle spray characteristics for lab and production nozzle scales with high viscosity and polymeric fluids
2. Determine correlations and models for nozzle scaling and for ligament formation and breakup

3. Benchmark Database

The database has been generated and is being packaged for online distribution.

Nozzles tested:

Pressure-Swirl:

Spraying Systems Co. Fine Spray Nozzle

Orifice diameter (d_o): 0.71 mm, 1.07mm

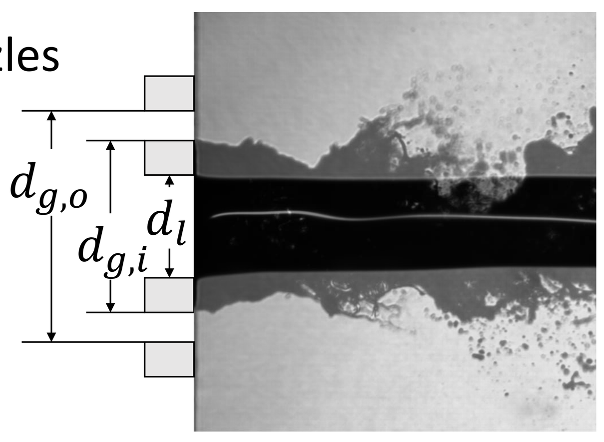
Supplementary fan nozzle: Veejet H1/4VV-40015 (d_o= 0.81 mm)

Washjet MEG-1501 (d_o = 0.59 mm)

Twin-Fluid:

Spraying Systems Co. ¼ J externally mixing twin-fluid nozzles

Scale	Nozzle	d_l	$d_{g,i}$	$d_{g,o}$
Lab	2050-70	0.51	1.27	1.78
Lab	2850-70	0.71	1.27	1.78
Production	60100-120	1.52	2.55	3.05

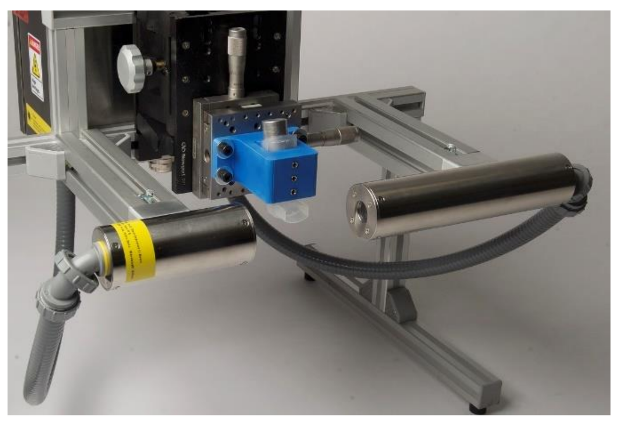


Testing fluids and viscosities

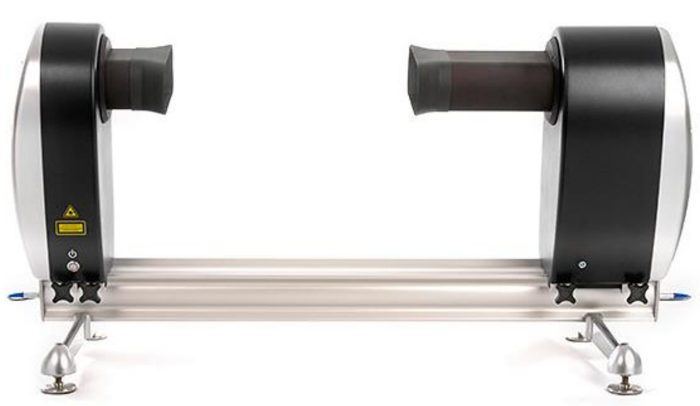
	Fluid	Wt. %	μ_l [mPa s]
Baseline (low-viscosity)	Water	-	1
High-viscosity	Glycerine (aq.)	60	12
		80	60
		85	148
		90	213
Non-Newtonian Polymer	CMC (aq.)	0.25	-
		0.5	-

Measurements:

Near-nozzle images
Mazlite Dropsizer



Droplet size distribution
Malvern Spraytec



6. Conclusions

- ✓ A **benchmark database** of particle size distributions and near nozzle images for pressure-swirl and two-fluid nozzles of varying scales was generated for low-viscosity, high-viscosity, and polymeric fluids.
- ✓ **Pressure-swirl** atomization was described by a perforation-based model.
  - ✓ A semi-empirical perforation-based model was developed to predict size distribution based on physical parameter
  - ✓ Effect of turbulence on perforation is reveal in fan spray nozzle experiments
  - ✓ Measurements of ligaments sizes, volume ratio and other parameters helps to improve correlations in the model.
- ✓ **Twin-fluid** atomization was studied fundamentally with droplet breakup.
  - ✓ A droplet breakup model was developed that predicts the size distribution.
  - ✓ The droplet breakup model was applied to twin-fluid sprays to give a good prediction of the droplet size distribution.
  - ✓ Effects of high-viscosity and polymeric fluids are clearly identified within the model framework

7. Future work

We have proposed to extend this project by further studying the atomization of complex fluids, such as solid suspensions and fluids with significant elongational viscosity, to further develop models and correlations for the droplet size distribution from such fluids.

4. Pressure-Swirl Modelling

Pressure-swirl nozzle atomization was described by a perforation-based model.

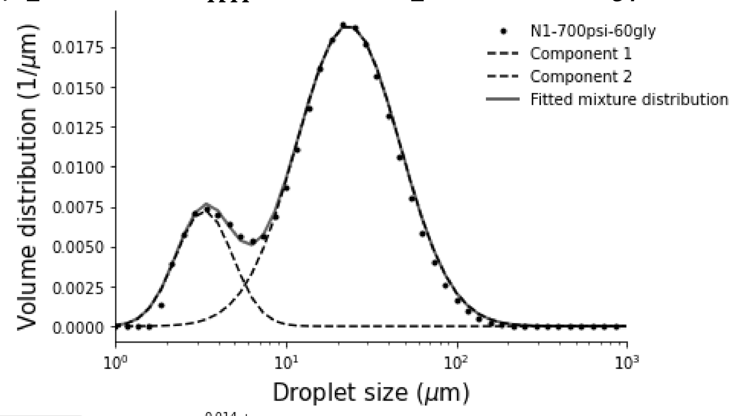
1. A **perforation-based atomization model** was developed that predicts two types of ligaments with different length scales.
   - Parameters in distribution function were correlated with physical parameters
   - The major peak corresponds to the spanwise ligaments is responsible for 95% of total fluid.
   - Neglecting smaller mode will result in ~20% increase in SMD.
   - Model explains the effect of operating conditions and fluid properties on distributions well.

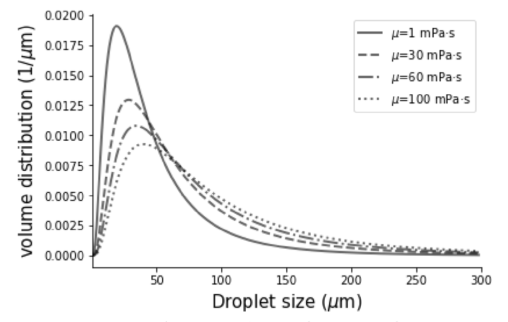
$$f_3(d) = k_v f_{3,1}(d) + (1 - k_v) f_{3,2}(d)$$

$$f_3(d) = f_{3,1}(d; \hat{\mu}_1, \hat{\sigma}_1)$$

$$f_3(d) = \frac{1}{d\hat{\sigma}_1\sqrt{2\pi}} exp\left(-\frac{1}{2}\left(\frac{ln(d/\hat{\mu}_1)}{\hat{\sigma}_1}\right)^2\right)$$

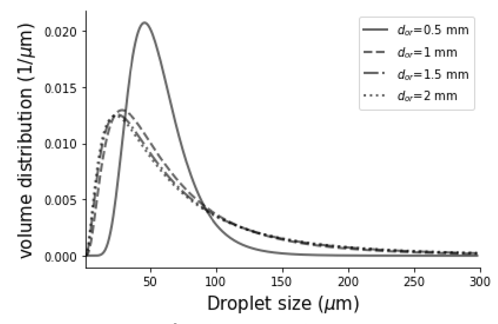
$$\hat{\mu}_1 = 1.96\lambda_{KH}^{0.589}, \qquad \hat{\sigma}_1 = 0.065 t_{or}^{0.517}$$





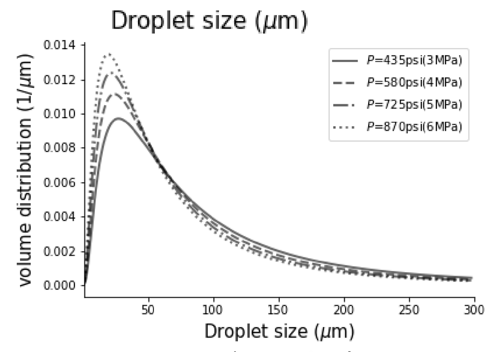
$\mu \uparrow \rightarrow \lambda_{KH} \uparrow \rightarrow \hat{\mu}_1 \uparrow$

$\hat{\sigma}_1$ do not change



$\hat{\mu}_1$ do not change

$d_{or} \uparrow \rightarrow t_{or} \uparrow \rightarrow \hat{\sigma}_1 \uparrow$

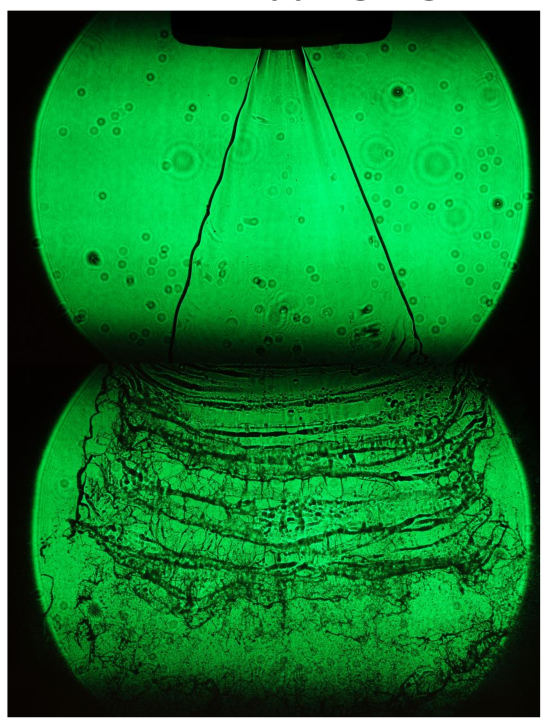


$P \uparrow \rightarrow \hat{\mu}_1 \downarrow$

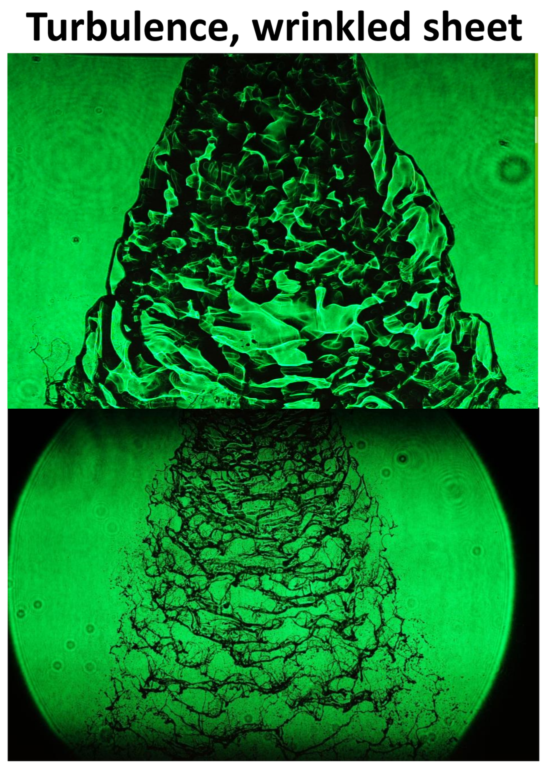
$P \uparrow \rightarrow \hat{\sigma}_1 \uparrow$

2. Fan nozzle reveals the origin of perforations

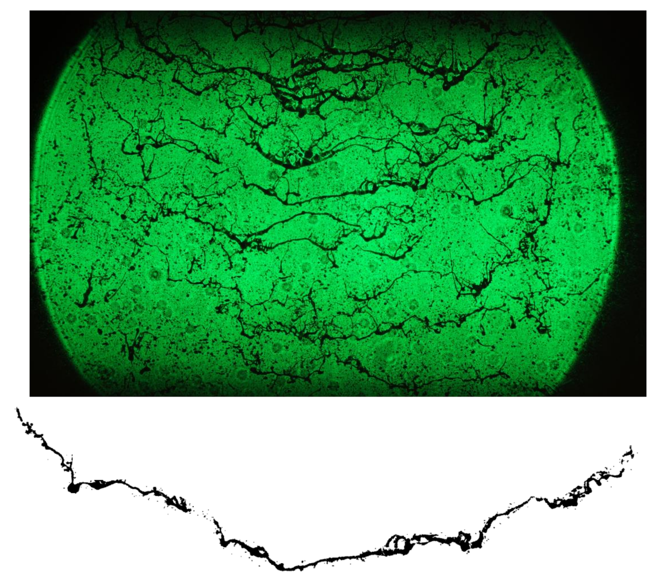
Laminar, Flapping regime



Turbulence, wrinkled sheet



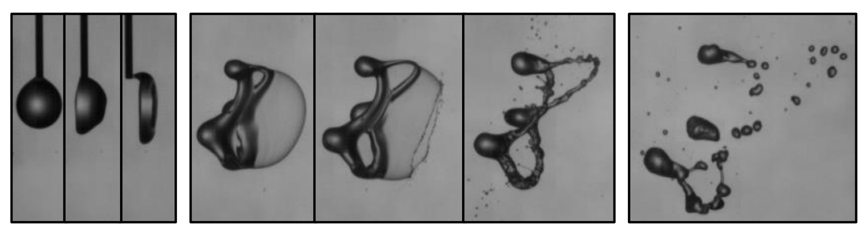
3. Measurements on ligament sizes and cross-sectional area help to verify the model and study physics behaviour

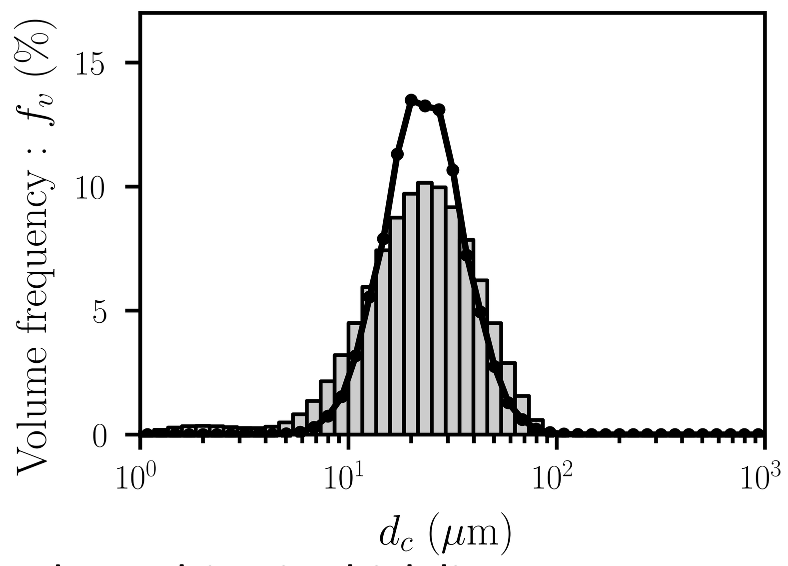


5. Twin-fluid modelling

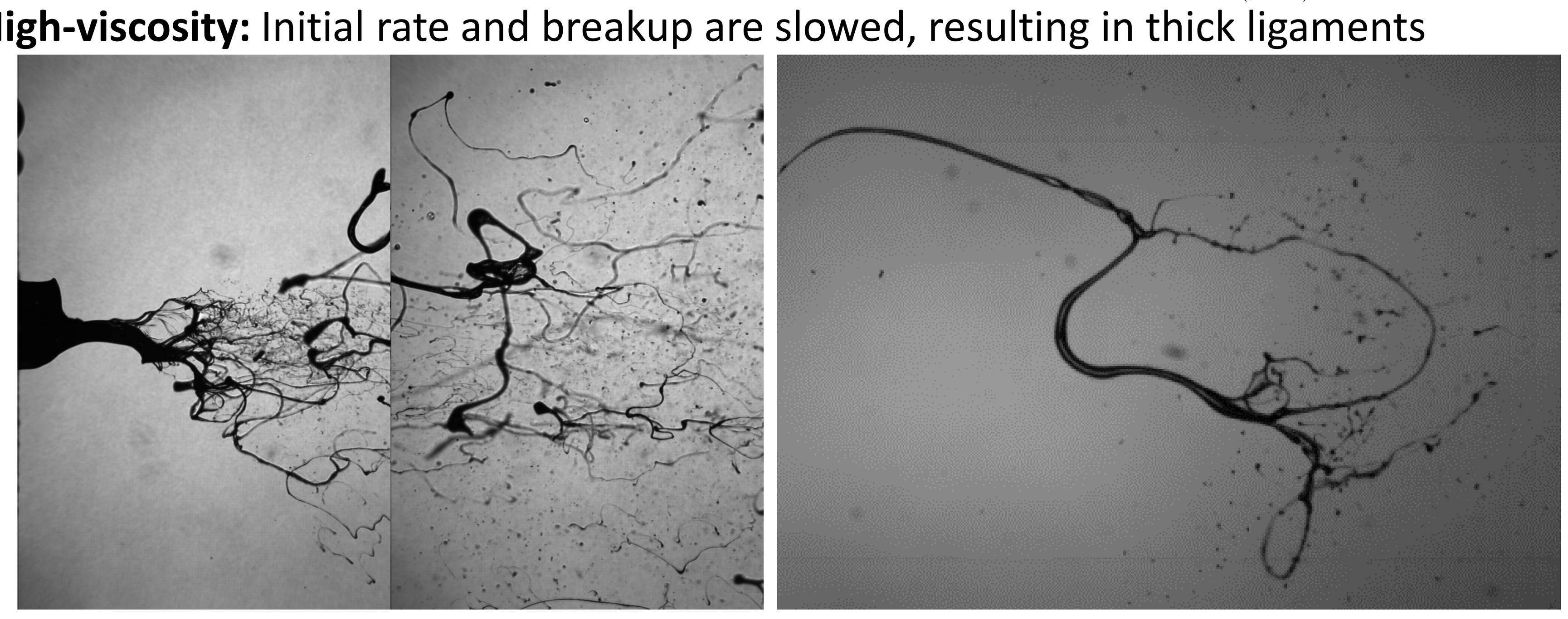
Twin-fluid atomization was studied fundamentally with droplet breakup.

1. A **droplet breakup model** was developed that predicts resulting **size distribution**.
   - The initial rate of deformation dictates the overall breakup size
   - a combination of breakup mechanisms leads to the distribution.
2. The droplet breakup model was applied to **spray modelling** to give a prediction of the **spray size distribution**.
   - Good agreement across a range of flow conditions and nozzle scales





High-viscosity: Initial rate and breakup are slowed, resulting in thick ligaments



Polymer: Initial rate is not slowed, but breakup is, resulting in stringy ligament network