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Development of a systematic characterization method for functional high-viscosity inkjet fluids

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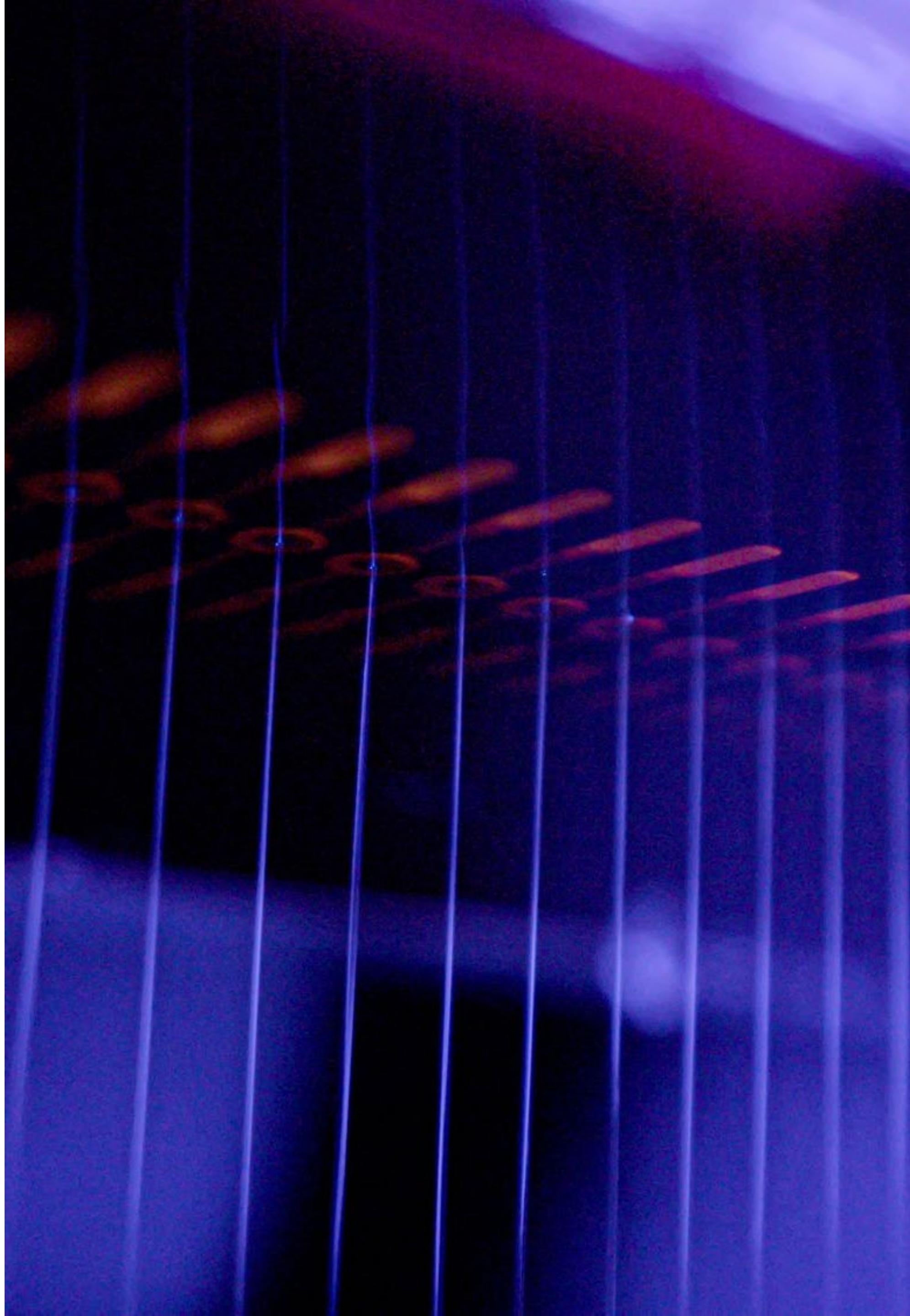
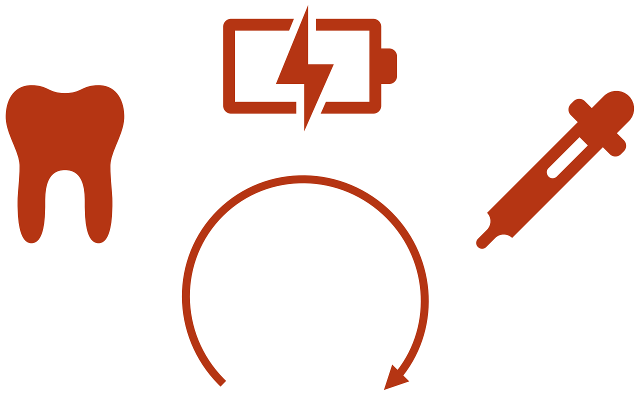


Agenda



Additive Manufacturing

Screenprinting

↓

Processing functional materials from various fields using inkjet technology

Overview

- Inkjet is a well known graphical printing technique
- But functional printing gains more relevancy recently
- In functional printing the materials are mostly tuned to the desired function not the printing process

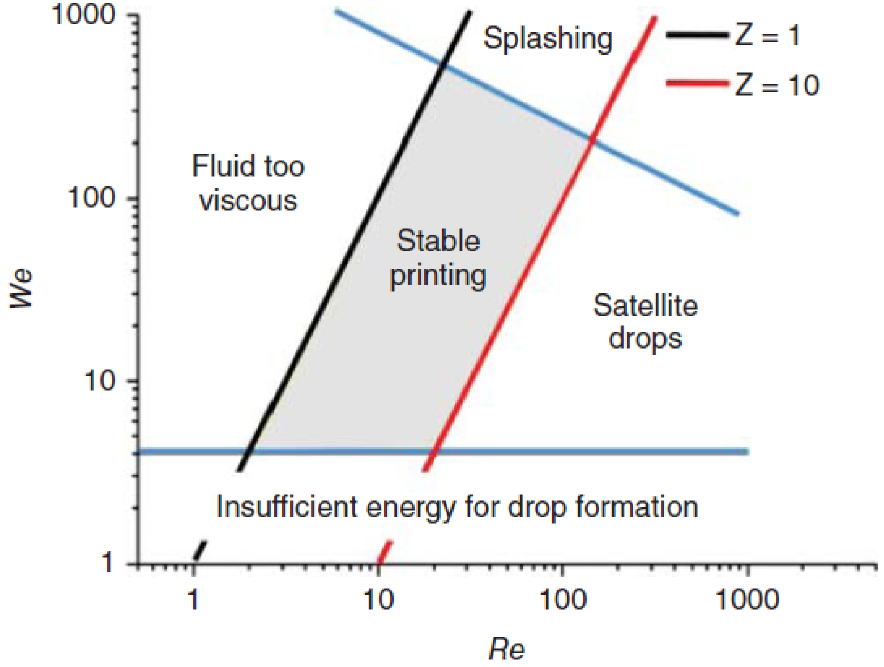
→ These new demands lead to the need for a different approach to inkjet printing and material testing

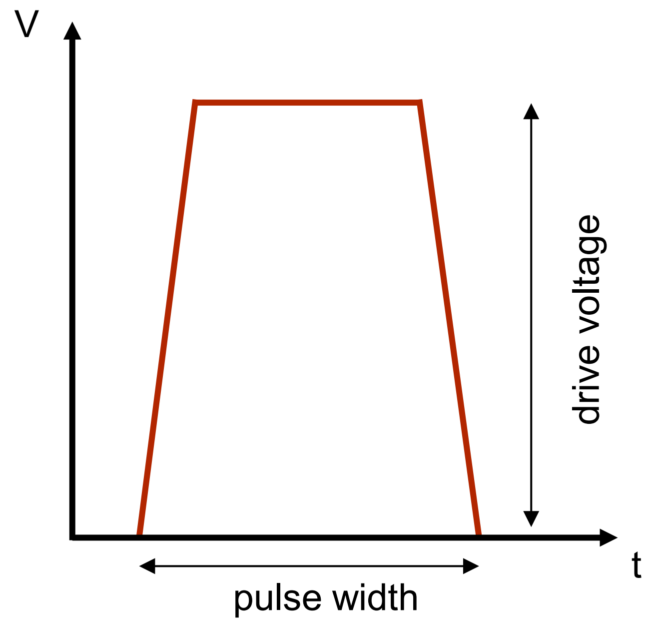
Overview
Fundamentals of Inkjet

- Evaluation of the physical properties of materials to assess jetability
- Most commonly used is the **Ohnesorge-number**

$$Oh = \frac{\eta}{\sqrt{\rho \cdot d \cdot \sigma}}, Z = 1/Oh$$

- The waveform is the driving force of the jetting process and creates an actuation in the printhead that ejects the material
- Waveform parameters need to be carefully tuned to the material and the desired printing conditions





- Which material properties of highly viscous materials influence droplet formation?
- How and by what methods can these properties be accurately characterized?
- What predictions can be made about jetting behavior based on these characteristics?

Research Questions

Schematic Workflow

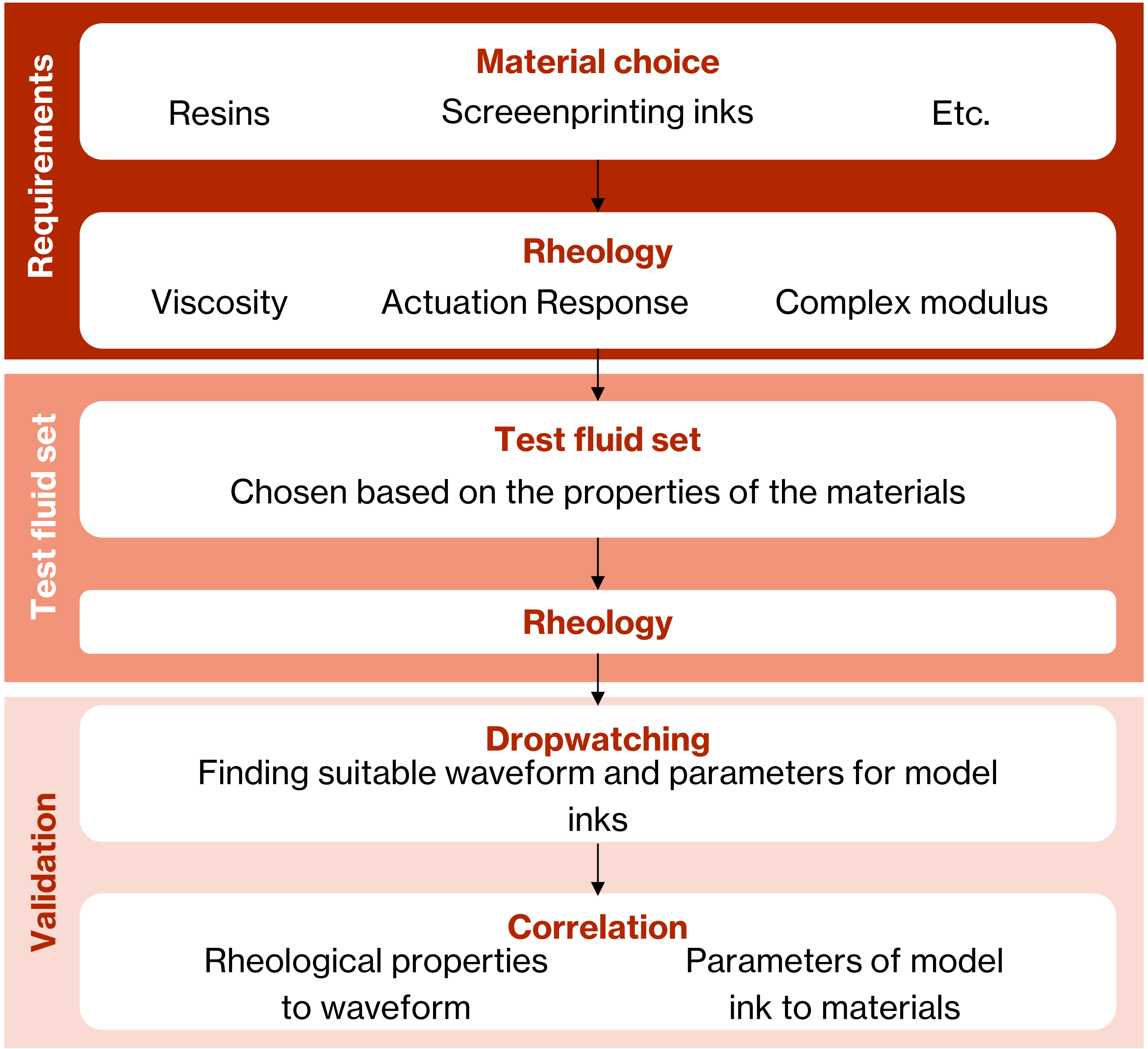
Functional materials are:

- complex
- expensive
- highly viscous at room temperature
- potentially toxic
- hard to clean

Waveform development is:

- expensive
- challenging
- time consuming

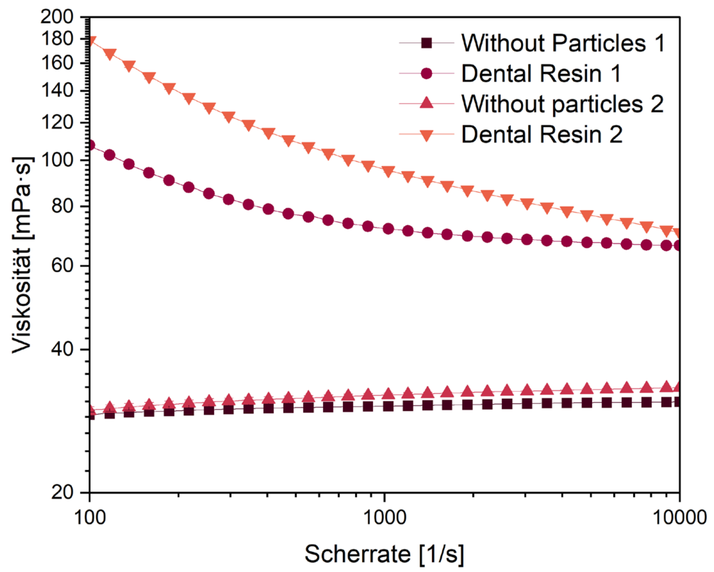
→ Model fluids can be an approach to save on expensive materials and do waveform development with simpler materials



Material overview

Dental resins

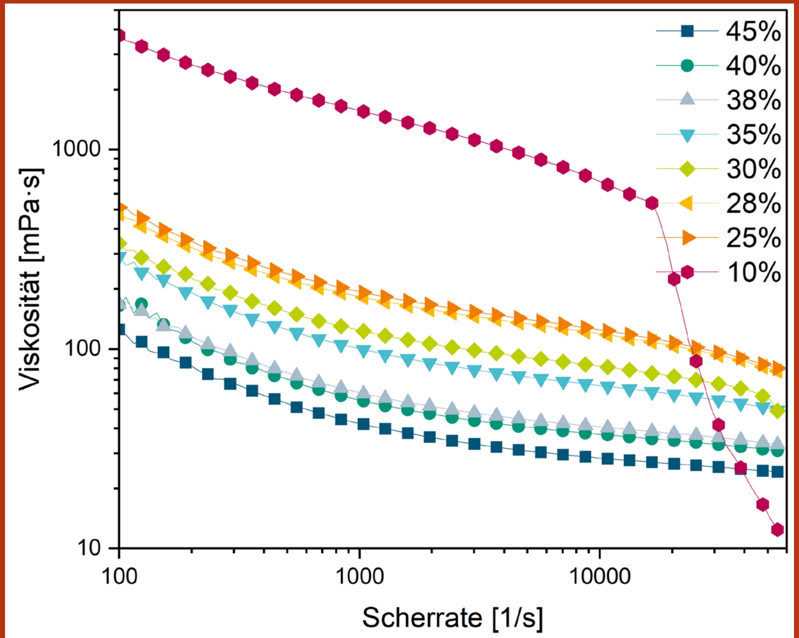
- Dental resins as an example of functional resins used in additive manufacturing
- Investigation of materials with and without particles
- Viscosity at room temperature well above the printable range
- Uniform heating of the materials poses a challenge for the fluidic system



Shear rate sweep of dental resins at 70 °C

Conductive screenprinting ink

- Silver-based screenprinting ink as an example of functional materials used in screen printing
- Investigation of the materials at various dilution levels
- Viscosity of the undiluted ink is well above the printable range
- Maintaining particle stability during high dilution can be challenging



Shear rate sweep of conductive screenprinting ink in various dilutions at 30 °C

Systematic test ink developement

Systematic test ink developement

- Formulation of test inks with different properties (viscosity, viscoelasticity, etc.) to replicate and simulate the properties of real materials

Newtonian Ink → **Viscoelastic Ink** → **Particle-loaded Ink**

Newtonian Ink

Properties:
- Viscosity
- Surface tension

Examples:
- PEG400
- PEG400 + isopropanol
- Glycerin + water

Viscoelastic Ink

Properties:
- Viscosity
- Surface tension
- Viscoelasticity

Examples:
- Polystyrene in DEP with different molecular weights

Particle-loaded Ink

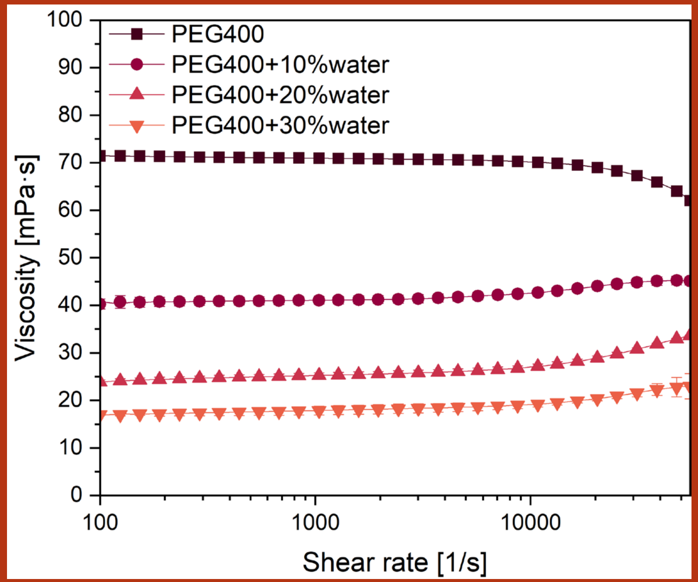
Properties:
- Viscosity
- Surface tension
- Viscoelasticity
- Particle size and -stability

Examples:
- Silica fillers
- various pigments

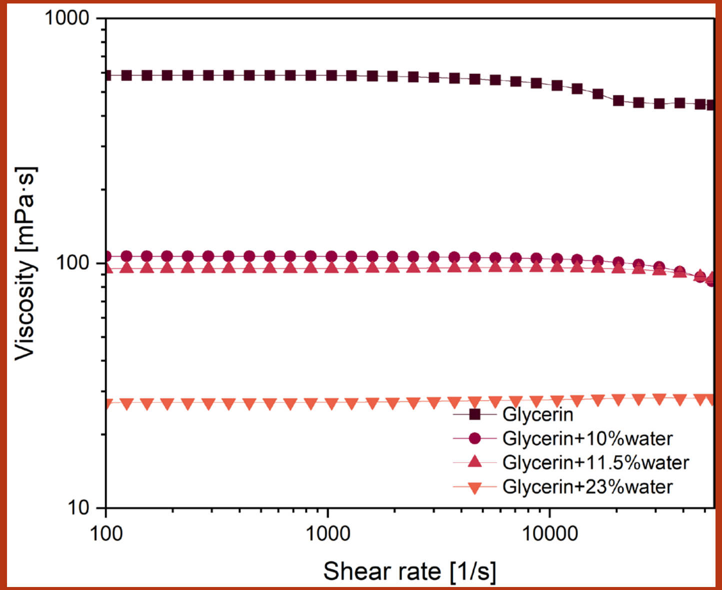
PEG 400 and glycerin-based test inks

- Polyethylene glycol and glycerin mixtures as newtonian inks

- Pure **PEG 400** is already a good Newtonian test ink as it has a viscosity of **70 mPas** at **30 °C**
- To achieve even higher viscosities **glycerin** in water can be used with viscosities around **100 mPas** at **10 % dilution**



PEG400 with isopropanol in various concentrations



Glycerin and water in various concentartions

Systematic test ink developement

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Examples:
- PEG400
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Particle-loaded Ink

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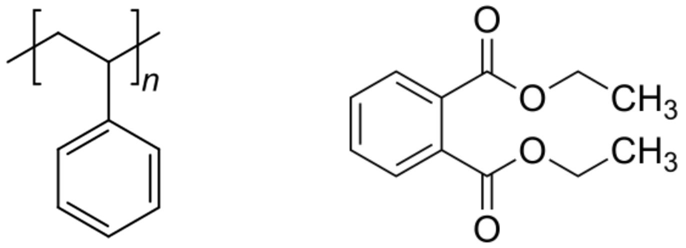
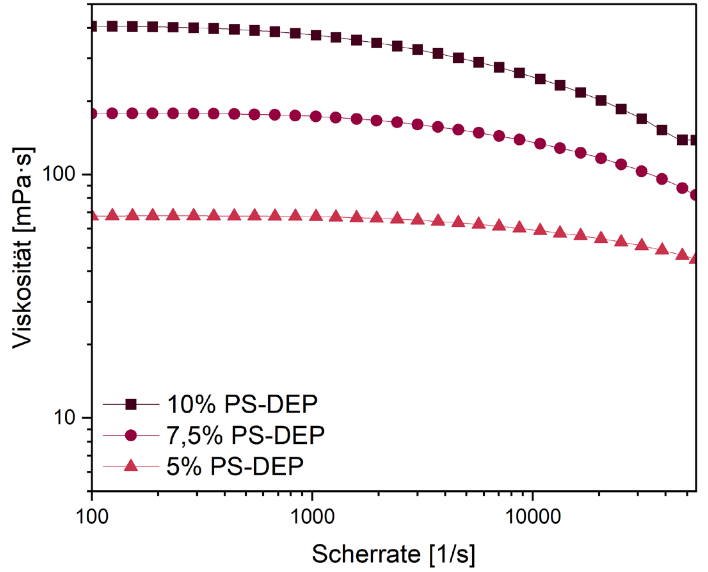
Preparation of PS-DEP solutions

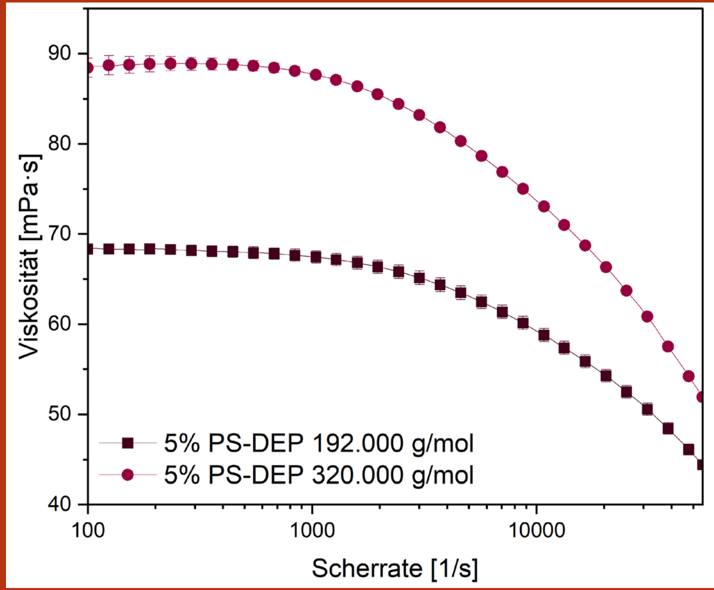
- Polystyrene and diethyl phthalate as a viscoelastic ink



- M_W of polystyrene: 192.000 g/mol and 320.000 g/mol
- Preparation at **80 °C over night**
- Measurement performed using an Anton Paar rheometer in a cone-plate configuration with a shear rate sweep from 100 to 55,000 s^{-1} at 30 °C, unless otherwise specified



PS-DEP solutions in various concentrations

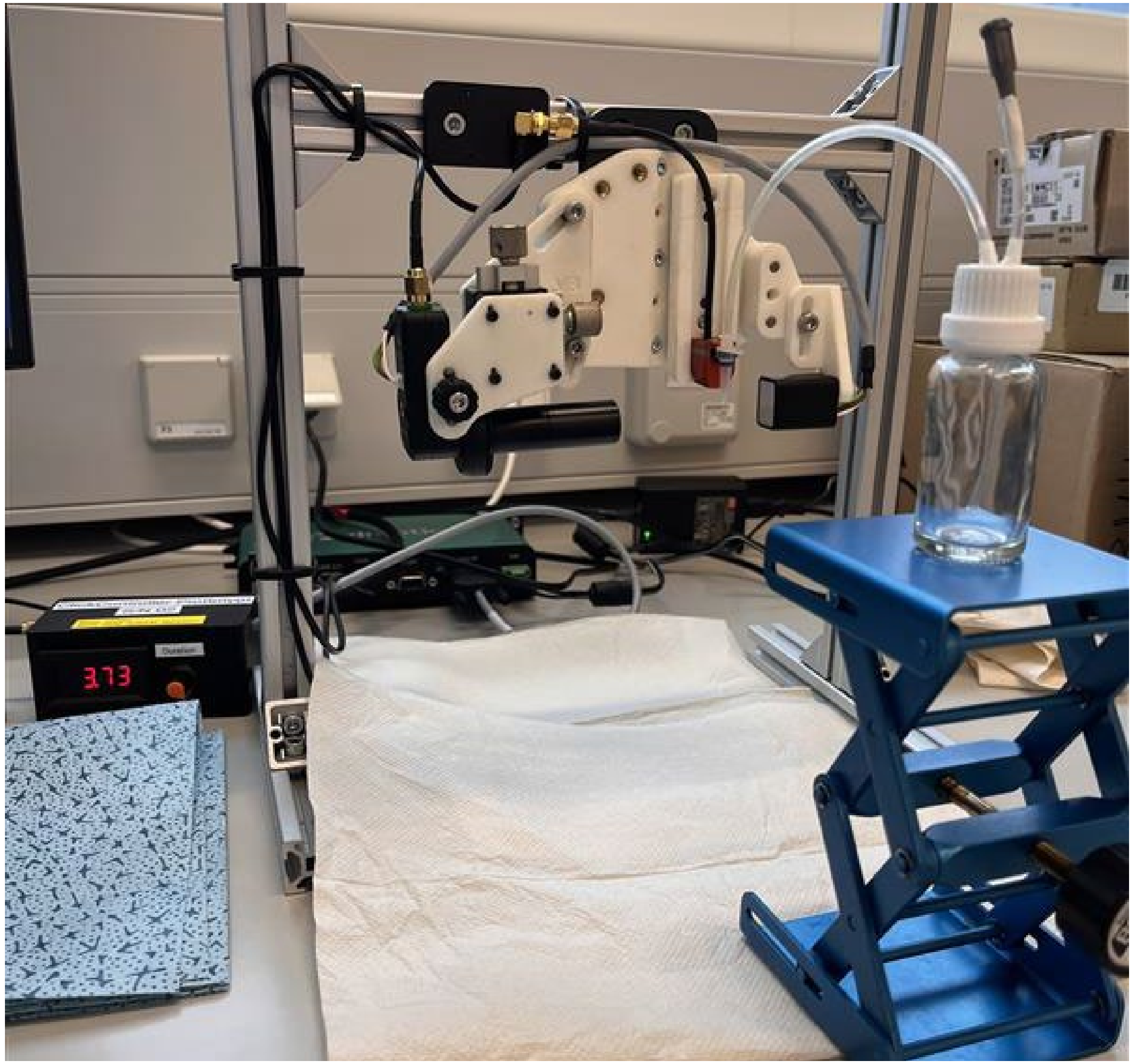


5% PS-DEP solution prepared three times to verify reproducibility

Jetting trials with newtonian inks

Clickjet Pico

- Initial trials performed with **Droptical Clickjet Pico**
- Controlled parameters:
  - Flash duration
  - Power factor
  - Signal duration
- Actuation via a piezo results in displacement of the nozzle and subsequently a droplet



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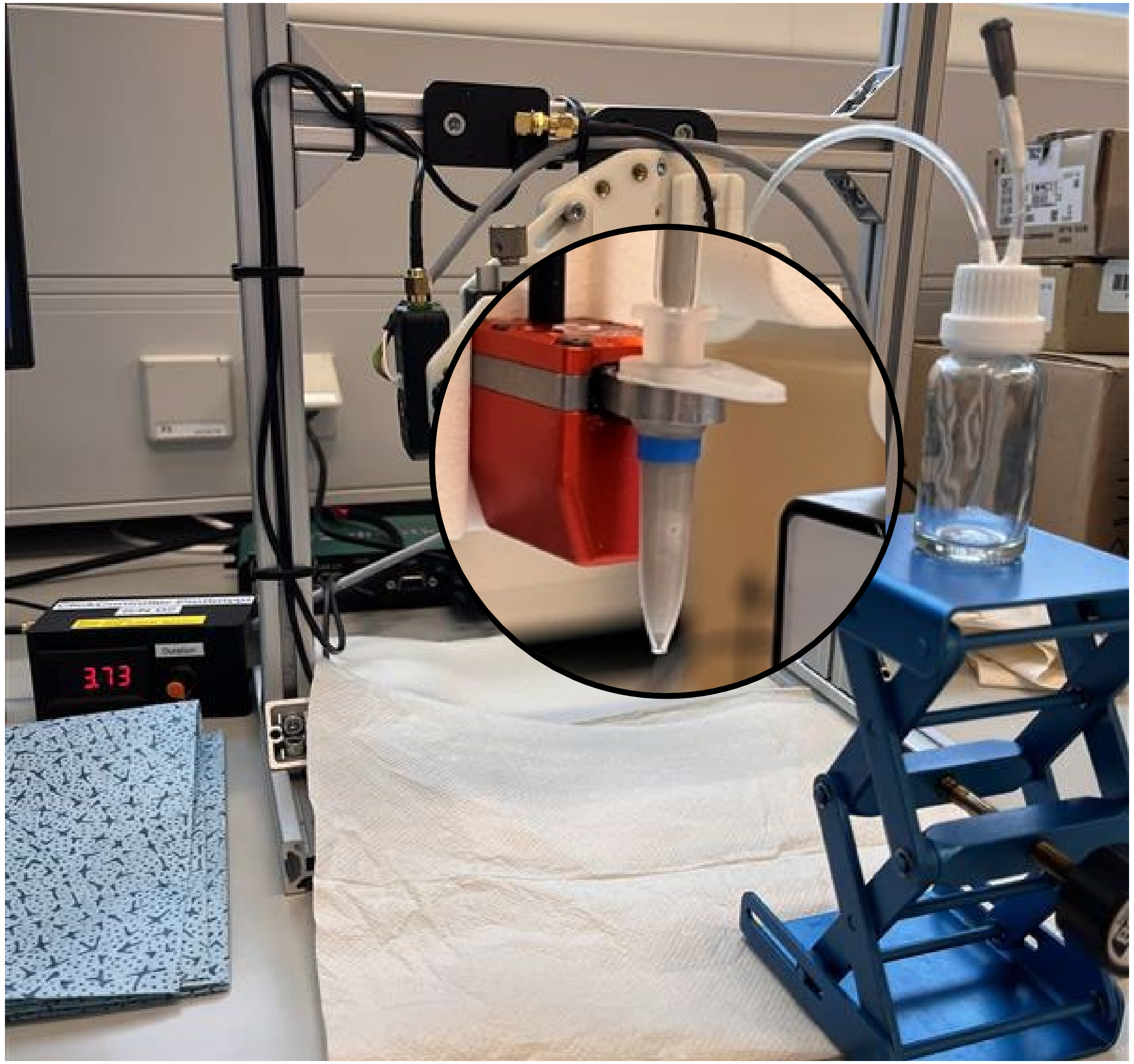
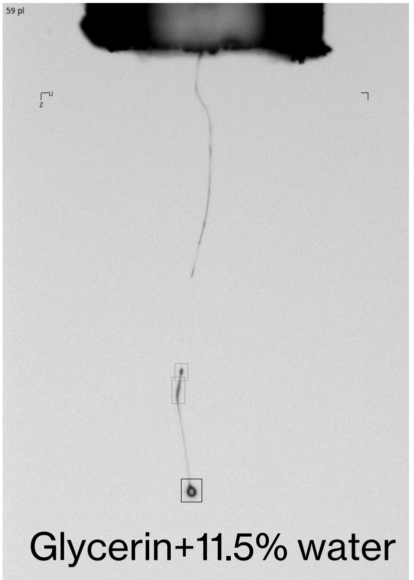
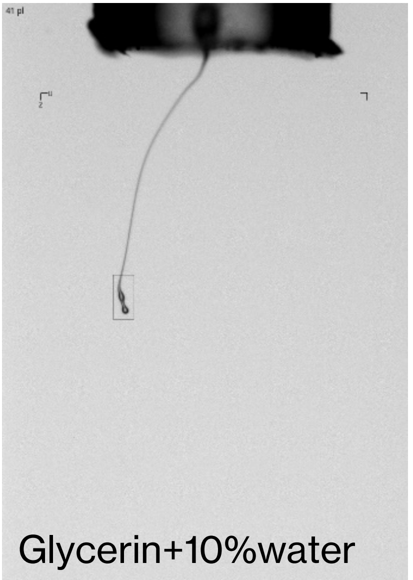
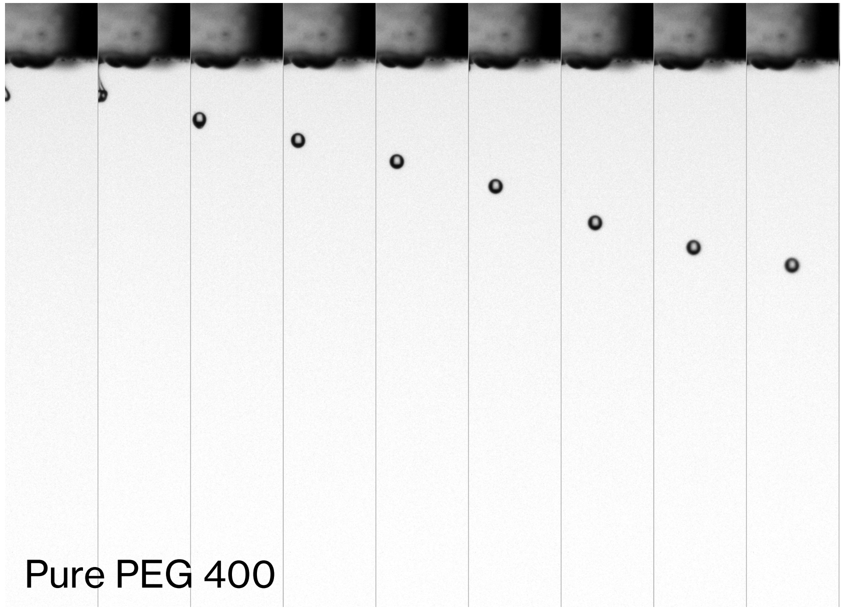


Clickjet Pico

- Limit of the Clickjet Pico was found with glycerin-mixtures
- **Glycerin** with 10 % water is barely ejected at full power factor with **107 mPas**
- **PEG 400** yields very stable droplets with the following settings:
  - Power factor: 20
  - Signal duration: 2.69

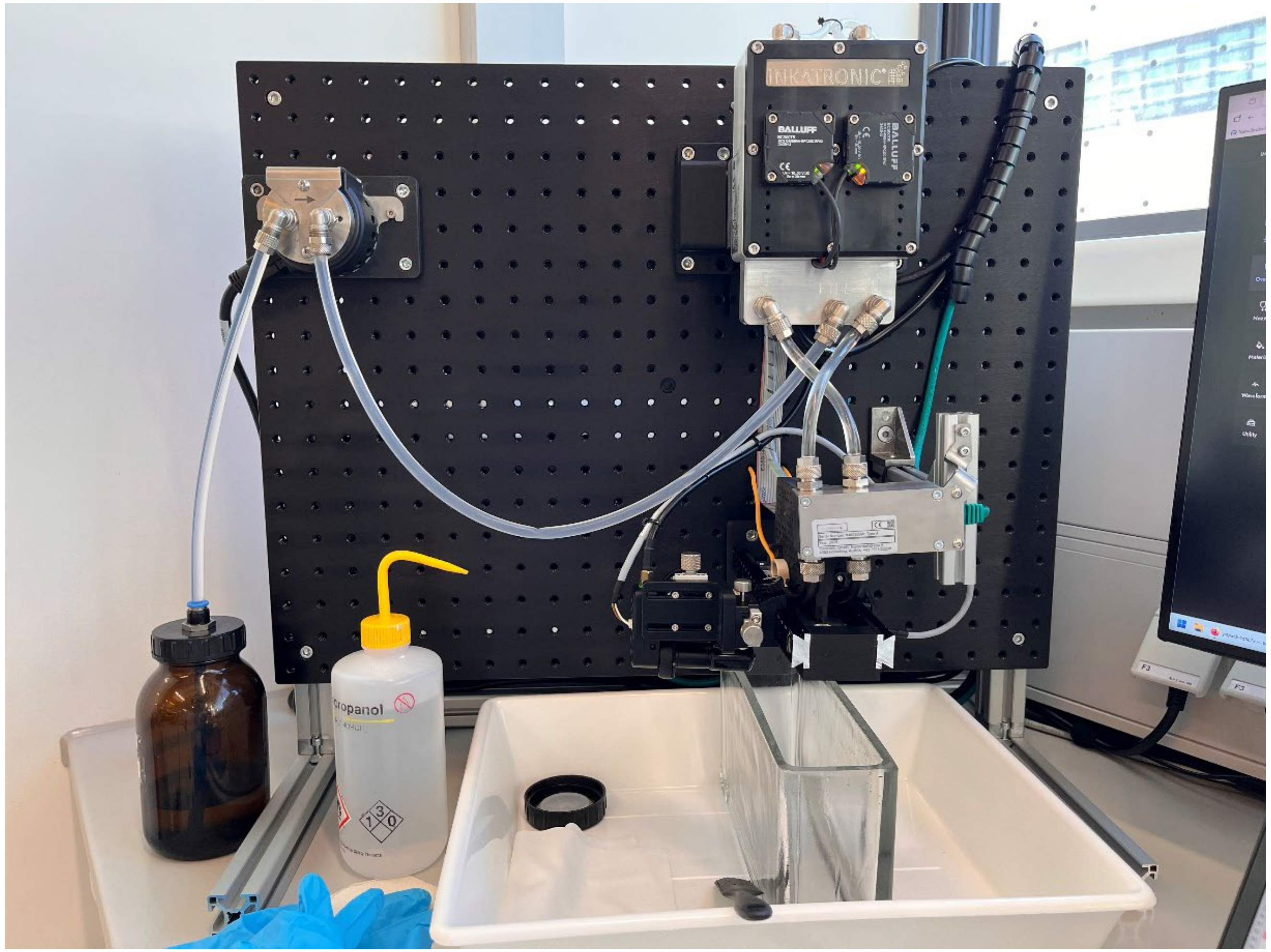

Glycerin+11.5% water


Glycerin+10%water


Pure PEG 400

Quantica Novojet

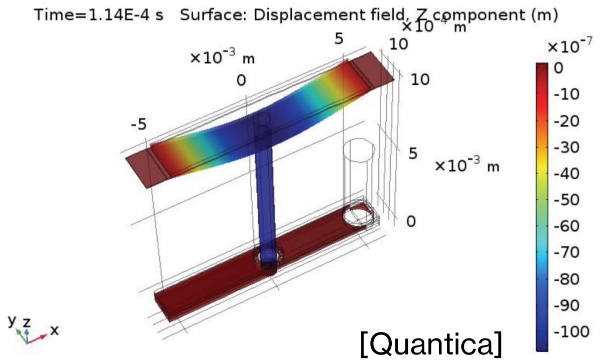
- Jetting with **Quantica Novojet Printhead**
- Can theoretically jet viscosities up to **250 mPas**
- Fluidic system **Inkatronic Lab Tank**



Quantica Novojet

	Quantica NovoJet™	Conventional Printheads[1]
Nozzle Count	96	128 - over 1000
Nozzle Diameter	50 µm and 90 µm	5 – 20 µm
Jettable Particles (d90)	9 µm	< 1 µm
Droplet Volume	150 pl – 300 pl	5 – 100 pl
Native Resolution	20 DPI	50 – 1080 DPI
Fluid Viscosity Range (Jetting temp)	1 mPa*s – 250 mPa*s	5 - max 100 mPa*s
Jetting Temperature	RT – 80 °C	RT – 80 °C
Frequency	8 kHz	30-50 kHz
Surface Tension	30-750 mN/m	20 – 30 mN/m

Displacement simulation



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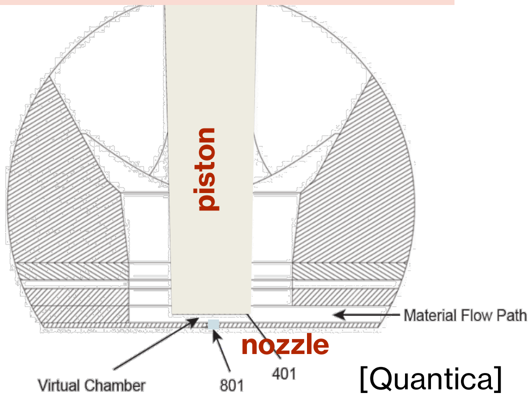
Piezo Element



[Quantica]

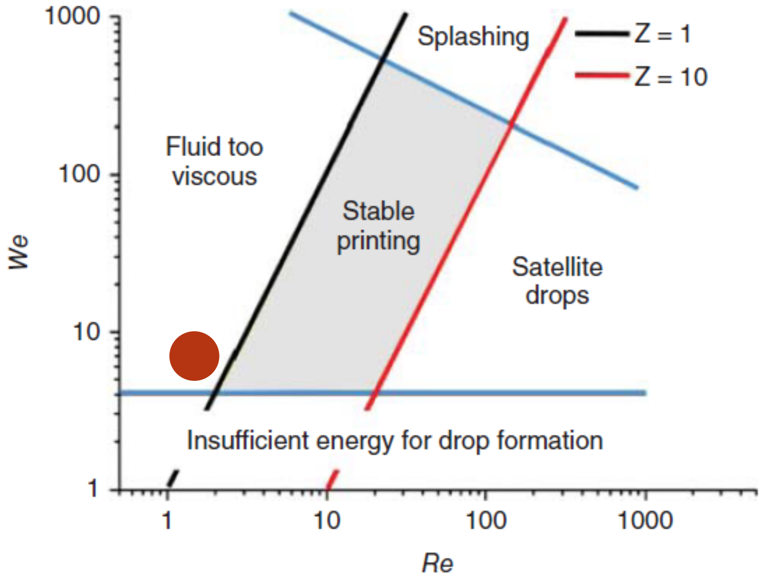
- **Large actuator displacement** - 100x more than conventional printheads

Potential for a lot new materials to be printed with this technology to exploit new applications and markets

Due to the new working principle of the printhead, are the existing process characterization for piezo inkjet printing still valid for the NovoJet™ technology?

Quantica Novojet

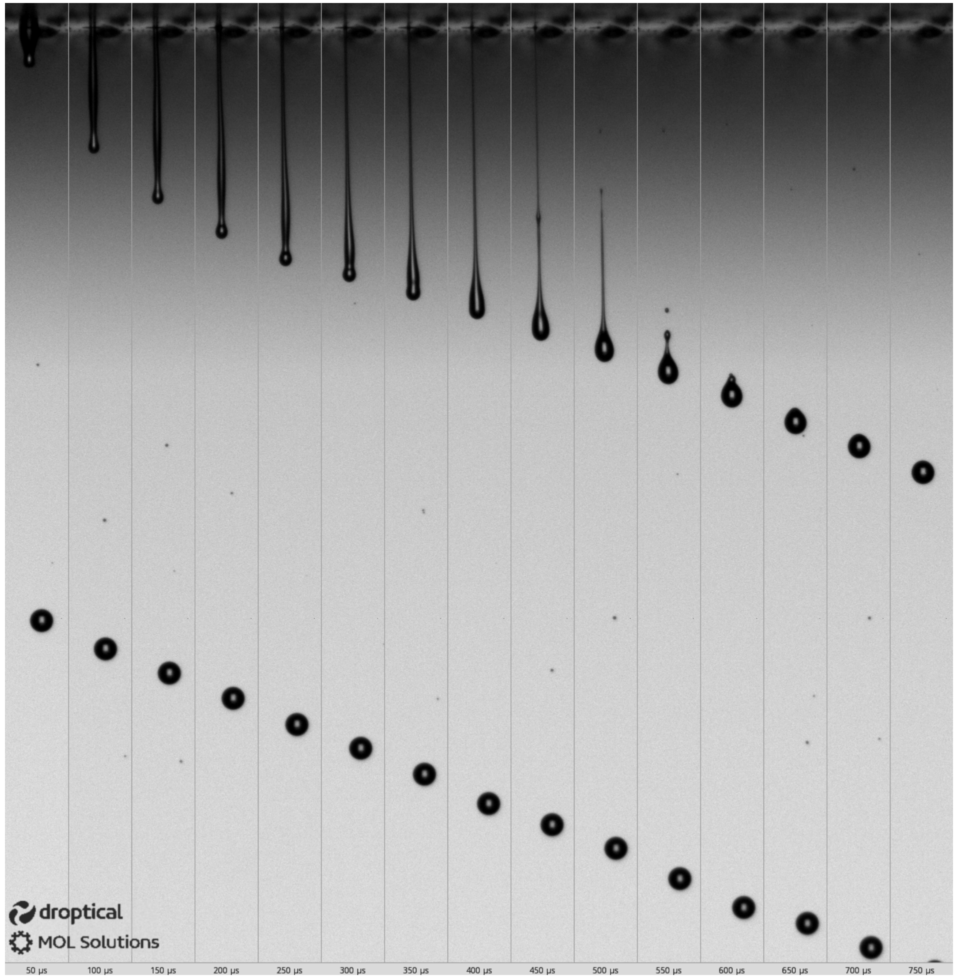
- Successful **jetting of PEG 400** with the setup
- Biggest problem lies in finding right process **window for the meniscus pressure**



Ohnesorge-Number of PEG400 is technically **out of the process window** for **conventional printheads:**

Oh=1.42

Z=0.70



Outlook

MATERTIALS AND INKS

- Adjusting of the viscosities of the viscoelastic ink

  →Achieve similar viscoelatic behavior in different viscosity ranges

- Developing a **particle loaded ink** system
- Test and evaluate **high frequency rheology** of the materials

JETTING UND DROPWATCHING

- Find **limitations of Quantica Novojet** with newtonian ink
- Dropwatching with viscoelastic inks
  - Clickjet Pico
  - Novojet printhead

→ Find correlations between ink parameters (rheology, etc.)and jetting behaviour

Contact details

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Thank you for your attention!

Sources

Slide 4:

B. Derby, "Inkjet Printing of Functional and Structural Materials: Fluid Property Requirements, Feature Stability, and Resolution," *Annu. Rev. Mater. Res.*, vol. 40, no. 1, pp. 395–414, 2010, doi: 10.1146/annurev-matsci-070909-104502

W. Zapka, "Inkjet Printing in Industry," 2022.

Sources

Pictures

Slide 1:

https://www.quantica.io/novojet-printhead

Slide 20:

M. S. Ben Hartkopp, Ramon Borrell, and Quantica GmbH, "Quantica_NovoJet_Technology_Whitepaper," 2022.

https://www.quantica.io/

Polystyrene in diethyl phtalate in literature

Vadillo et al., 2010:

Various concentrations of 210,000 g/mol PS in DEP

No information provided on the temperature or duration of the synthesis

Vadillo et al., 2012:

10% solution of PS with various molecular weights in DEP

Prepared at 180 °C for several hours

Tuladhar et al., 2008:

Various concentrations of 195,000 g/mol PS in DEP

Prepared at 130 °C for 10 hours

Sources

PS-DEP preparation

Vadillo, Damien C.; Mathues, Wouter; Clasen, Christian (2012): Microsecond relaxation processes in shear and extensional flows of weakly elastic polymer solutions. In: *Rheol Acta* 51 (8), S. 755–769. DOI: 10.1007/s00397-012-0640-z.

Vadillo, D. C.; Tuladhar, T. R.; Mulji, A. C.; Mackley, M. R. (2010): The rheological characterization of linear viscoelasticity for ink jet fluids using piezo axial vibrator and torsion resonator rheometers. In: *Journal of Rheology* 54 (4), S. 781–795. DOI: 10.1122/1.3439696.

Tuladhar, T. R.; Mackley, M. R. (2008): Filament stretching rheometry and break-up behaviour of low viscosity polymer solutions and inkjet fluids. In: *Journal of Non-Newtonian Fluid Mechanics* 148 (1-3), S. 97–108. DOI: 10.1016/j.jnnfm.2007.04.015.