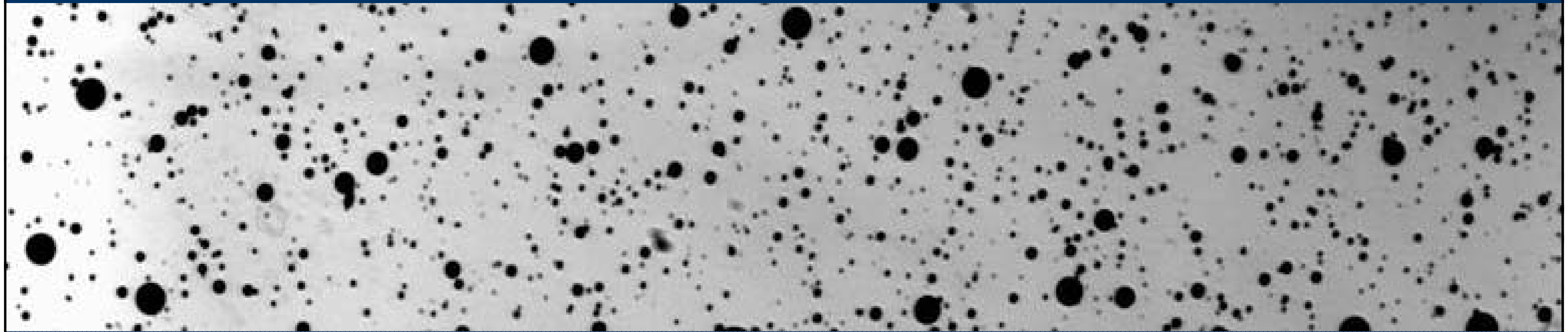


Optical analysis of air release in a liquid flow behind an orifice

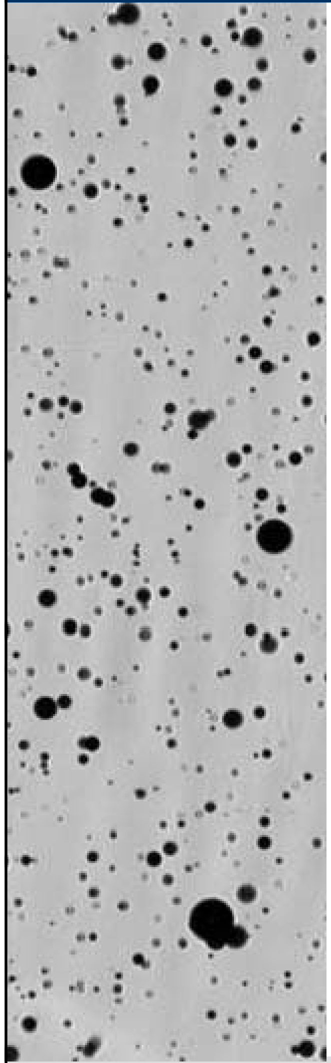
Uwe Iben[1] and Hans-Arndt Freudigmann[2]

14th Workshop on Two-Phase Flow Predictions / Halle-Wittenberg

[1] Dr.rer.nat. Dr.-Ing. Uwe Iben
Robert Bosch GmbH,
Center for Research and Advanced Engineering
Robert Bosch Campus 1,
71272 Renningen , Germany
uwe.iben@de.bosch.com

[2] Hans-Arndt Freudigmann
Robert Bosch GmbH,
Center for Research and Advanced Engineering
Robert Bosch Campus 1,
71272Renningen, Germany
hans-arndt.freudigmann@de.bosch.com

Content



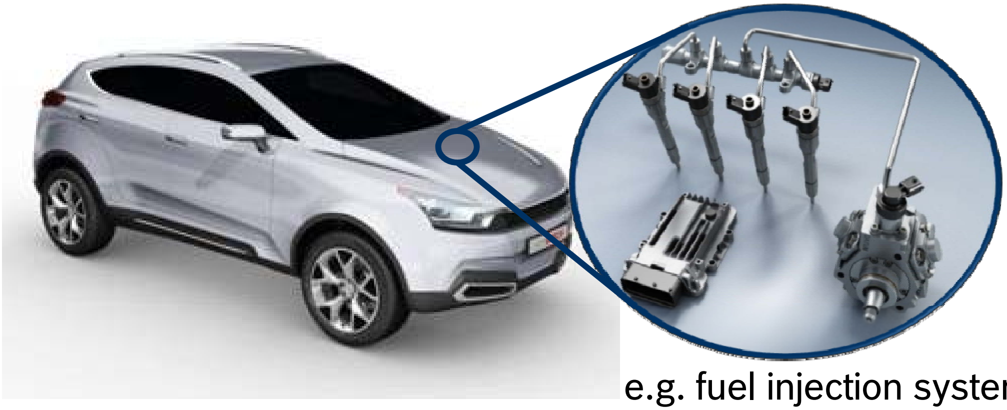
Motivation

Experimental setup

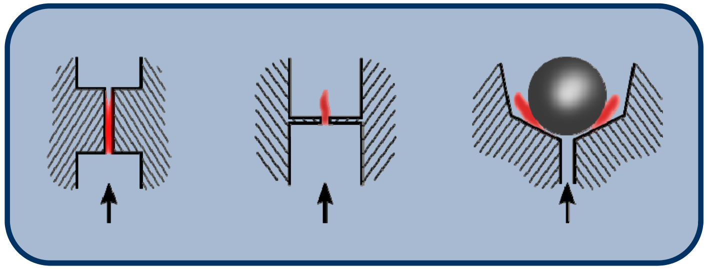
Results

Conclusion

Hydraulic systems, cavitation and air release



e.g. fuel injection systems



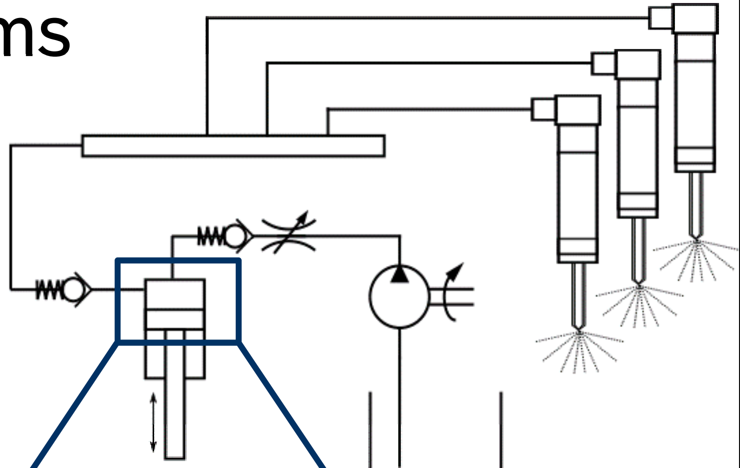
Basic components (simplified)

- **Cavitation in hydraulic systems can lead to:**
  - Erosion
  - Vibration & noise
  - Alteration of hydraulic liquids
  - Chocked flow phenomena
  - Efficiency losses vs. acoustic decoupling
  - **Air release** (each liquid contains air)

Notes:

- Cavitation can not be avoided in general – it has to be controlled (focus on erosion)
- The same is valid for air release
- Cavitation occurs on small time & spatial scales (ns, µs / nm, µm)
- But: Air release occurs on larger time & spatial scales than cavitation (ms, s , h or days in some cases / µm, mm)

Air release in hydraulic systems



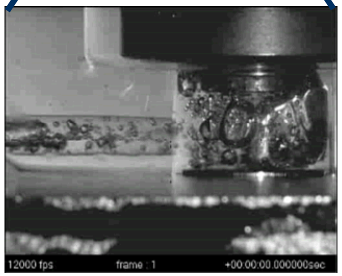
➔ Degassed air leads to bubbles in the liquid:

- **Change of liquid properties**
  - Density
  - Bulk modulus
  - Speed of sound
  - Viscosity

  } Physical properties

- **Change of hydraulic system properties**
  - Mass flow
  - Generated forces
  - Eigen-frequencies
  - Vibration & noise

  } Functional properties

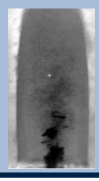


Suction and compression phase in a cylinder of a high pressure piston pump

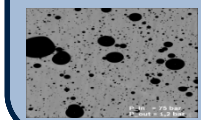
Note: Compression -> hot bubbles -> Diesel lightening

Research objectives*:

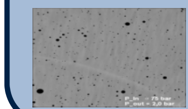
Cavitation



Degassing



Dissolving of air



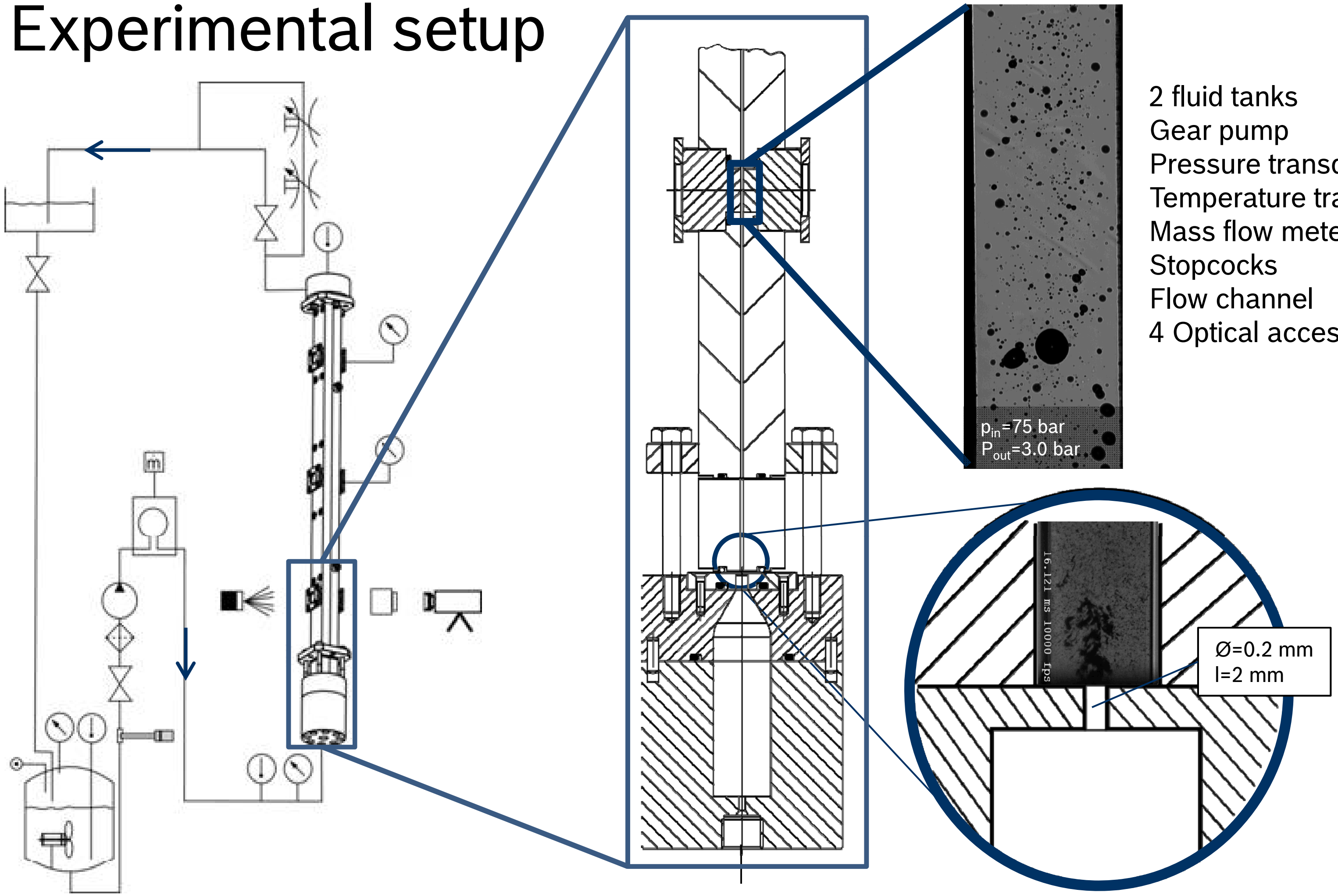
Modelling

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho v}{\partial z} = 0$$

Optical measurements of gas bubbles in a flow of oil behind a micro orifice, Iben, U.,Wolf, F., Freudigmann,H.-A., Fröhlich, J., Heller, W.; To be published in: „Experiments in Fluids“, Springer

BOSCH

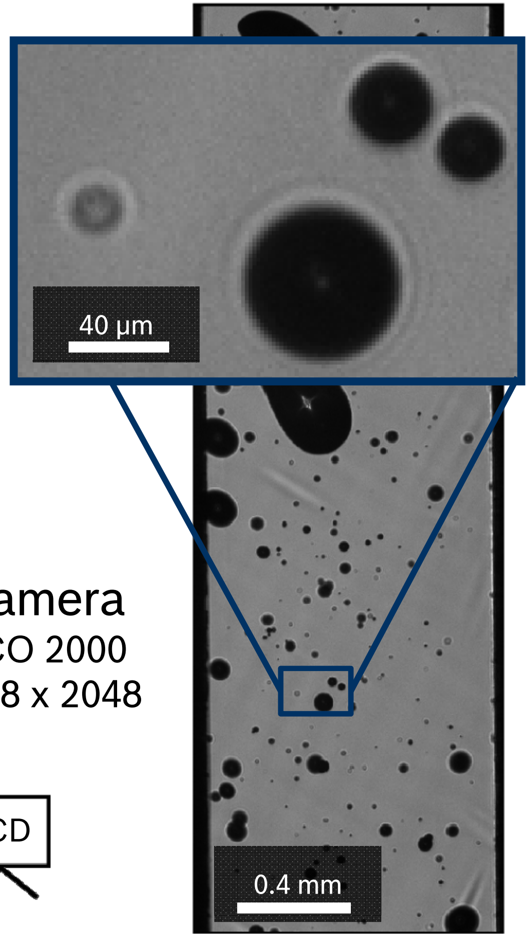
Experimental setup



2 fluid tanks
Gear pump
Pressure transducers
Temperature transducers
Mass flow meter
Stopcocks
Flow channel
4 Optical accesses

BOSCH

Optical setup - shadowgraphy

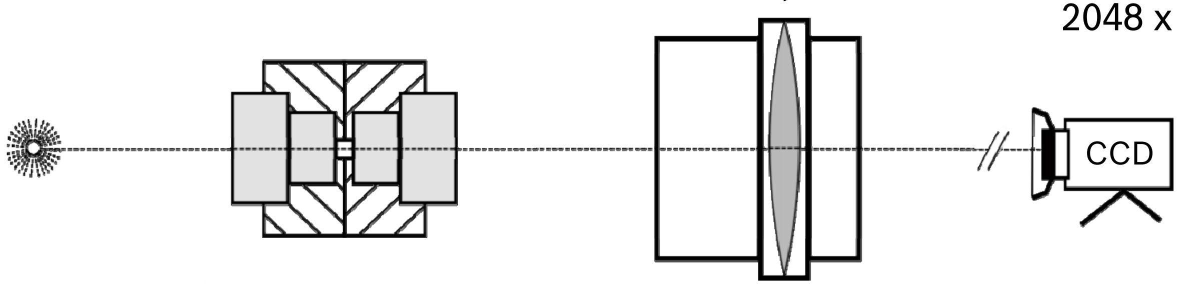


Flash light
NanoLite

Flow Channel
1 mm x 1 mm

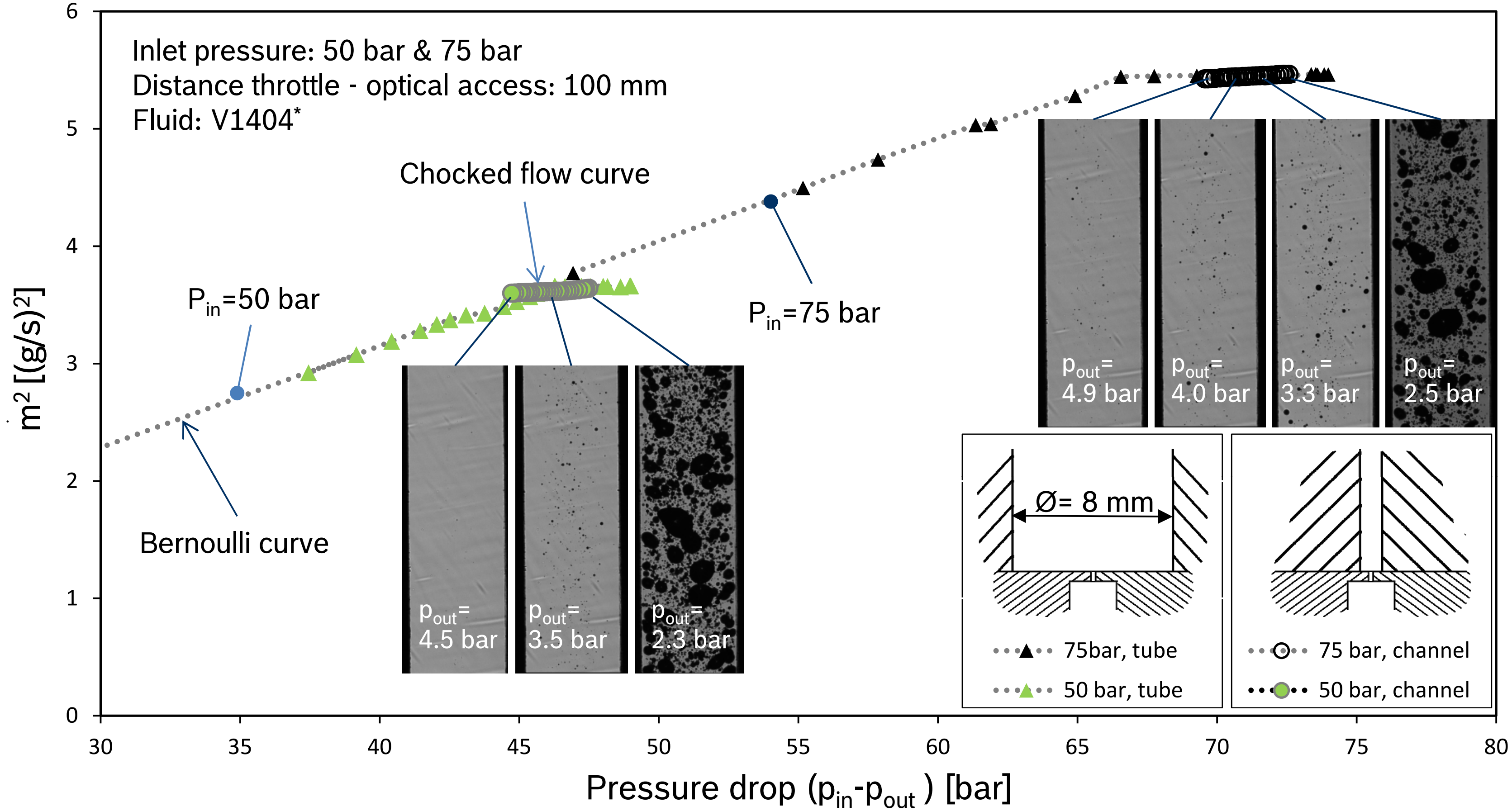
Objective
B.Halle, f=100 mm

Camera
PCO 2000
2048 x 2048



BOSCH

Choked flow - air release



Results

Bubble recognition & characterization

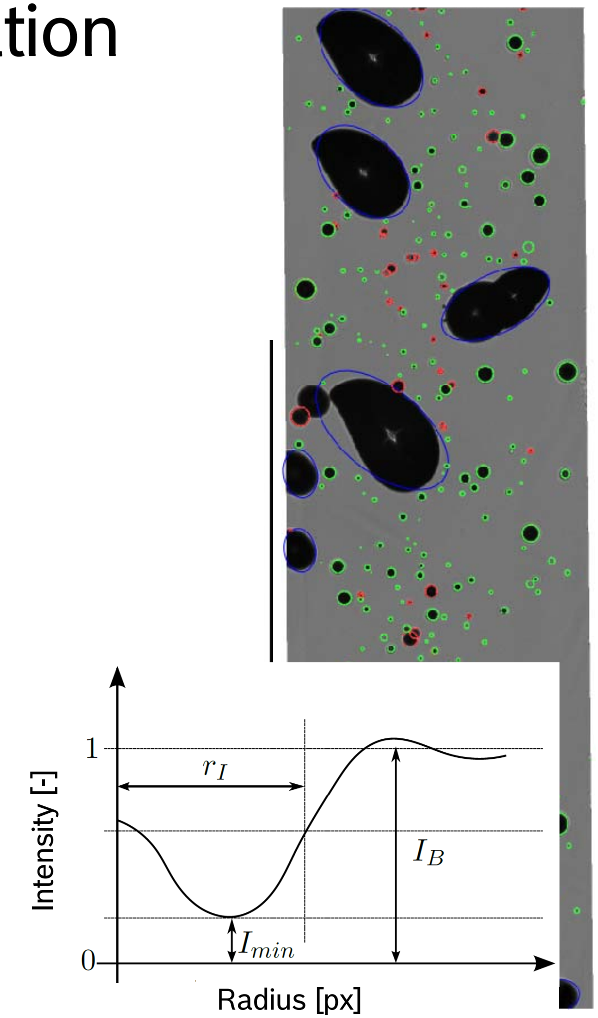
1. Image preparation

2. Segmentation of bubble images
- Hough-Transformation ➔ spherical bubbles
- Image binarization ➔ spherical and non-spherical bubbles

3. Determination of bubble size
- Determine intensity profile for round bubble images
- Determine bubble radius at half intensity level

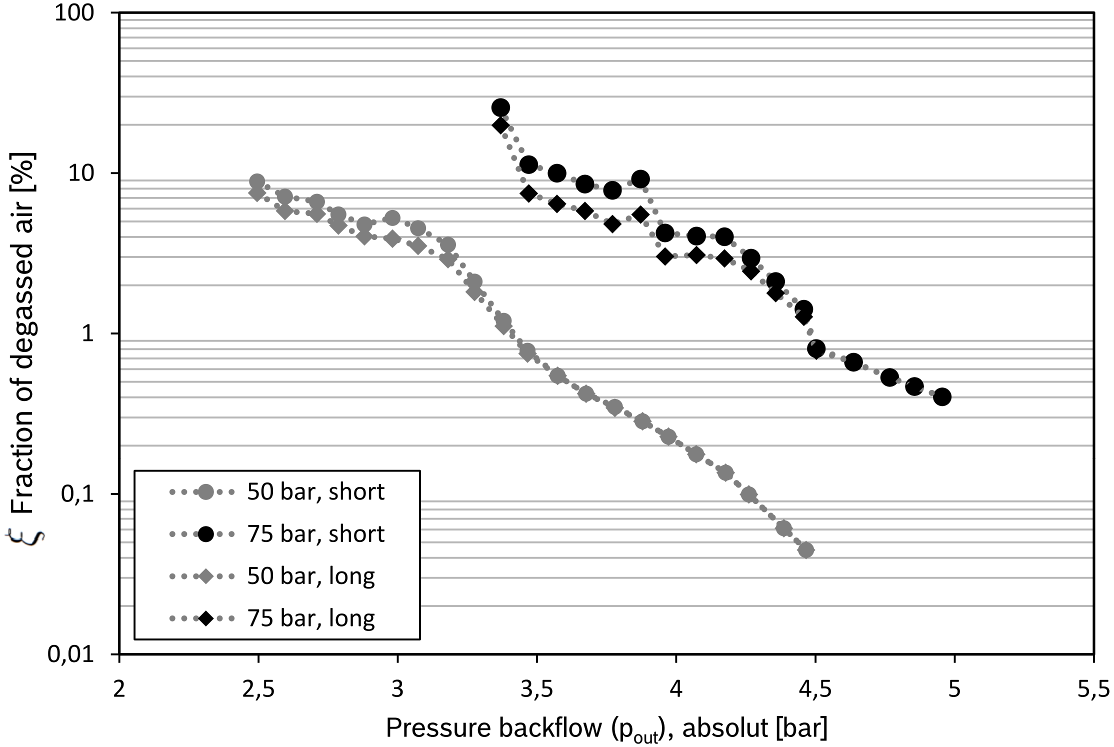
4. Size correction
- Determine optical scale
- Size correction using the contrast

$$I := \frac{I_B + I_{min}}{2} \rightarrow r_i$$



Baltzer, K., Automatisierte Erkennung von Gasblasen in Zweiphasenströmungen, Bachelor Thesis, 2014, Universität Konstanz

Degassing – results



- Distance: 100 mm
- Liquid is saturated with air at atmospheric pressure :

$$c_g = 1.03 \cdot 10^{-3} \frac{\text{mol}}{\text{mol}}$$

$$p_b = p_l + \frac{2\sigma}{r_b}$$

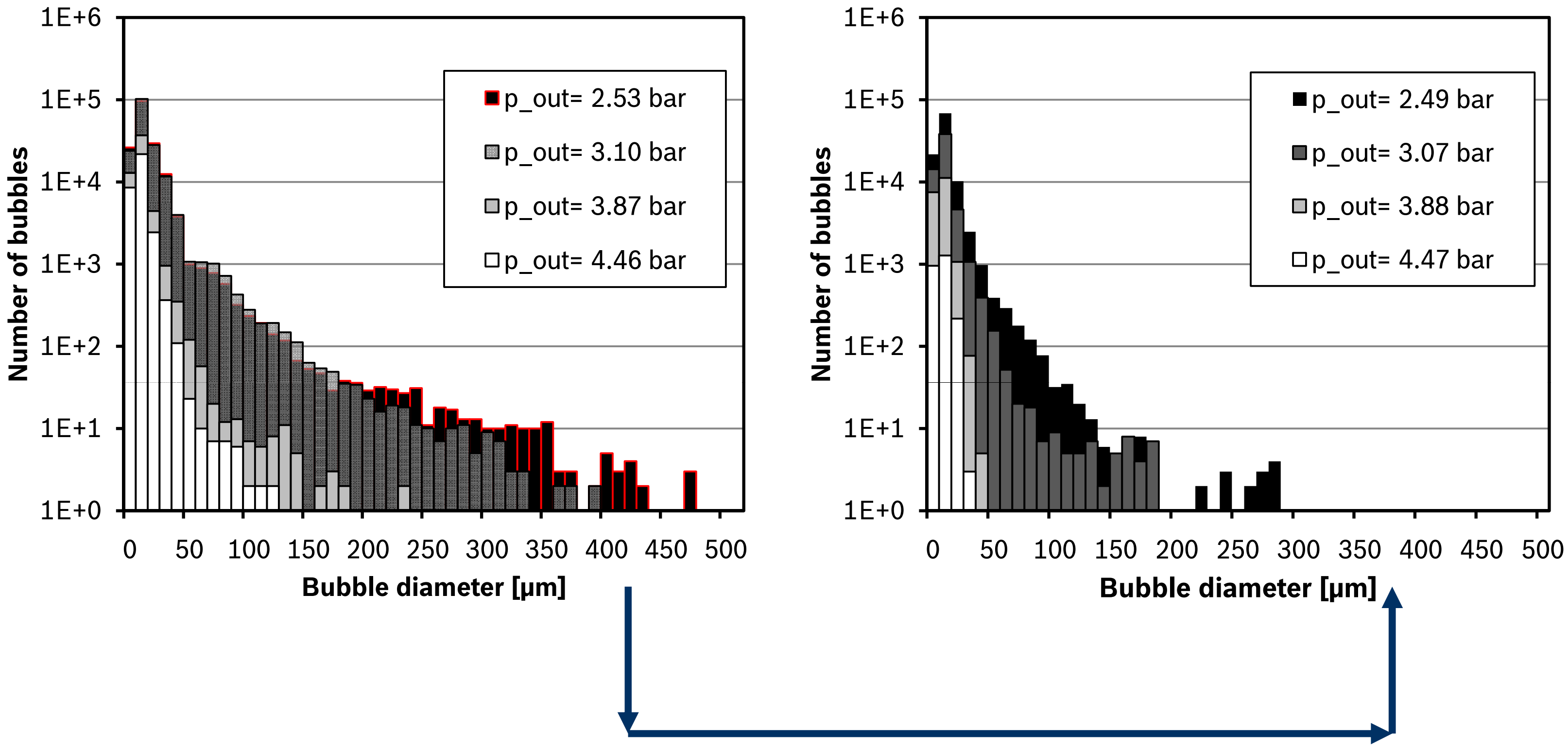
$$\xi := \frac{n_l \cdot c_g}{n_g} \cdot 100, \qquad n_l = \left(V_{channel} - \sum V_{bubbles}\right)\frac{\rho_l}{M_l} \;\&\; n_g = \frac{\sum p_b V_b}{R T_l}$$

BOSCH

Bubble size distribution – 100 images

→ Inlet pressure: 75 bar

→ Inlet pressure: 50 bar



BOSCH

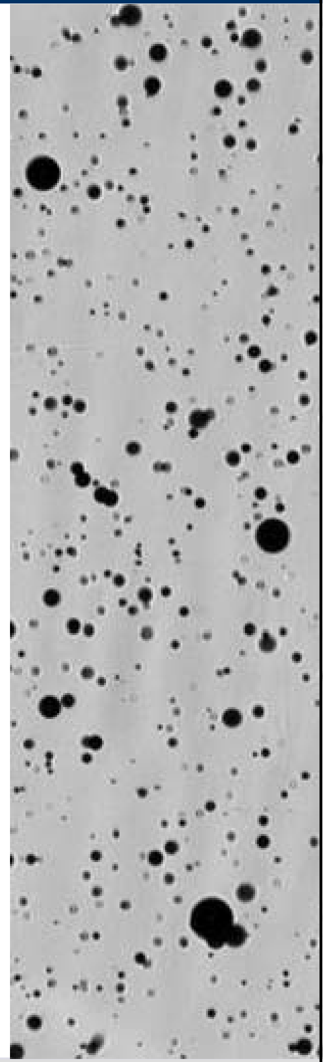
Conclusion

Present Work & Results for V1404 and stated conditions

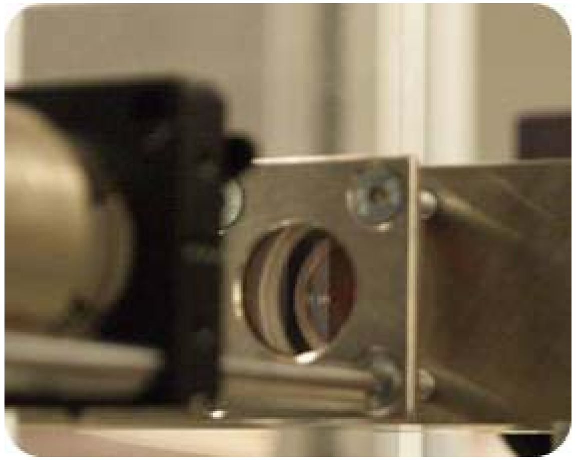
- → Gas bubbles in hydraulic systems affect system behavior significantly
- → Degassing of air is strongly linked to cavitation
- → Degassing occurs only at choked flow conditions
- → Degassing is very sensible to outlet pressure; approx. exponential correlation
- → Number and size of bubbles depend on in- and outlet pressure conditions

Future Work

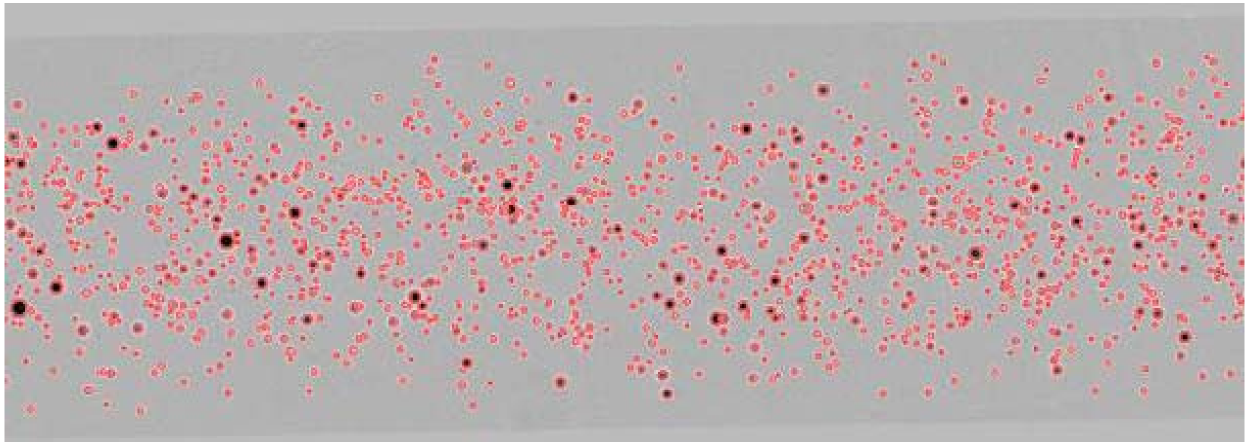
- → Variation of air content in liquid (air content in tank)
- → Variation of orifice dimensions and geometry (D/L)
- → Modelling of air release in hydraulic systems



BOSCH



Thank you!



BOSCH