Design of a capacitance sensor for void fraction measurement using QuickField

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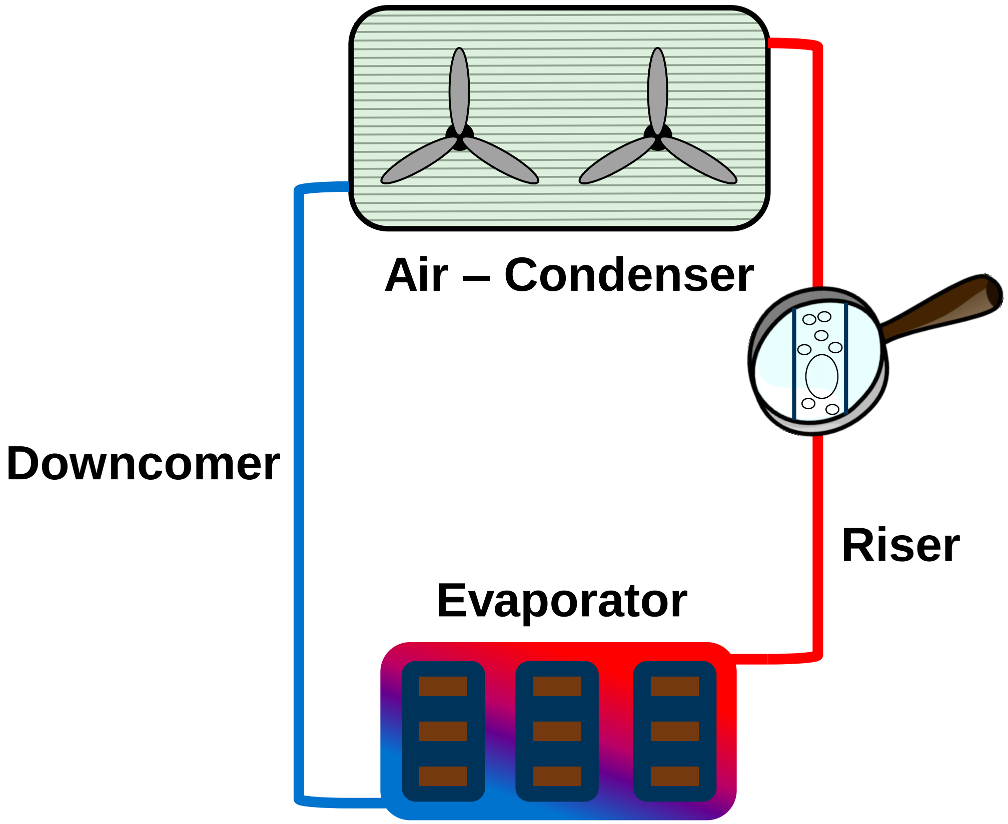
Motivation: Sensor for measuring two-phase flows



Optimization

Capacitance sensor

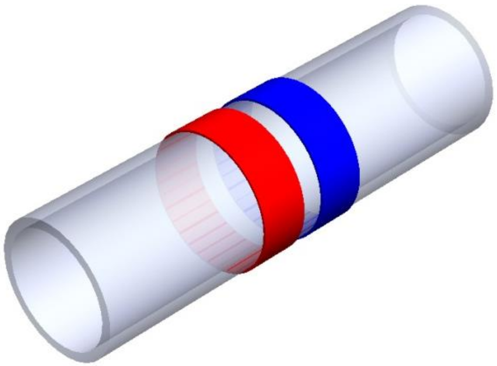
(Void fraction measurement of gas-liquid two-phase flow)

$$\alpha = \frac{V_g}{V}$$

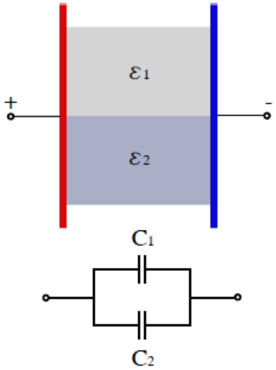
Agenda

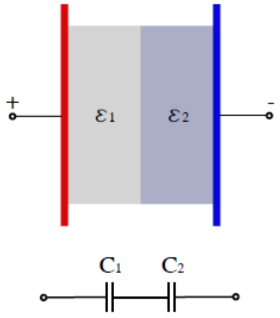
1 Problem description
2 Model description
3 Method
4 Numerical results
5 Experimental setup
6 Comparison of results
7 Conclusion

Ring-type capacitance sensor



Analytical approach
(Ideal plate capacitor)





QuickField

Optimization of sensor
(High sensitivity)

Calibration of sensor
(Non linear response)

Numerical approach

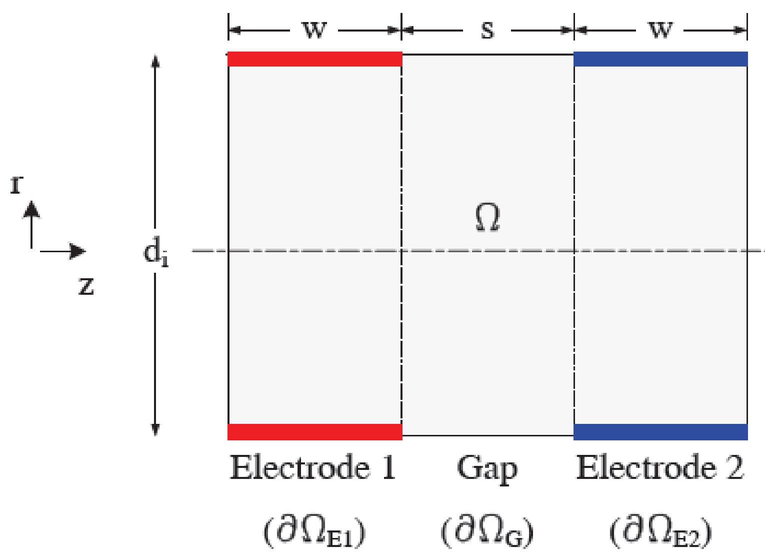
Assumptions in order to simplify problem description

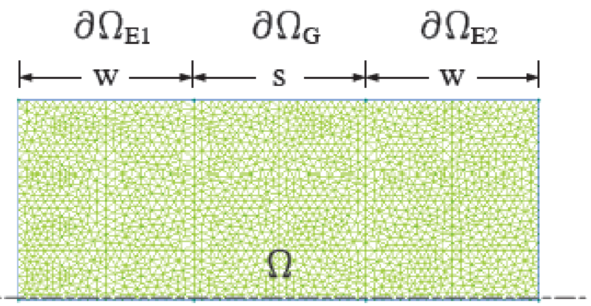
- Neglecting the effect of fringing field
- Constant relative permittivities
- No free charge in the domain
- Electrostatic approach
- Axis-symmetric geometry

Laplace's equation:

$$\frac{1}{r}\cdot\frac{\partial}{\partial r}\cdot\left(\varepsilon_r\left(r,z\right)\cdot r\cdot\frac{\partial\phi\left(r,z\right)}{\partial r}\right)+\frac{\partial}{\partial z}\cdot\left(\varepsilon_r\left(r,z\right)\cdot\frac{\partial\phi\left(r,z\right)}{\partial z}\right)=0$$

Numerical model: optimization of sensor in terms of sensitivity





$$Sensitivity = C_l - C_g$$

$$C = 2 \cdot \frac{W}{\Delta V^2}$$

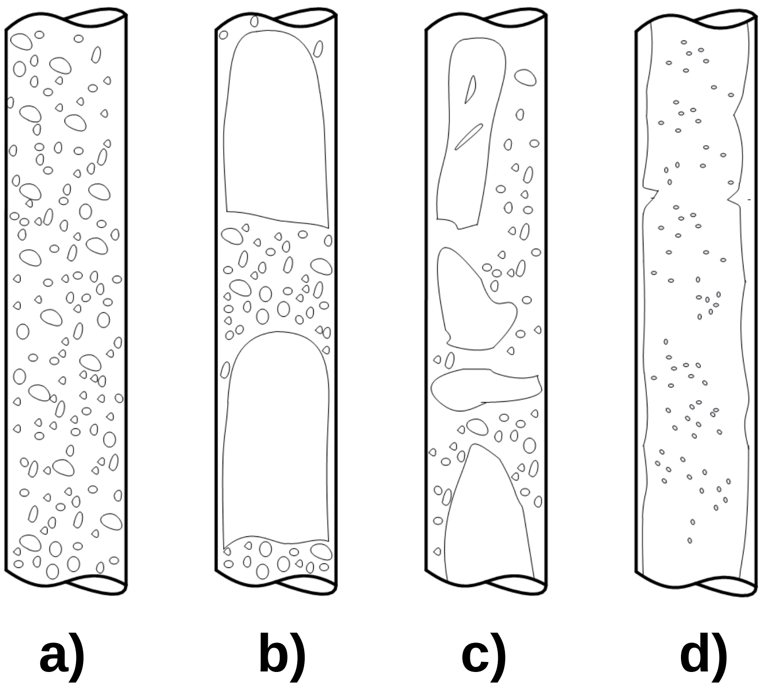
B.C.:

$$\phi(r,z) = \begin{cases} V_0 & (\partial\Omega_{E1}) \\ 0 & (\partial\Omega_{E2}) \end{cases}$$

$$\frac{\partial \phi(r,z)}{\partial r} = 0 \qquad (\partial\Omega_G)$$

$$\frac{\partial \phi(r,z)}{\partial z} = 0 \qquad (\text{left, right})$$

Numerical model: sensor output depending on flow pattern



a) Bubbly flow: Maxwell model

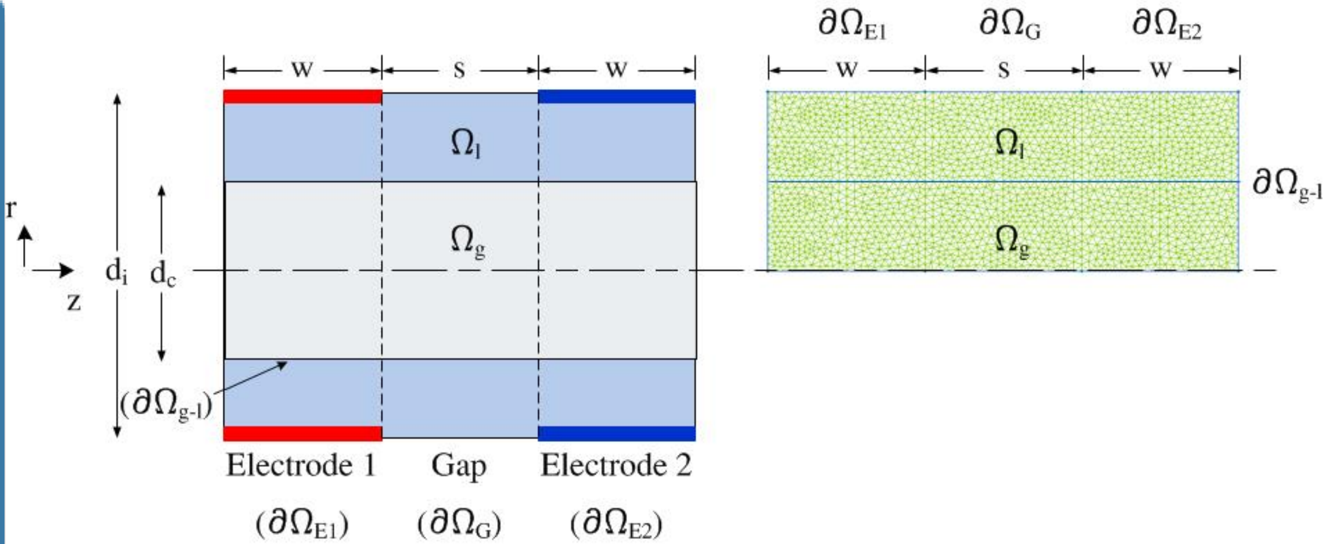
b) Slug flow

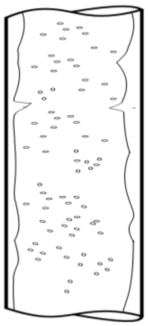
c) Churn flow

b) and c): Combination of a) and d)

d) Annular flow: gas core model

Numerical model: Annular flow

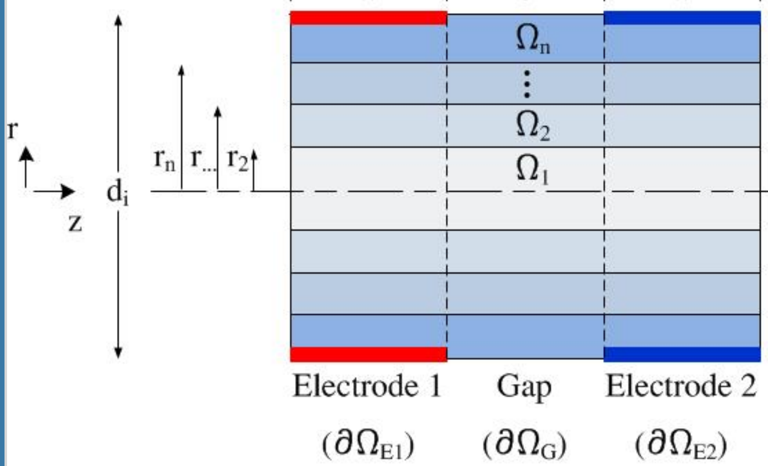


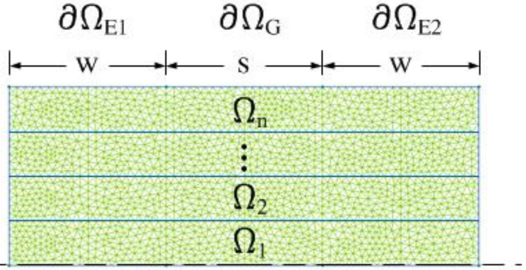


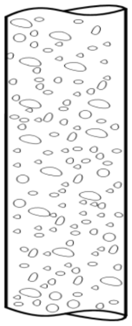
B.C.:

$$\varepsilon_l \cdot \left.\frac{\partial \phi(r,z)}{\partial z}\right|_{r=r_c} = \varepsilon_g \cdot \left.\frac{\partial \phi(r,z)}{\partial z}\right|_{r=r_c} \qquad (\partial \Omega_{g-l})$$

Numerical model: Bubbly flow







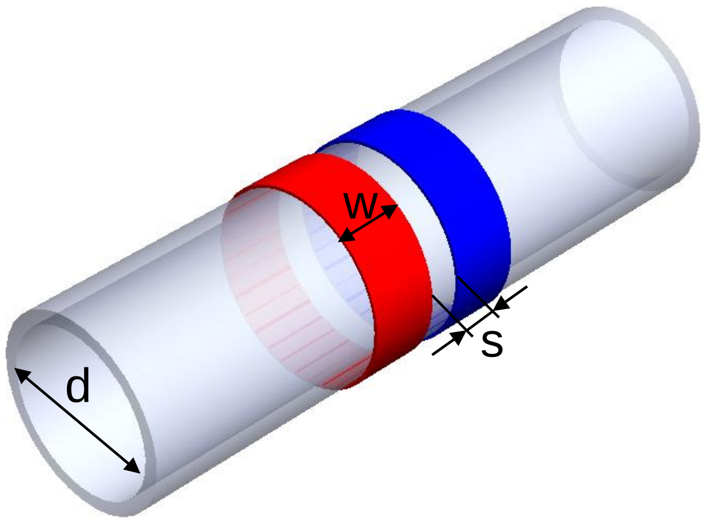
$$\alpha\left(\frac{r}{R}\right)=\langle\alpha\rangle\cdot\frac{n+2}{n}\cdot\left[1-\left(\frac{r}{R}\right)^{n}\right]$$

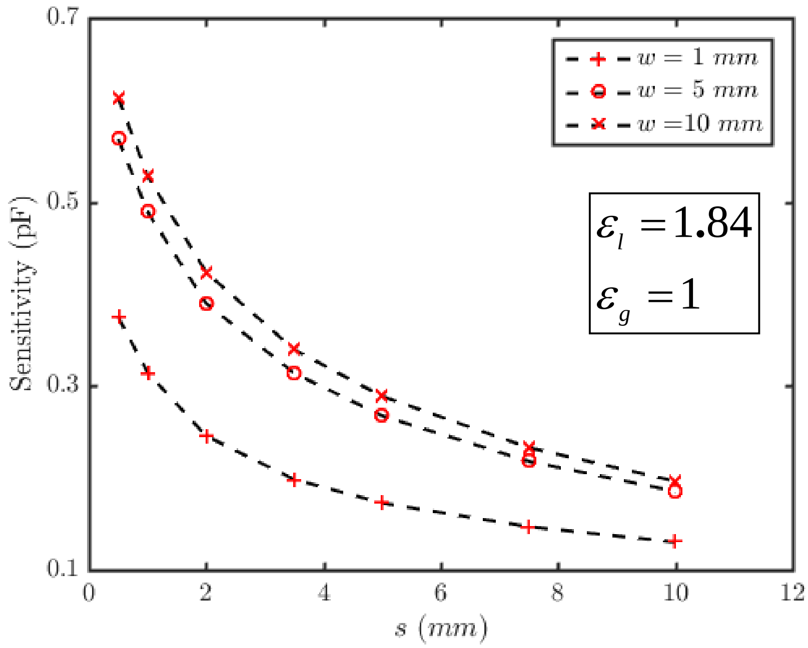
$$\varepsilon_m\left(\frac{r}{R}\right)=\varepsilon_l\cdot\frac{1+2\cdot\alpha\left(\frac{r}{R}\right)\cdot\frac{\varepsilon_g-\varepsilon_l}{\varepsilon_g+2\cdot\varepsilon_l}}{1-\alpha\left(\frac{r}{R}\right)\cdot\frac{\varepsilon_g-\varepsilon_l}{\varepsilon_g+2\cdot\varepsilon_l}}$$

Method: MATLAB as Automation Client

QuickField	**Basic configurations** (Problem type, model class, geometric model,…)
MATLAB	**Setting start parameters** (Physical and geometric properties)
MATLAB	**Serial analysis** (Physical and geometric properties)
QuickField	**Solving problems** (Simulation of cases and solution)
MATLAB	**Evaluation of data** (Calculation of capacitance, graphs,…)

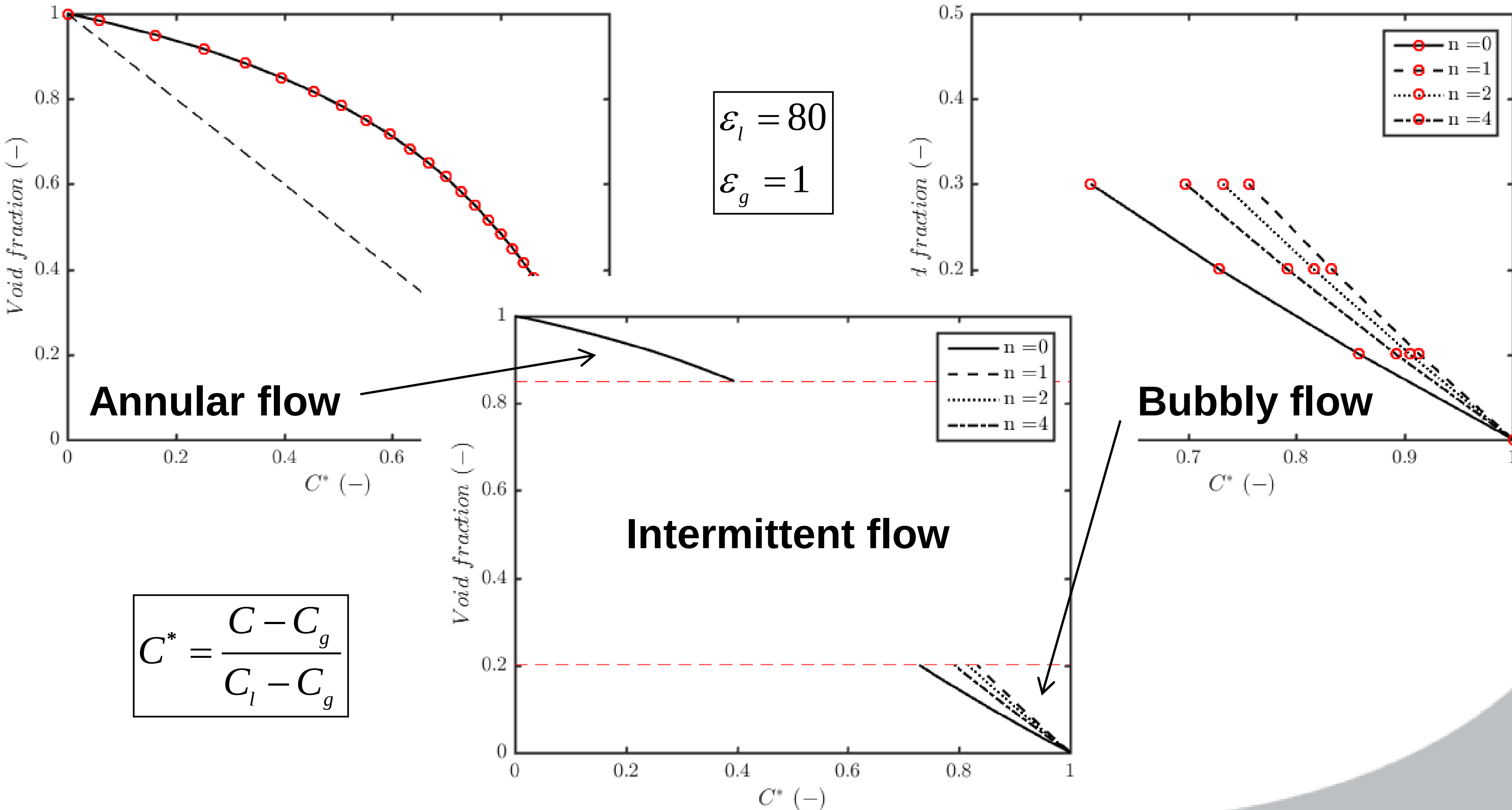
Numerical results: Optimization





Design parameters: $\frac{w}{d}=0.42 \quad \frac{s}{d}\leq 0.08$

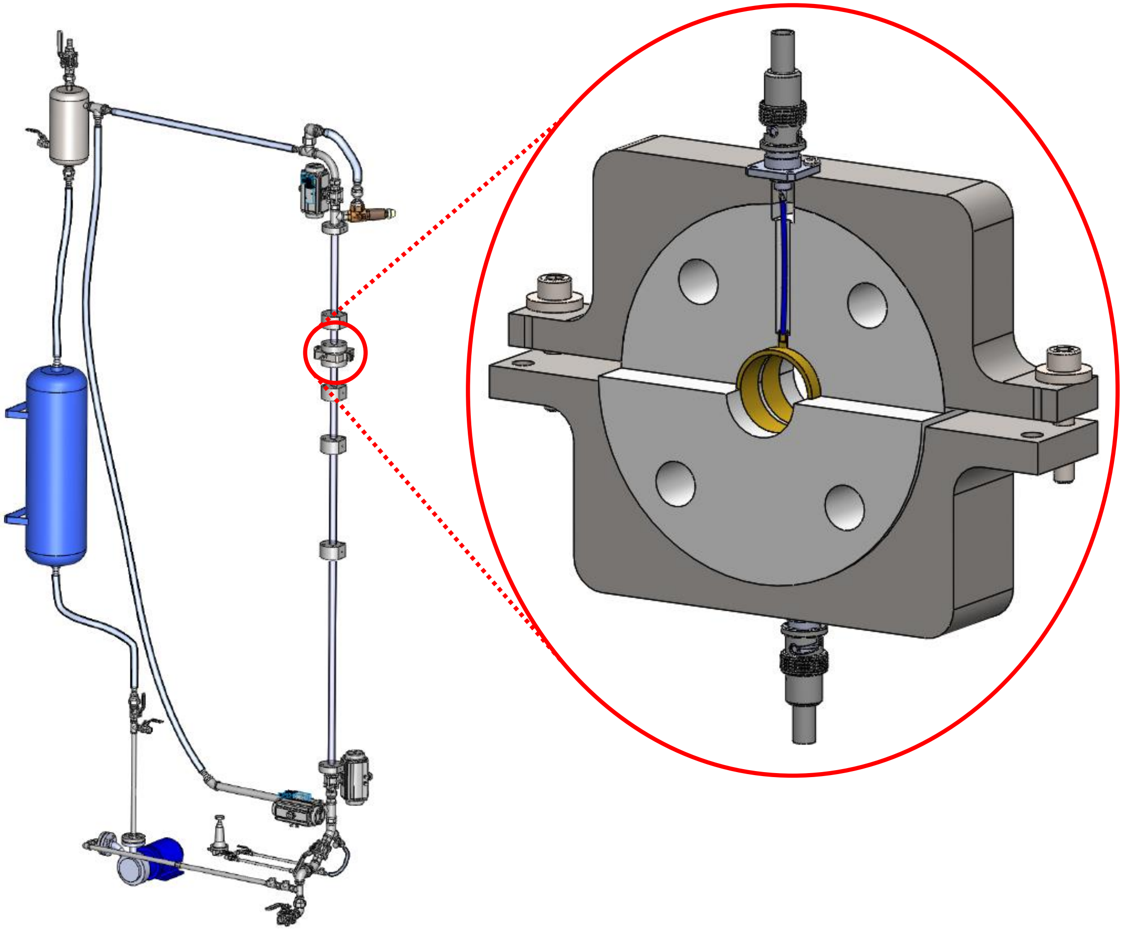
Numerical results: Calibration curve for distilled water



$$\varepsilon_l = 80$$
$$\varepsilon_g = 1$$

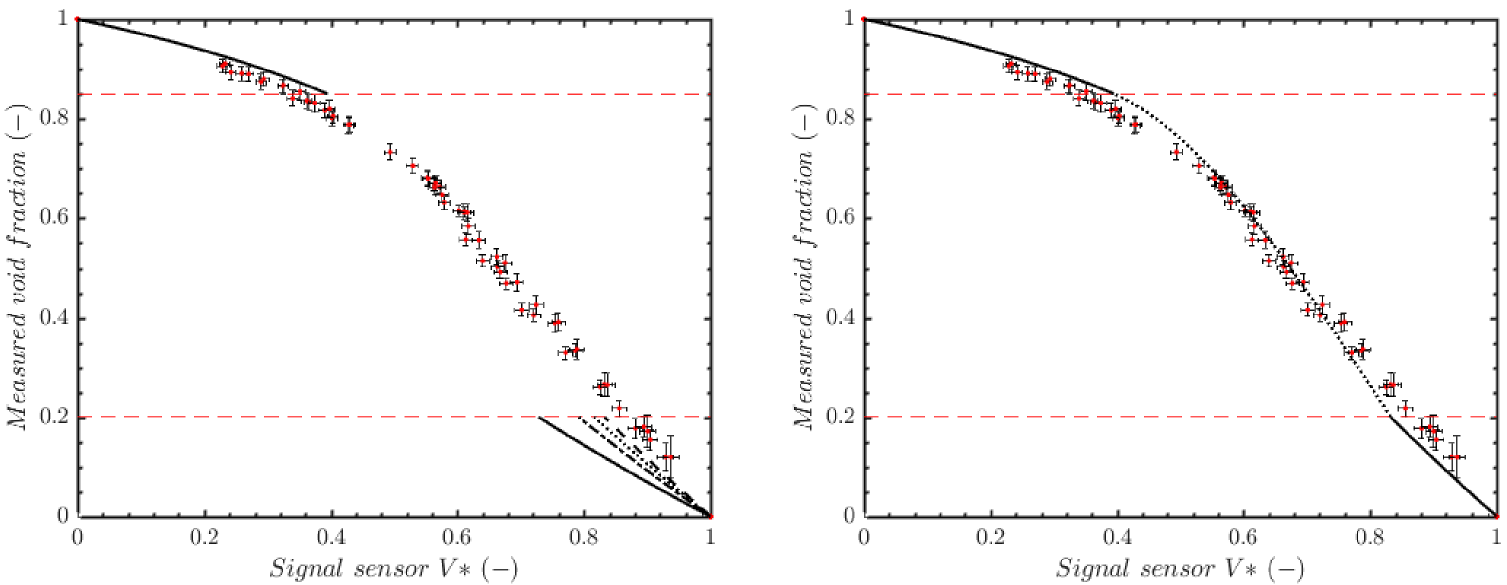
$$C^* = \frac{C - C_g}{C_l - C_g}$$

Experimental setup: sensor and test rig



- Ring-type capacitance sensor with shielding
- Boonton 72 BD capacitance meter
- Dynamic experiments based on air-distilled water two-phase flow
- Quick-closing valves as calibration standard

Comparison of experimental and numerical results



$$V^* = \frac{V - V_g}{V_l - V_g}$$

- **Numerical model follows the trend of the experimental results.**
- **Linear void profile yields most accurate results for bubbly flow.**
- **Overall RMSE of numerical model is 0.033.**
- **Maximum deviation of numerical model is 0.08.**

Conclusions

- QuickField was used to optimize and calibrate a capacitance void fraction sensor.
- Simple and fast serial analysis using QuickField along with MATLAB.
- The numerical results agree well with experimental data of air-distilled water tow-phase flow.
- Applicability of models to other fluids and geometric configurations of the sensor?

References

For detailed information and further literature I would like to refer to my thesis, which will be published soon:

Development and construction of a System for the Measurement of the Void Fraction and Frictional Pressure Drop in a Two-Phase Closed Loop Thermosyphon