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Liquid properties effects on Coriolis and thermal mass flow meters at very low flow rates

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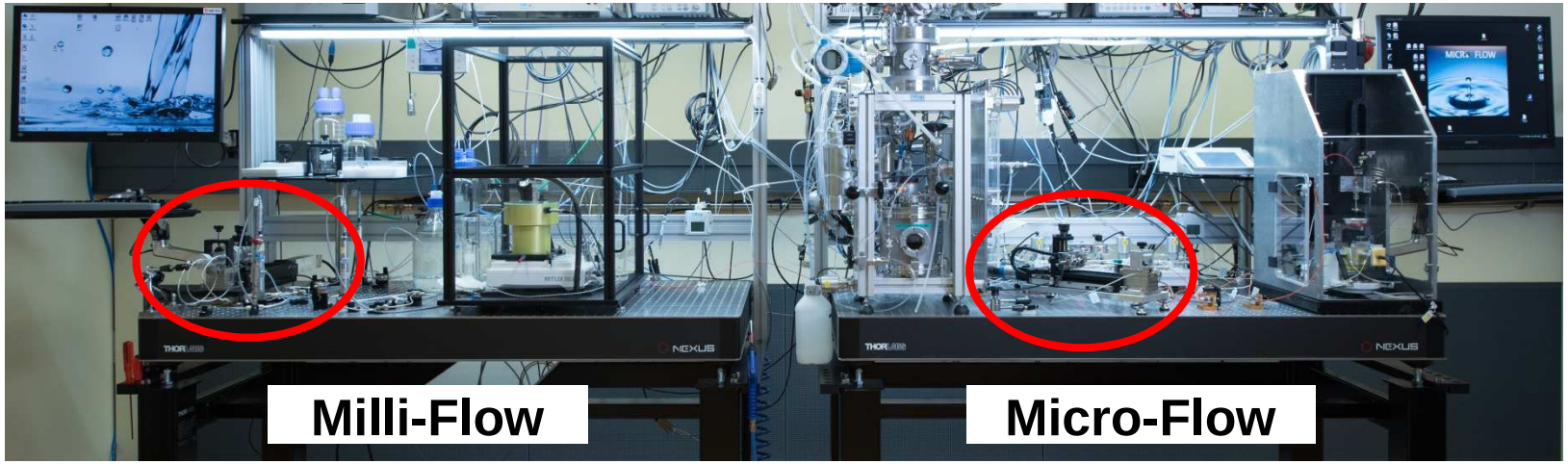
Agenda

1. METAS piston provers
2. Liquids and flow meters
3. Thermal mass flow meter and aqueous solutions
4. Conclusion

METAS Piston Provers

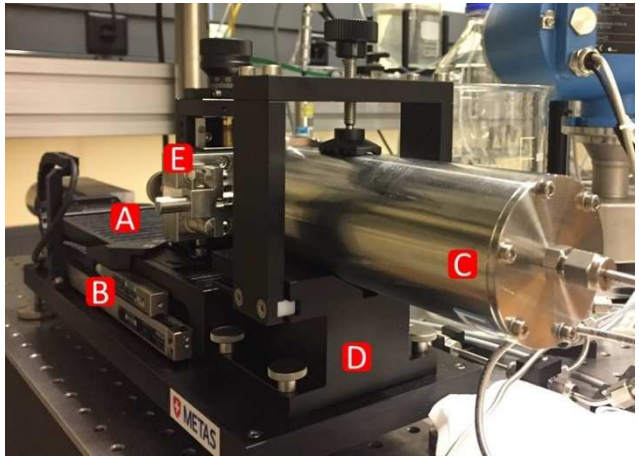


- **Flow rates: 50 nl/min – 400 ml/min (3 µL/h – 24 L/h)**
- **Pressure range: 0 – 8 bar**
- **Temperature: room temperature (22°C)**
- **Uncertainty: 1.0 % – 0.07 % (steady flow rate)**

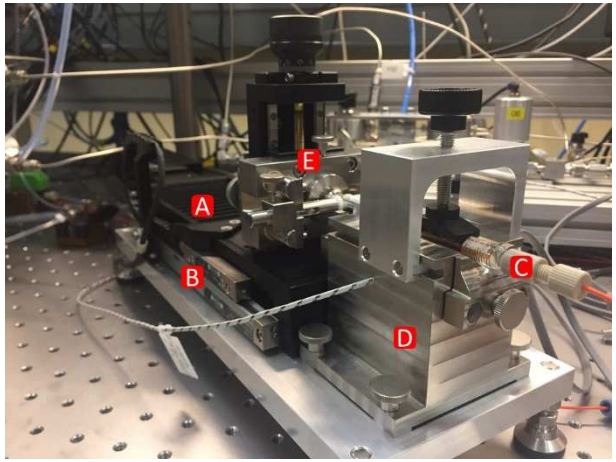
METAS Piston Provers

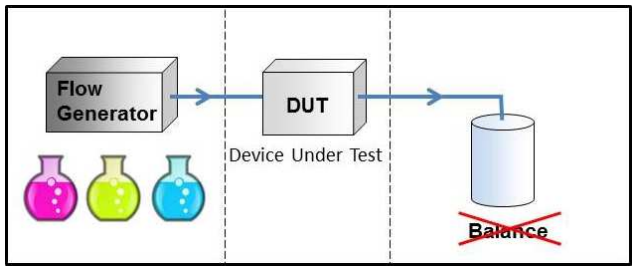
- The speed range for the METAS piston prover

Milliflow facility
4.0 mm/s – 4.0 µm/s



Microflow facility
0.1 mm/s - 0.1 µm/s





Speed * Cross-section = Volume flow rate

Liquids and flow meters

- Liquid properties at approximately 21.4 °C

Property	Water	Reference oil 2BW [1]	Reference oil 5BW [1]	Reference oil 10AW [1]
Dyn viscosity η ($kg \cdot m^{-1} \cdot s^{-1}$)	$0.9624 \cdot 10^{-3}$	$2.361\ 10^{-3}$	$5.903\ 10^{-3}$	$8.419\ 10^{-3}$
Spec. heat capacity c_p ($J \cdot kg^{-1} \cdot K^{-1}$)	4184	2130	2067	2046
Th. conductivity λ ($W \cdot m^{-1} \cdot K^{-1}$)	0.600	0.143	0.151	0.147
Density ρ ($kg \cdot m^{-3}$)	997.9	767.5	796.4	805.9

[1] the reference oils are commercially available at https://zmk-wolfen.de/, ZMK & ANALYTIK GmbH in Germany

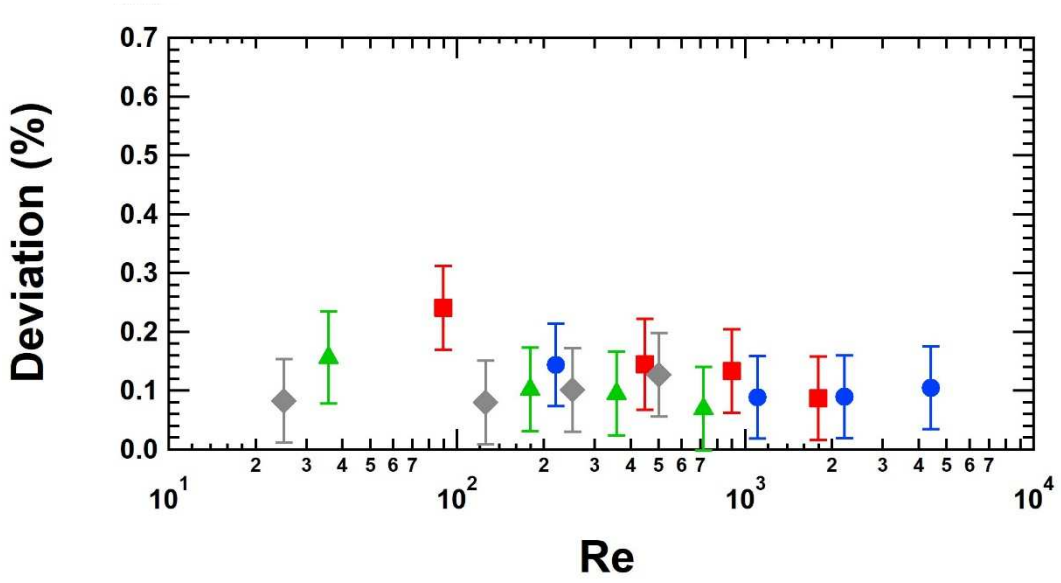
Liquids and flow meters

- Flow meters

Flow meter	Type	Flow rates
Cubemass DCI DN01 *Endress+Hauser AG*	Coriolis	200.0 g/min 100.0 g/min 50.0 g/min 10.0 g/min
miniCori M12 *Bronkhorst High-Tech B.V.*	Coriolis	3.3 g/min 1.0 g/min 0.3 g/min 0.1 g/min
SLI-0430 *Sensirion AG*	Thermal	100 µl/min 40 µl/min 20 µl/min 10 µl/min 5 µl/min

Liquids and flow meters

- *Cubemass DCI DN01, Coriolis flow meter*

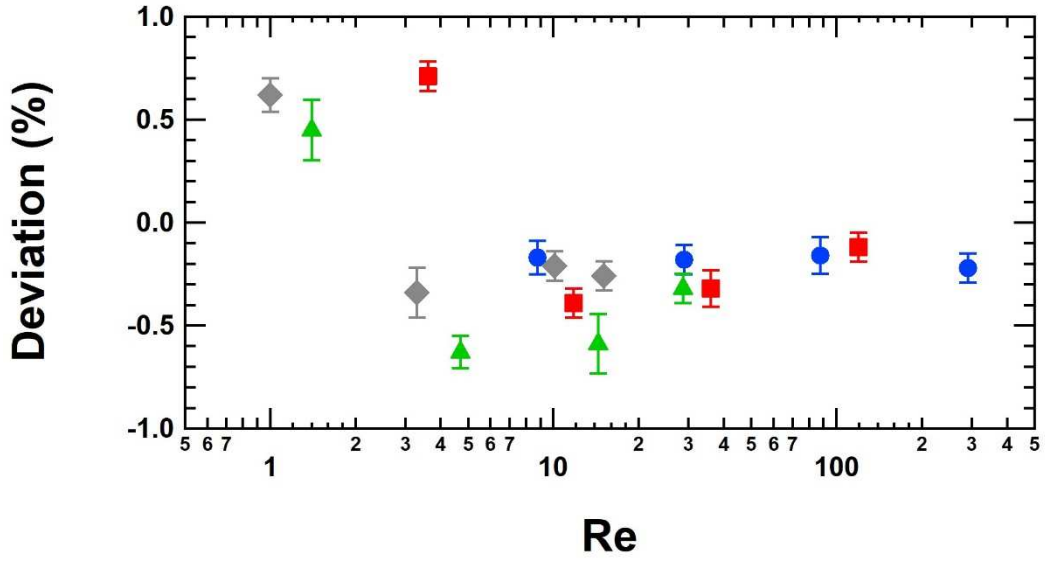


Zero flow correction

- Water 1.0 mPa*s
- liquid 2BW 2.4 mPa*s
- liquid 5BW 6.0 mPa*s
- liquid 10AW 8.4 mPa*s

Liquids and flow meters

- *miniCori M12, Coriolis flow meter*



Zero flow correction

- Water 1.0 mPa*s
- liquid 2BW 2.4 mPa*s
- liquid 5BW 6.0 mPa*s
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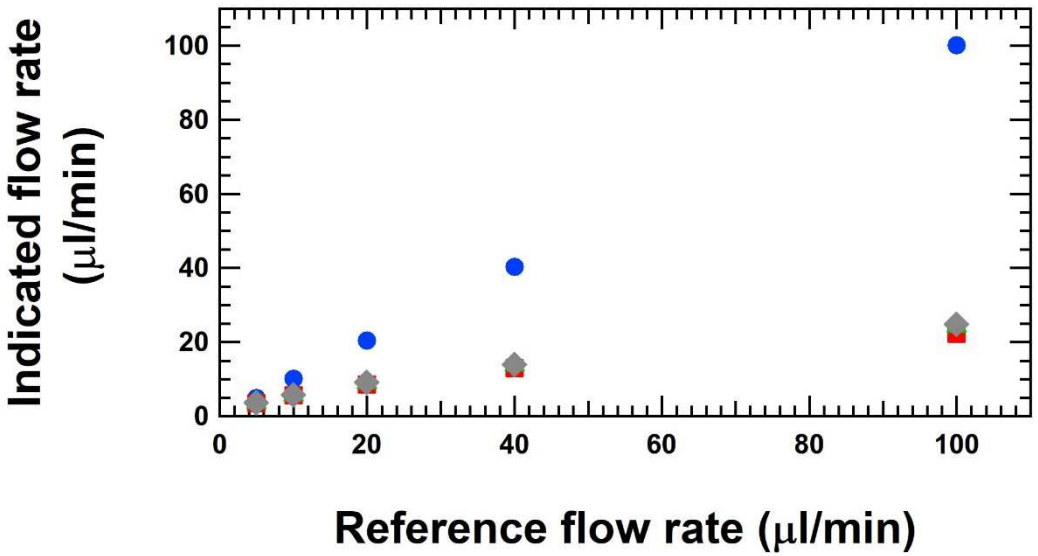
Liquids and flow meters

- *SLI-0430, thermal flow meter*



Water	1.0 mPa*s
liquid 2BW	2.4 mPa*s
liquid 5BW	6.0 mPa*s
liquid 10AW	8.4 mPa*s

- Scaling seems to be complicated.
- Many different regimes in theory.
- Manufacturer calibrates flow meter with water and IPA. Parameters are stored in HW.

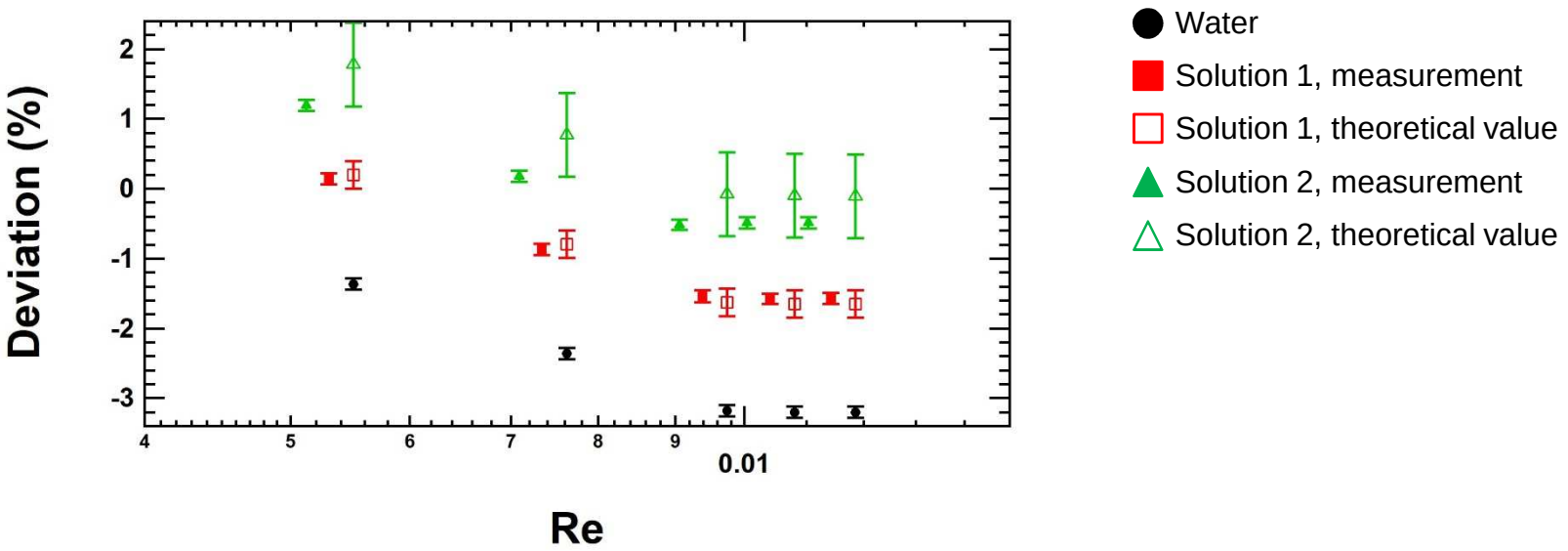
Liquids and flow meters

- *SLI-1000, thermal flow meter with aqueous solutions*
- Liquid properties at 20.0 °C

Property	Water	Etanol	Solution 1 (1.1 %wt EtOH)	Solution 2 (2.2 %wt EtOH)
Dyn viscosity η ($kg \cdot m^{-1} \cdot s^{-1}$)	$1.002 \cdot 10^{-3}$	$1.189 \cdot 10^{-3}$	$1.040 \cdot 10^{-3}$	$1.078 \cdot 10^{-3}$
Spec. heat capacity c_p ($J \cdot kg^{-1} \cdot K^{-1}$)	4184	2430	4164.7	4145.9
Th. conductivity λ ($W \cdot m^{-1} \cdot K^{-1}$)	0.600	0.200	0.596	0.591
Density ρ ($kg \cdot m^{-3}$)	998.21	789.34	996.18	994.17

Liquids and flow meters

- *SLI-1000, thermal flow meter with aqueous solutions*



For the anemometric regime with flow rates larger than 2 g/h (33 µl/min), $P_{heater} \sim q_m^{0.33}$. Assuming that the heater power is linearly dependent on the heat capacity of the liquid, the conversion factor should be:

$$q_{m,Sol} \cong q_{m,H2O} \cdot \left(c_{p,H2O}/c_{p,Sol}\right)^3$$

And for volume flow rate (q_V) we get:

$$q_{V,Sol} \cong q_{V,H2O} \cdot \left(\rho_{H2O}/\rho_{Sol}\right) \cdot \left(c_{p,H2O}/c_{p,Sol}\right)^3$$

Liquids and flow meters

- *Thermal mass flow meter*
  - **Estimating a scaling behavior** for the reference oils with the sensor parameters set to the water calibration turned out to be a very **difficult task**.
  - Thermal mass flow meters are calibrated with
    - **Water** for applications with aqueous liquids
    - **IPA** for applications with hydrocarbons

    Scaling behavior applicable

- Importance of **calibrating the flow sensor with the process-oriented liquid** that will be used for the measurements.

Conclusion

- **No obvious dependency** on viscosity for the Coriolis mass flow meters (small diameters)
- The thermal mass flow meters showed obviously **strong dependencies on the thermal properties of the liquids**.
- **Estimating a scaling behavior** for the reference oils with the sensor parameters set to the water calibration turned out to be a very **difficult task**.
- The calibrations of a thermal mass flow meter with water and aqueous solutions offered **a scaling behaviour**.
- No effect of the viscosity on the thermal mass flow meter performance could be investigated.
- Importance of **calibrating the flow sensor with the process-oriented liquid** that will be used for the measurements. This will increase the quality of the measurements results and considerably decrease the uncertainty.

Thank you very much for your attention