Physikalisch-Technische Bundesanstalt
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Ultrasonic Flowmeter for flow rates below 100 l/h

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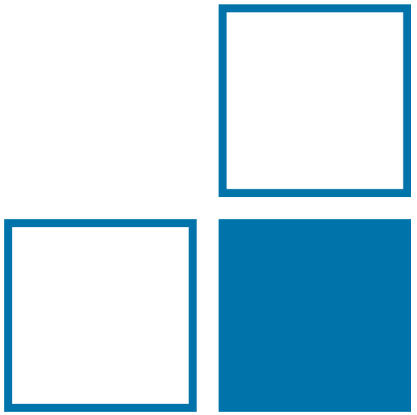


Overview

- motivation
- USM for pipeline application
- principle of capillary USM
- results
- conclusion

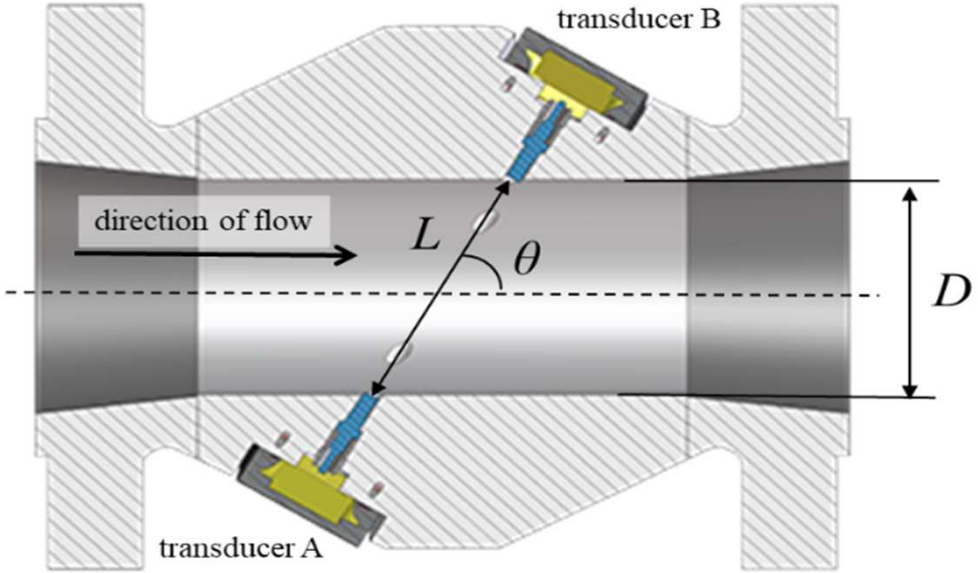
Motivation

- mechanical meters are available for Qmax of 10 000 l/h, but turn-own ratios of more than 1:100 are hardly to achieve, e.g. positive displacement meter
- drum-type gas meters able to measure flow rates down to 15 l/h but difficult to handle (oil as sealing liquid, long measuring times needed because of usage of complete revolution)
- diaphragm gas meter don't provide sufficient repeatability,
- electronic meter like laminar flow elements and thermal gas meter are quite sensitive to gas composition

→ Ultrasonic meter might provide some advantages used as transfer standard in particular for flow rates below 100 l/h

- diagnostics functionality
- speed of sound monitoring
- wide pressure range applicable may be used

Principle of pipeline ultrasonic meters (USM)



$$t_{AB} = \frac{L}{c + v\cos\theta}$$

$$t_{BA} = \frac{L}{c - v\cos\theta}$$

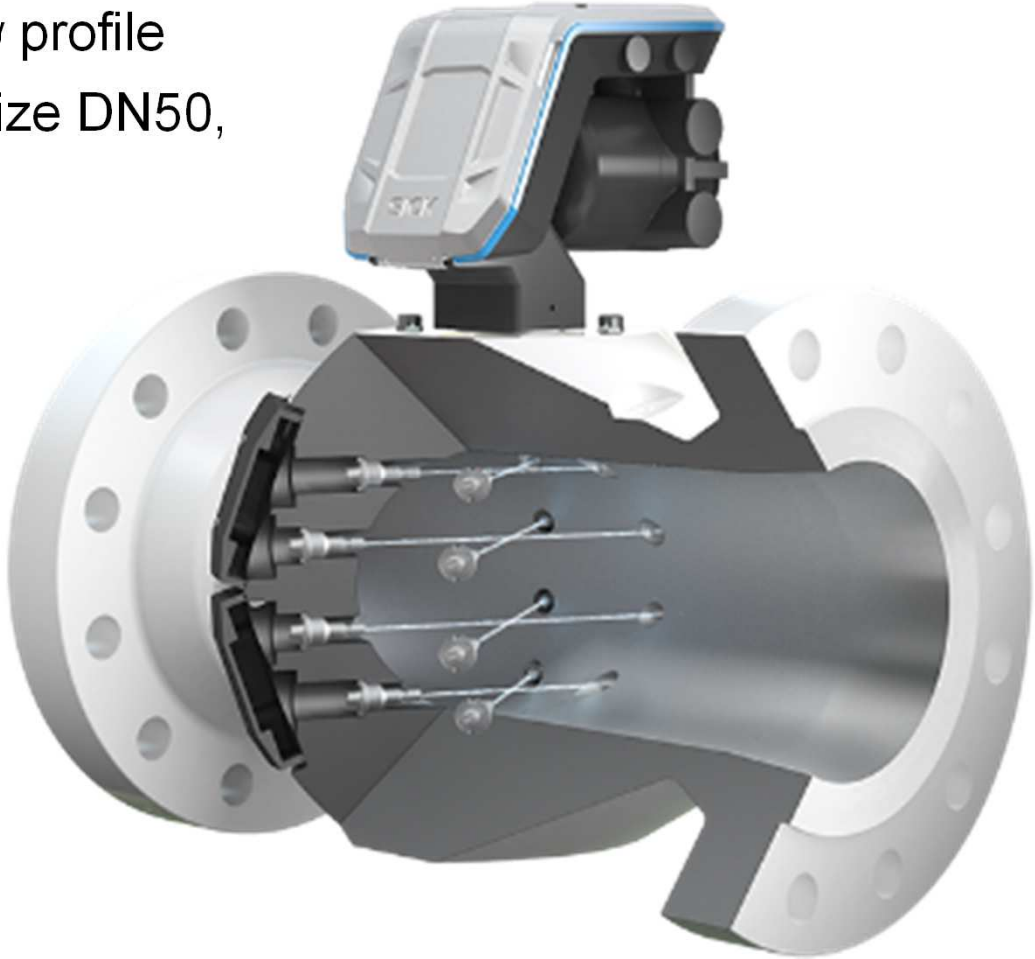
$$v_{path} = \frac{L}{2\cos\theta}\left(\frac{1}{t_{AB}} - \frac{1}{t_{BA}}\right)$$

$$c_{path} = \frac{L}{2}\left(\frac{1}{t_{AB}} + \frac{1}{t_{BA}}\right)$$

- don’t disturbe the pipe diameter
- low pressure loss
- in case of high gas velocity → sound waves are blown away

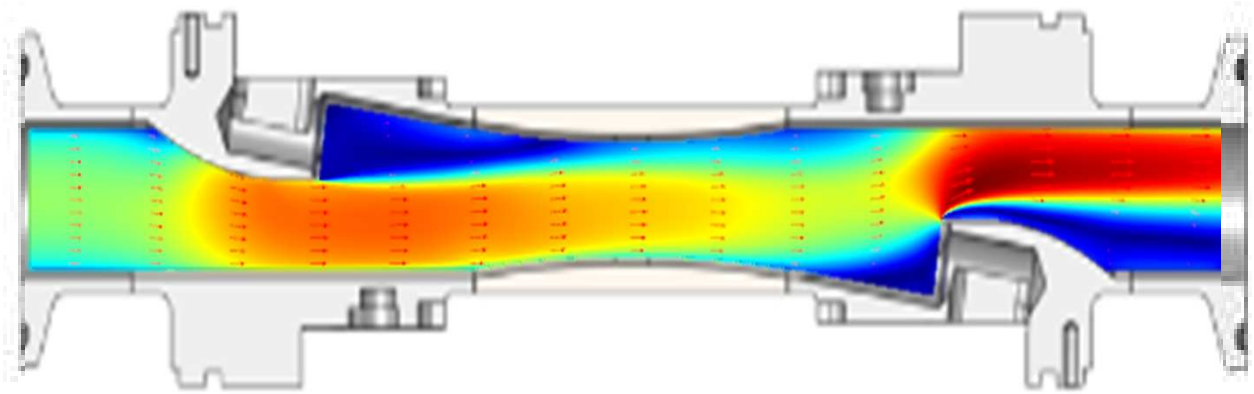
Example of standard USM

- Standard configuration with 4 path levels
- 8 path lay out allows distinction between swirl and asymmetry in the flow profile
- smallest multi-path meter are size DN50, still Qmax 160 000 l/h



Drawing of a USM FLOWSIC600-XT

geometrical restrictions for USM



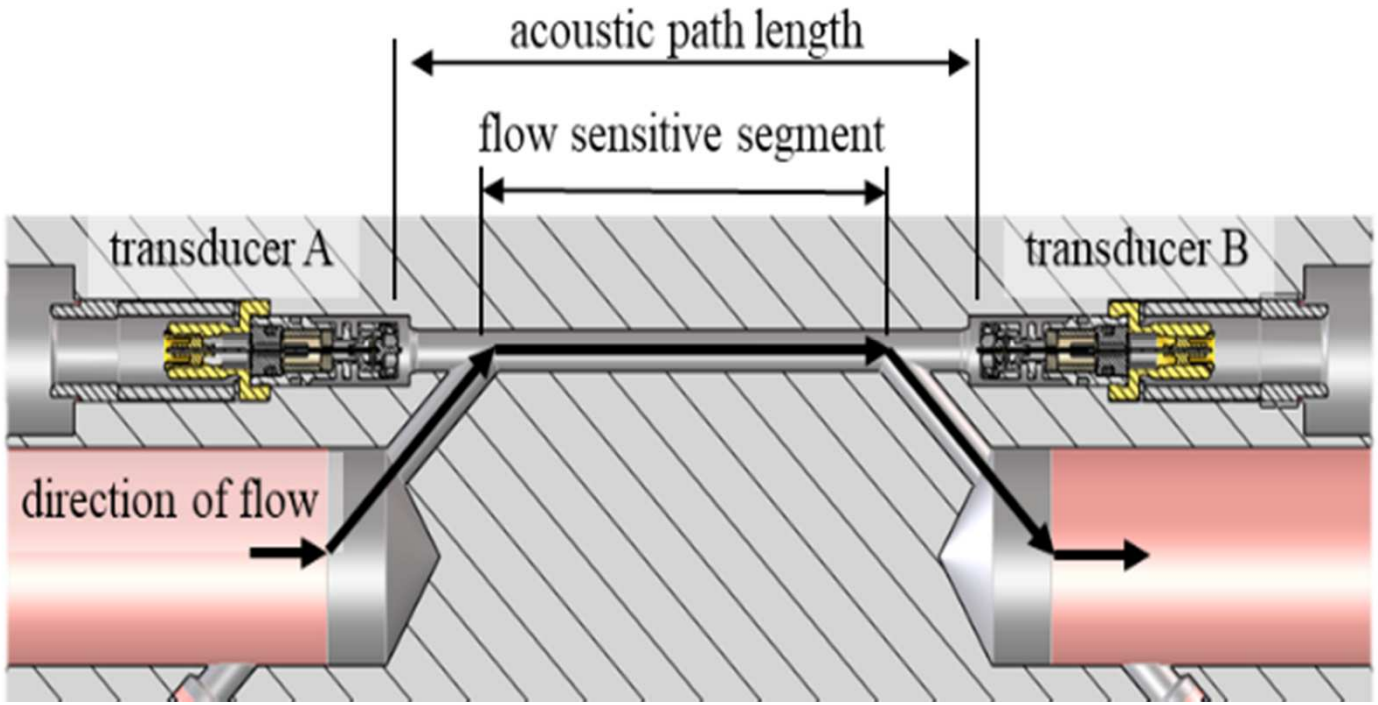
example of a DN25, single path, liquid USM

- Inclined arrangement of multi- and even single paths layouts difficult to design below DN 50
  - minimum required path length for sufficient time resolution
  - fixed dimension of the transducer for reasonable signal frequency

- flow rate of less than 1000 l/h need pipe diameters of some millimeters only

Principle of capillary USM

transducer arrangement in line with the measuring section provides freedom in respect to diameter and path length



first prototype shall be based on available standard transducers (135kHz) and signal processing electronics

Properties of signal propagation

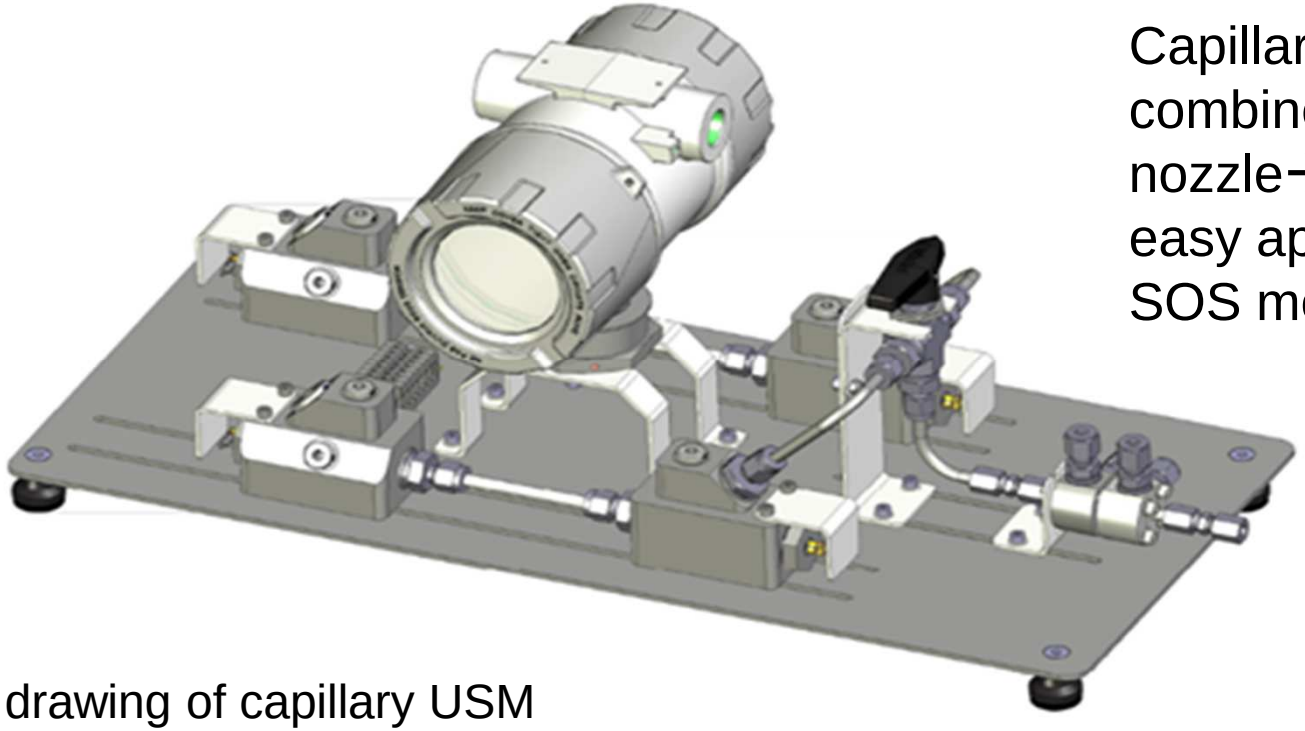
- in dependency of capillary diameter different wave modes can propagate
- for simplicity of signal processing we aimed for the propagation of the 1st mode only

	Nitrogen	Methan	Hydrogen
Speed of sound [m/s] @ 101kPa, 20°C	349,1	445,0	1304,1
f_cut-on [kHz], Di 4mm	51,1	65,2	191,1
Dmax_f(1,1) [mm]	1,5	1,9	5,7
$q_{V,max}$ [l/h] @ 33m/s	214	348	2991

$$f_{\mathrm{cut-on}} = \frac{1.84118}{\pi D} c \sqrt{1 - \left(\frac{v}{c}\right)^2}$$

in case of f_{sound} = 135 kHz and v_{max} = 33 m/s
a inner pipe diameter of 4 mm chosen for reasonable Q_{max} of up to 1000 l/h

Design of capillary USM



drawing of capillary USM

Capillary USM may be combined with critical nozzle→ this allows easy application as an SOS monitor

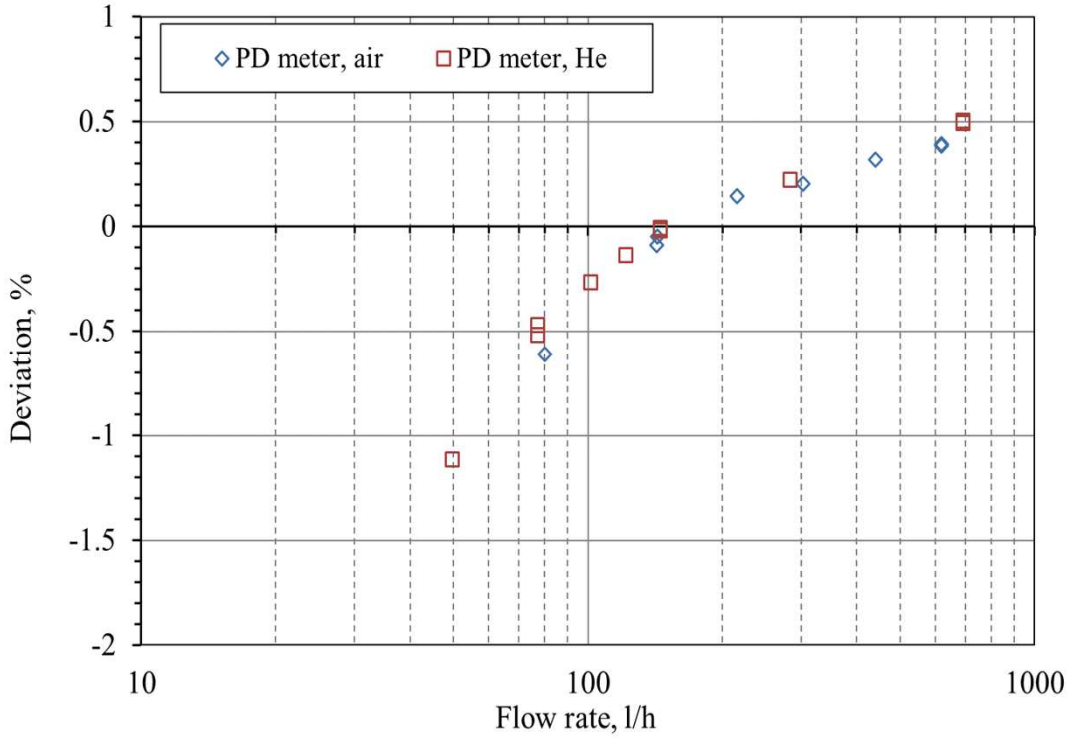
- 2-path electronics allows for 2 different capillary diameters and length
- small diameter → reduction of Q_{max} and Q_{min} respectively
- long capillary→ reduction of Q_{min} because of reduced influence of zero point noise but reduced signal power at receiver

Test setup

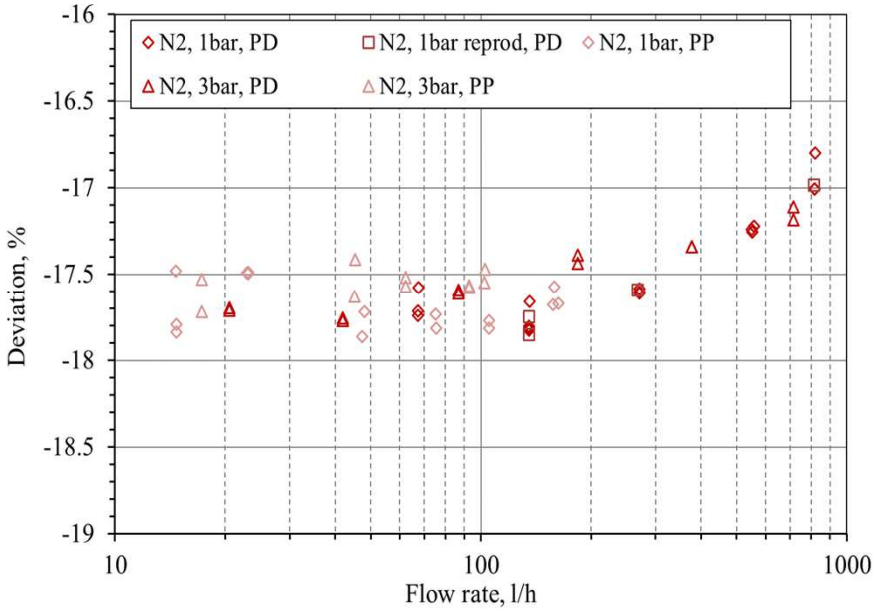
Facility for flow rates determination with mercury sealed piston provers and interferometric velocity measurement

- pipe diameter of 144 mm, 44 mm and 19 mm
- independent to gas composition
- up to 600 l/h
- min. 0.1 l/h
- U = 0.15% (k=2)

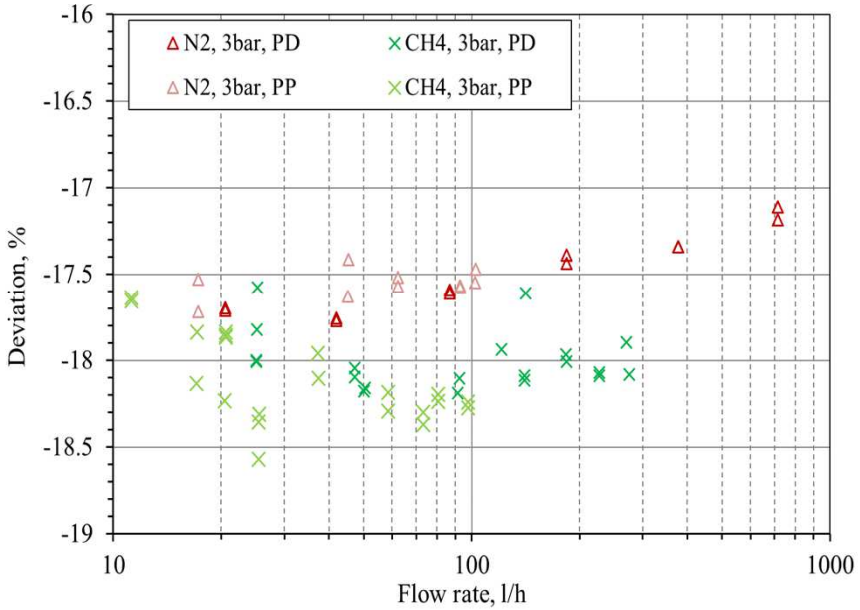
- for higher flow rates a positive displacement meter was applied



Results of the capillary USM



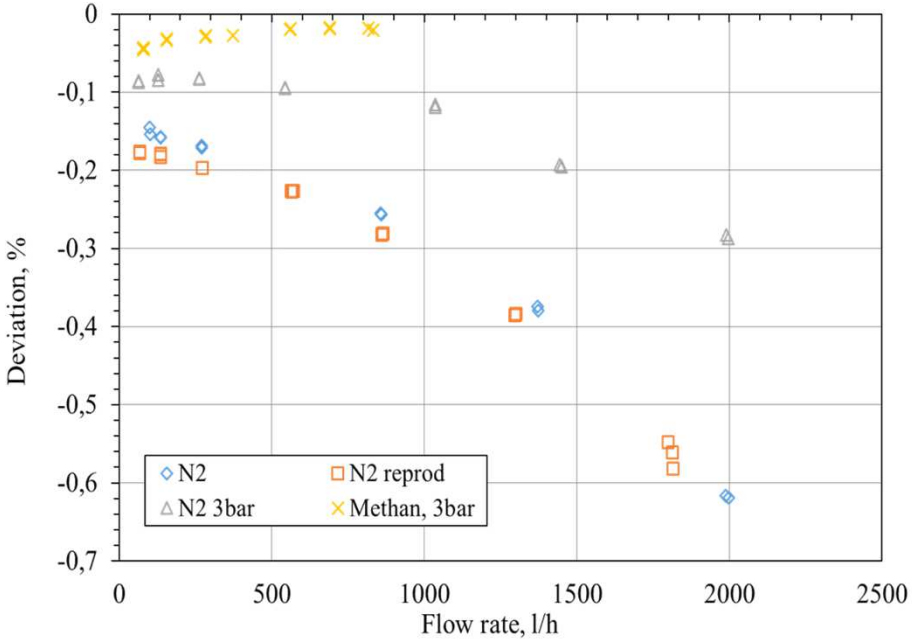
Results with nitrogen with p_{USM} ≈ 1bar and p_{USM} ≈ 3bar)



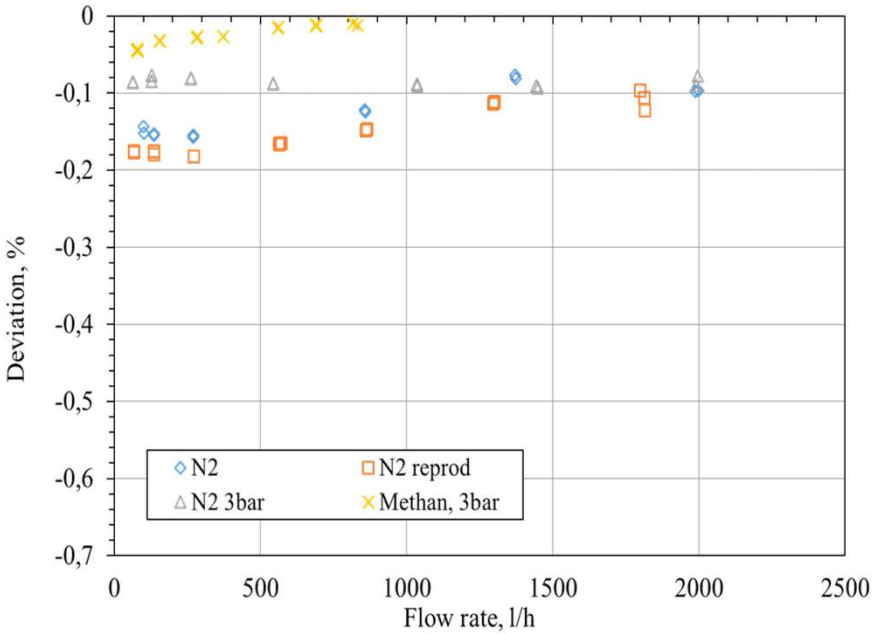
Results with nitrogen and methane (p_{USM} ≈ 3bar)

too weak ultrasonic signals due to the acoustic signal attenuation in methane at 1 bar and a path length of 323 mm

Measurement of speed of sound



Speed of sound deviation from theoretical value (with Mach-number correction for inclined design)

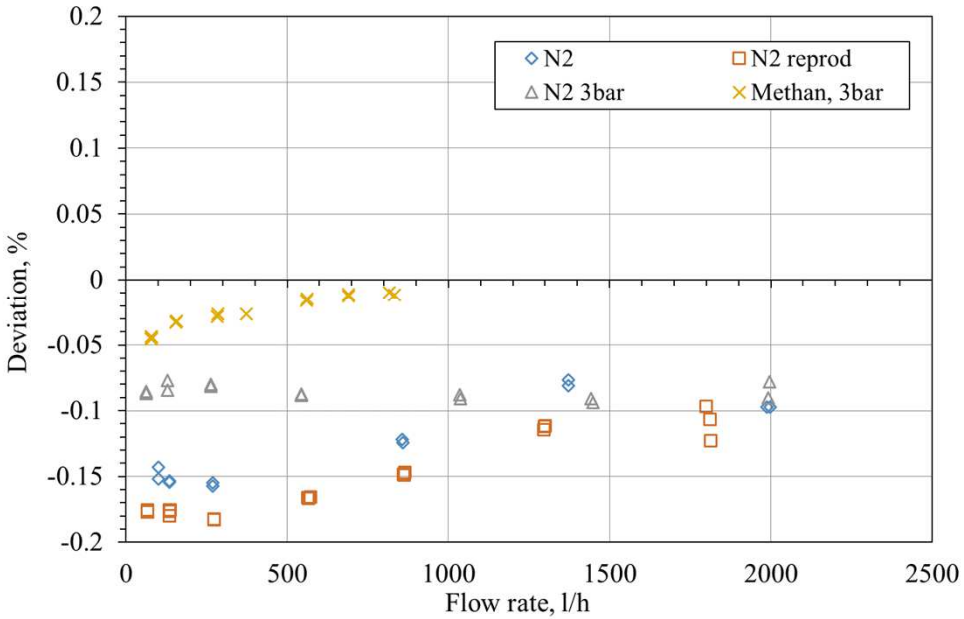


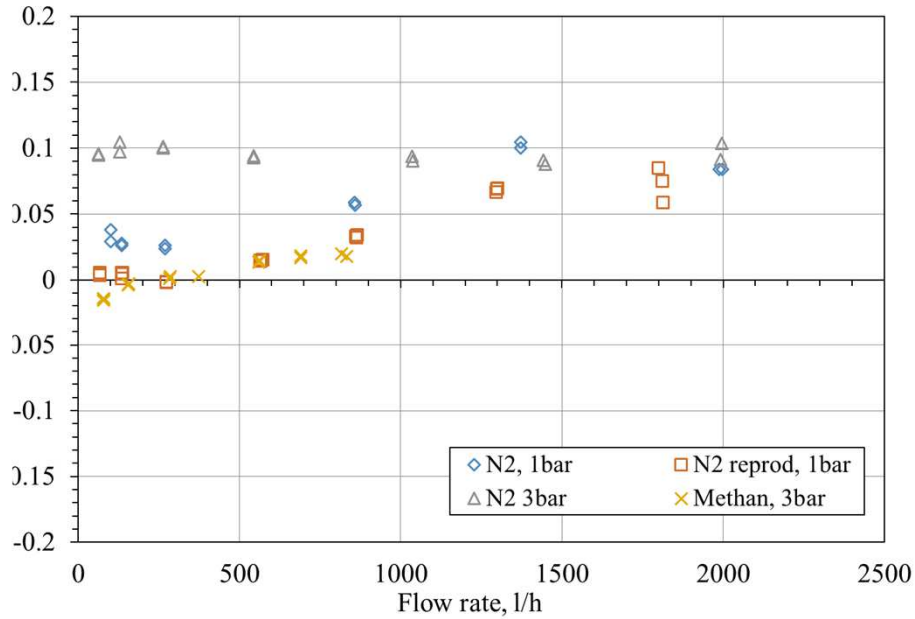
Speed of sound deviation from the theoretical value (based on signal travel time measurement)

$$c' = \frac{c}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$$

Speed of sound correction based on Mach number for pipeline USM (inclined pathes)

Correction



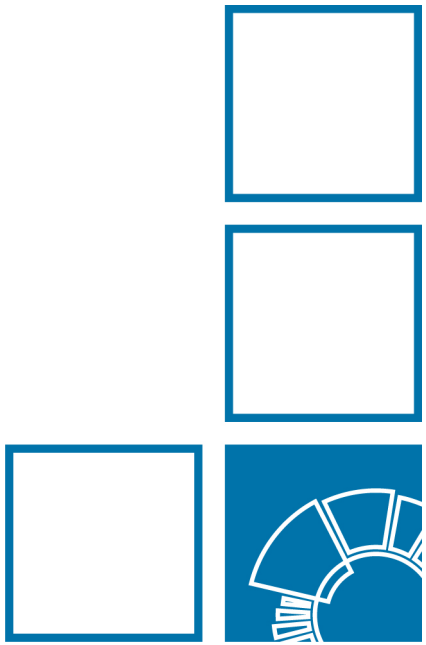


- Speed of sound deviation from the theoretical value without consideration of the ultrasonic signal burst frequency
- needs to be considered especially for gases with relaxiation effect, e.g. CH_4, CO_2

- Speed of sound deviation corrected by considering the burst frequency at methane (0.9m/s @ 135 kHz)

Conclusion

- the described prototype has shown the applicability of a capillary USM for flow rate measurements
- flow rate range down to 10 l/h was reached with different gases
- good linearity and repeatability for low flow rates compared to the positive displacement meter
- capillary USM is usable as speed of sound monitor
- further investigation needed to sort out the remaining issues regarding to different gases



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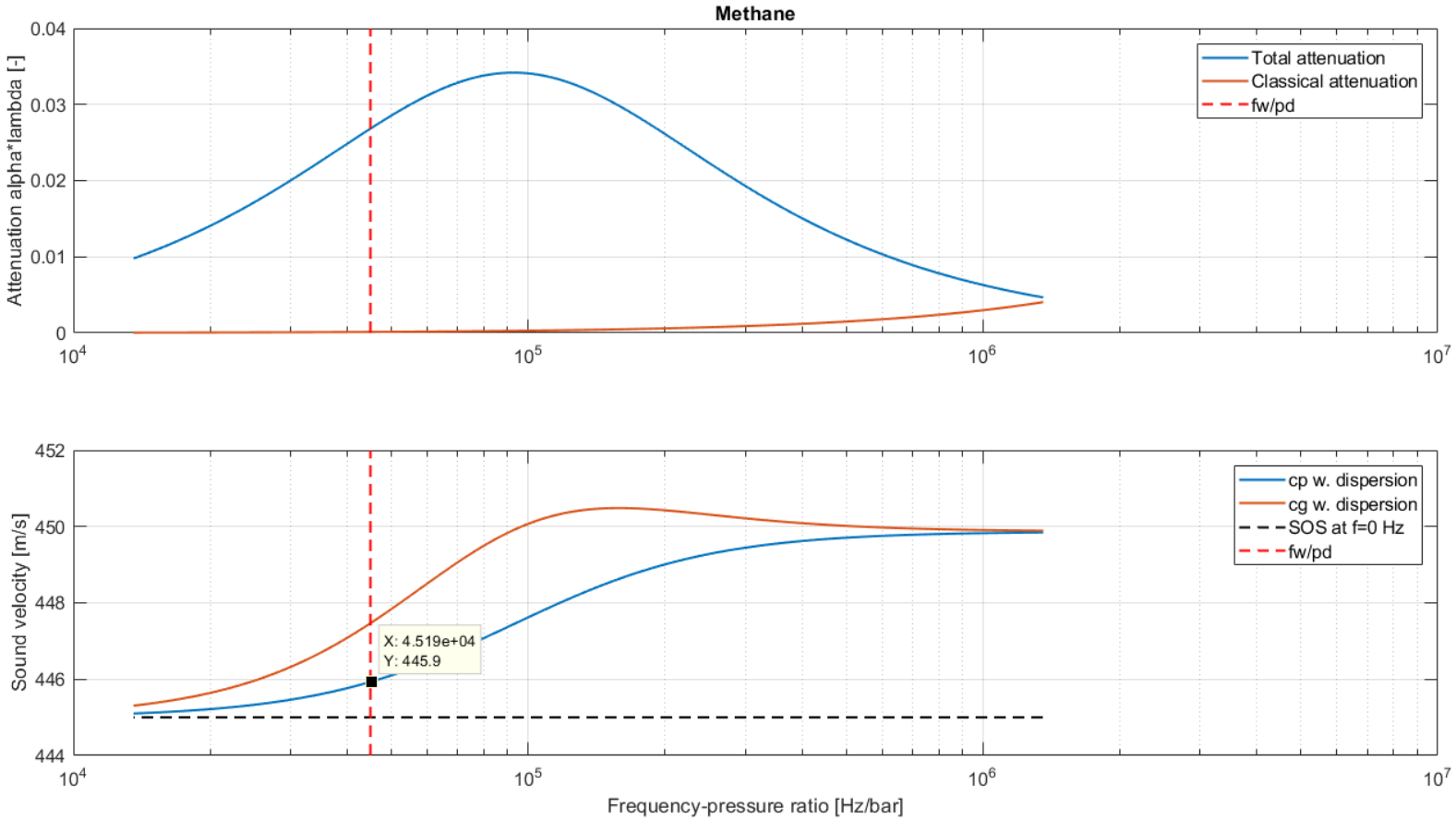
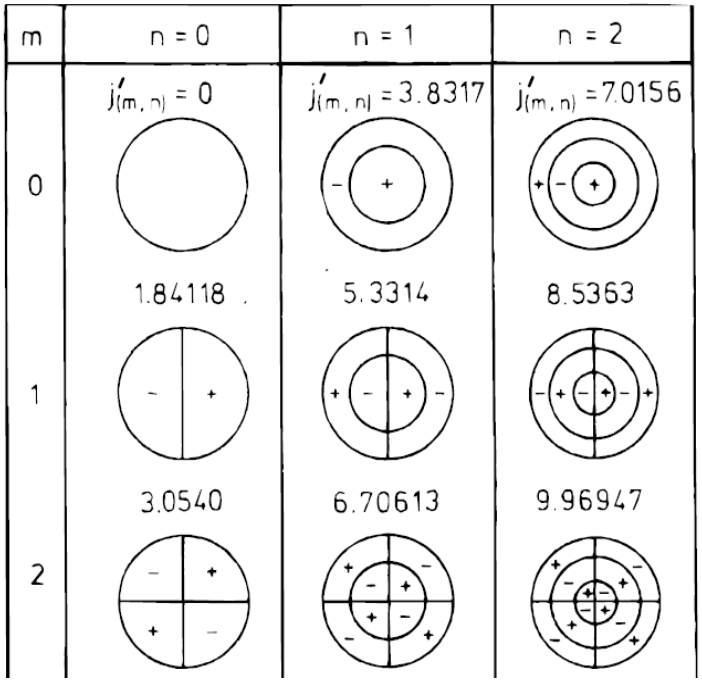
Analysis Methan



Mode propagation in capillaries



- Increasing diameter of capillary allow propagation of different modes
- In case of propagation of different modes in the capillary the signal at the receiver sensor is a mixture of different fast waves
- In case of sufficient small diameter only propagation along capillary axis is possible