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Are liquid ultrasonic flowmeters independent of fluid properties?

Pico Brand and Jan G. Drenthen

Pico Brand
2015-03-19

1. **Principle of operation**
2. Fluid dynamics influencing the performance
3. Elimination of those influences
4. Practical calibrations
5. Long term stability ultrasonic flow meters.

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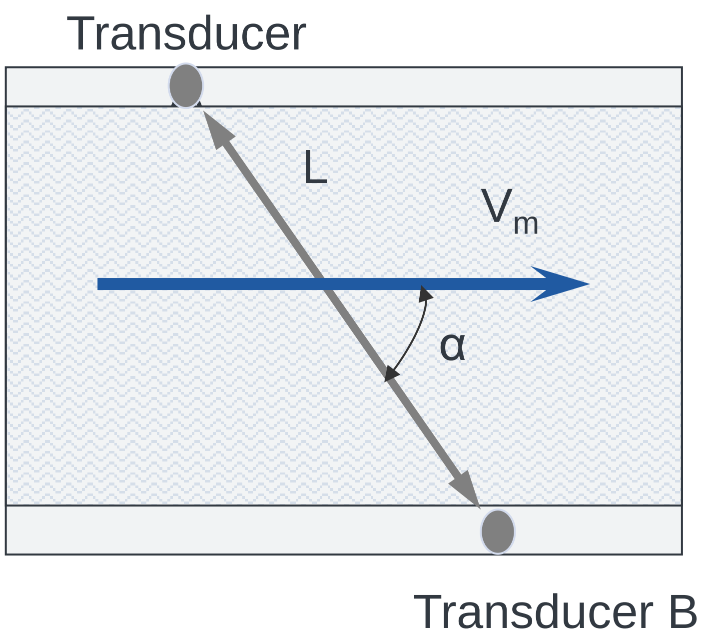
Measuring principle

Acoustic signals are transmitted and received along measuring path L.

A sound wave going *downstream* with the flow, travels faster than a sound wave going *upstream* against the flow.

The difference in transit time is directly proportional to the flow velocity of the liquid.



Measuring principle

Transit time

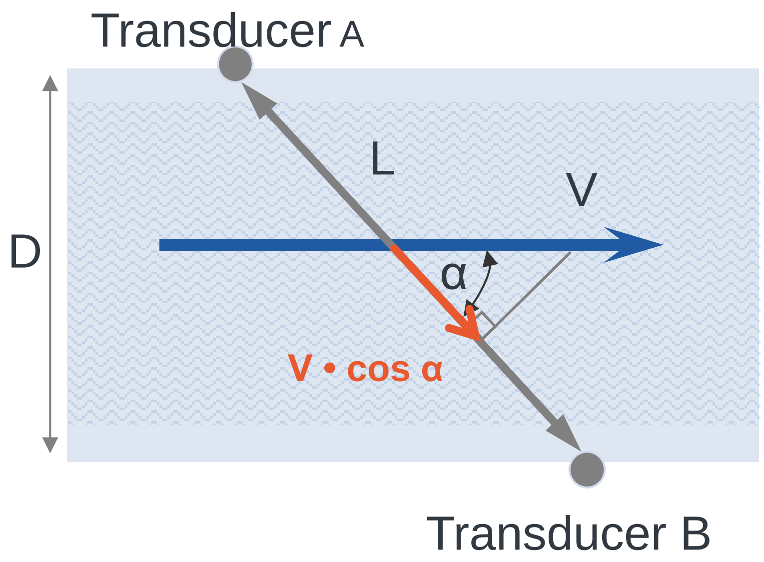
$$T = \frac{distance}{speed}$$

Upstream

$$T_{ab} = \frac{L}{C+v\cos(\alpha)}$$

Downstream

$$T_{ba} = \frac{L}{C-v\cos(\alpha)}$$



D = pipe diameter
L = path length
V = Medium flow velocity
C = Medium sound velocity

Measuring principle

Flow calculation

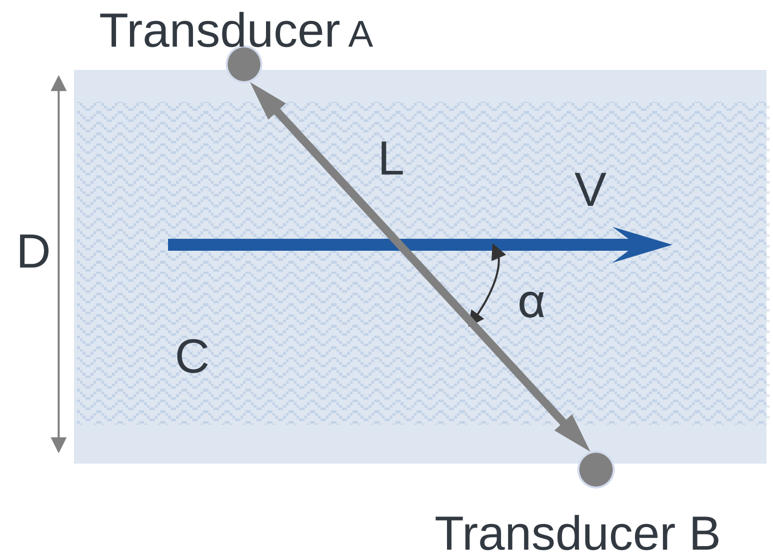
$$V = \frac{L}{2\cos(\alpha)} \times \frac{t_{ba} - tab}{t_{ba} \times tab}$$

$$A = \frac{\pi D^2}{4}$$

$$L = \frac{D}{\sin(\alpha)}$$

$$Flow = velocity * area$$

$$Flow = \frac{\pi D^3}{4\sin(2\alpha)} \times \frac{t_{ba} - tab}{t_{ba} \times tab}$$



D = pipe diameter
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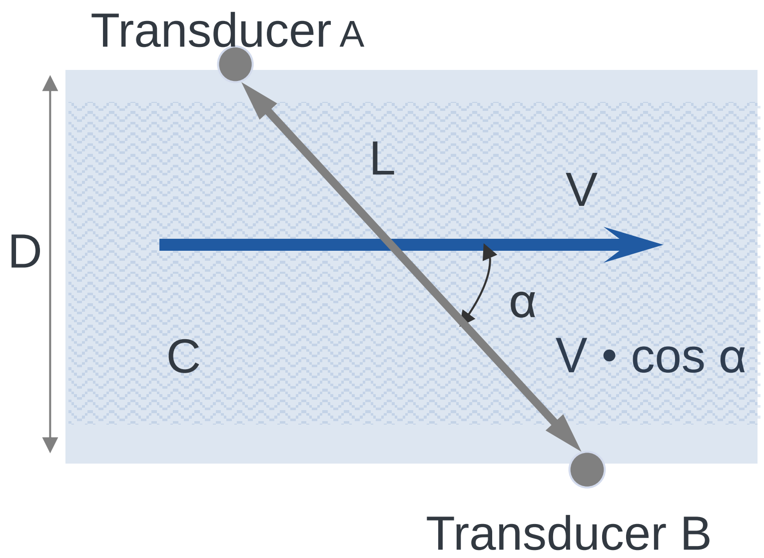
Measuring principle

$$\text{Flow} = \frac{\pi D^3}{4\sin(2\alpha)} \times \frac{t_{ba} - tab}{t_{ba} \times tab}$$



Calibration Factor (= Calibration constant) is determined during calibration

Independent of:

- Density
- Temperature
- Viscosity
- Velocity of sound

D = pipe diameter
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Reynolds Number

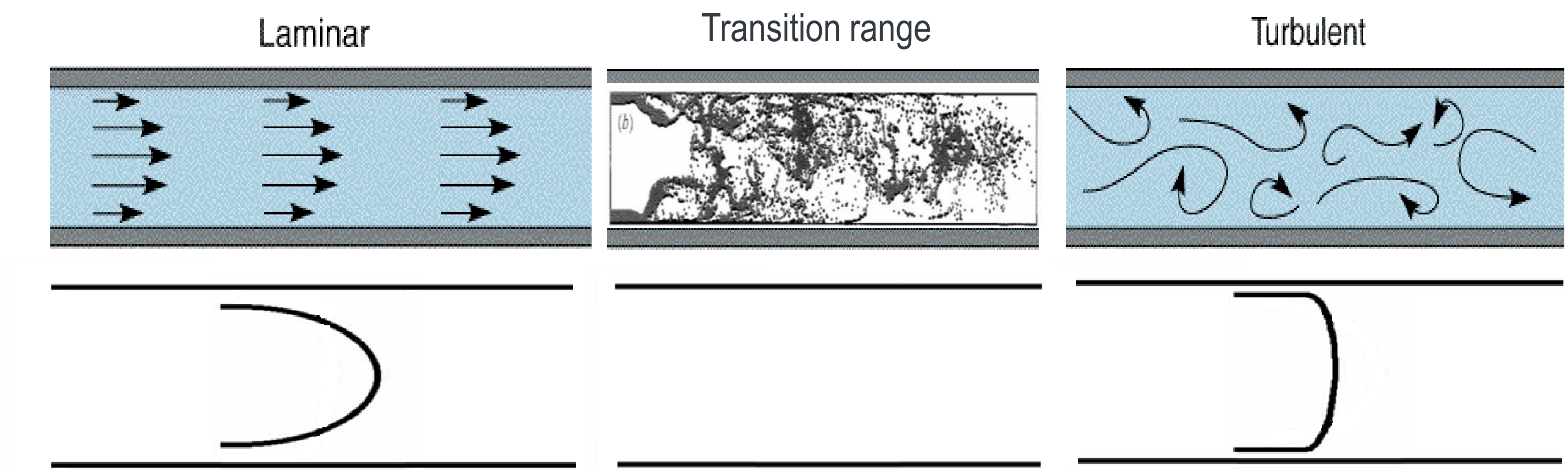
Reynolds number (Re) is a dimensionless quantity that is used to help predict similar flow patterns in different fluid flow situations.

Reynolds number is defined as the ratio of inertial forces to viscous forces

$$R_e = \frac{v x D}{\mu}$$

$\bar{v}$	= Velocity
D	= Diameter
μ	= Kinematic viscosity

Flow regimes



Parabolic flow profile	Not stable	Flat flow profile
Re < 2.000	**2.000 < Re > 8.000**	**Re > 8.000**

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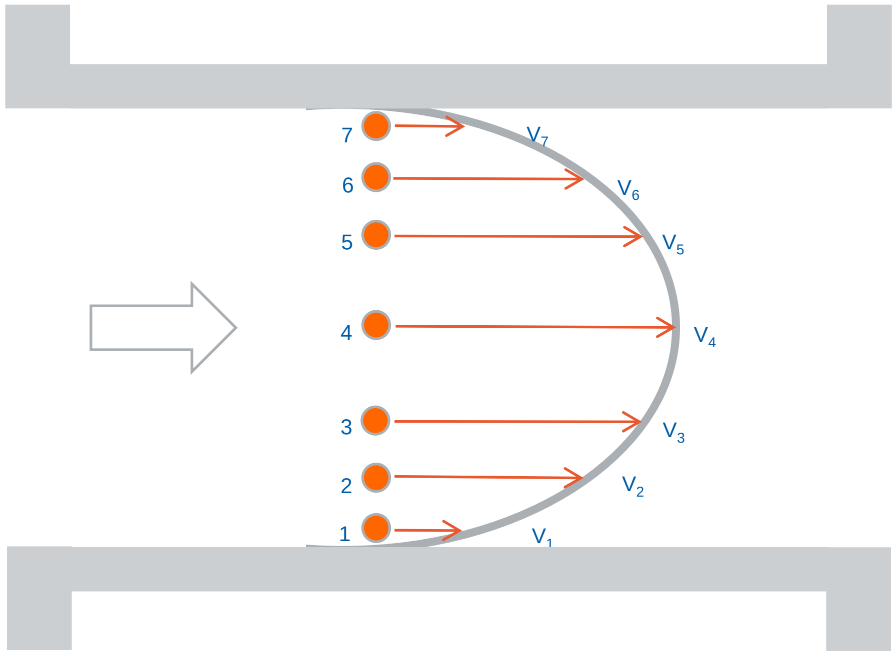
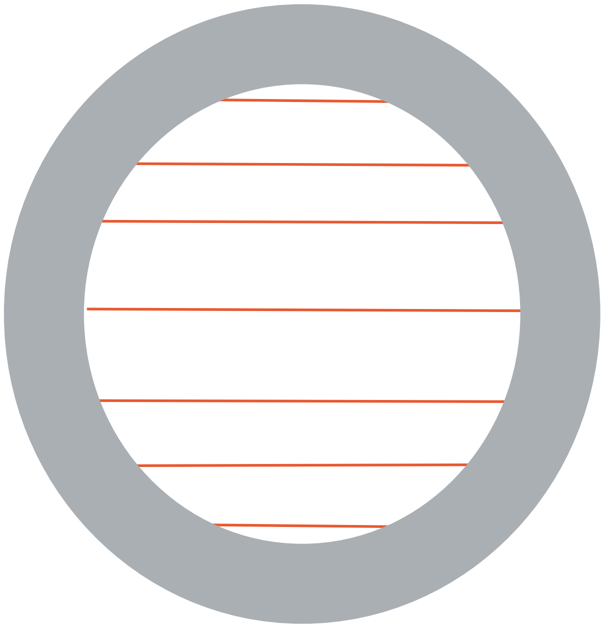
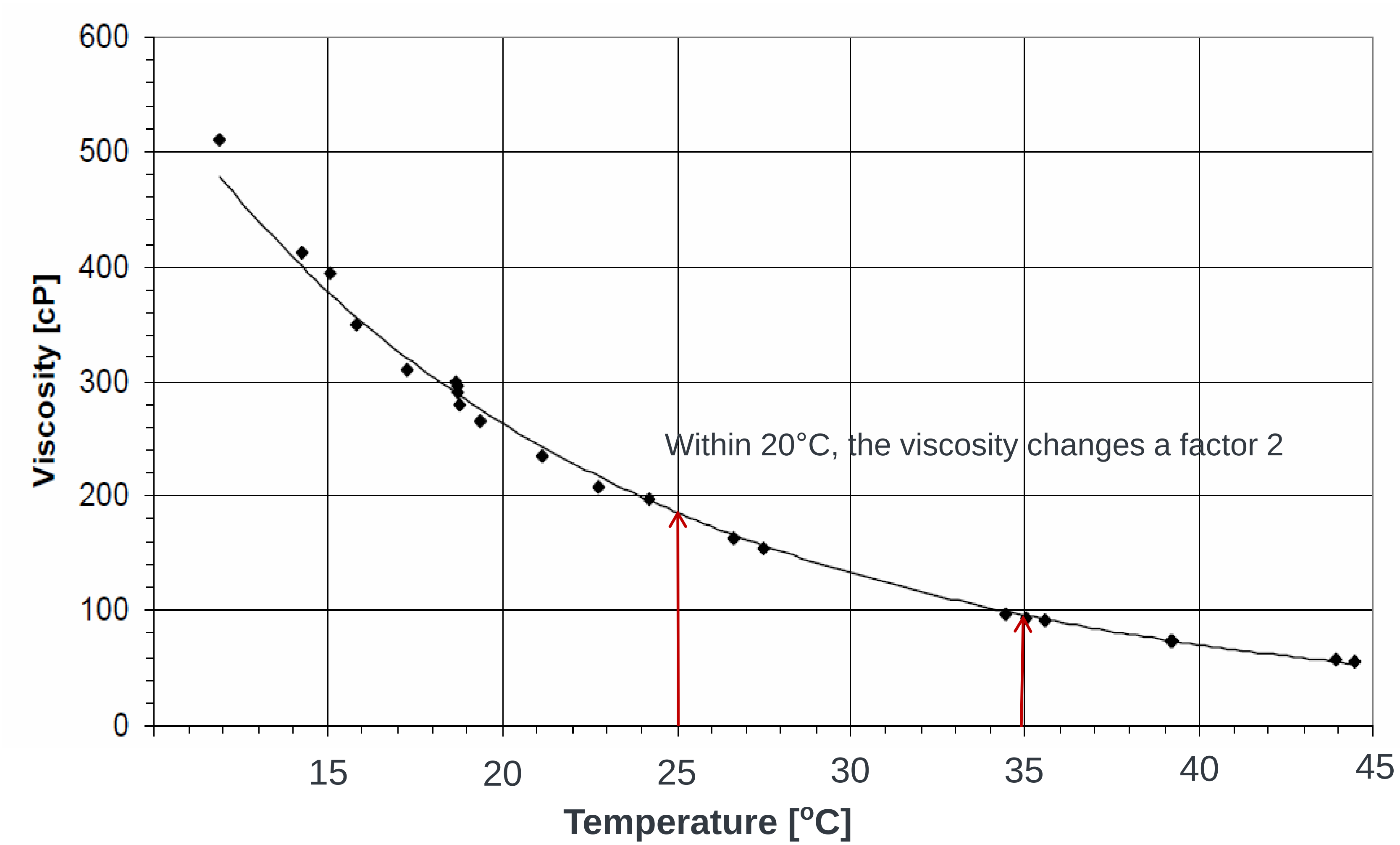
Average velocity measurement





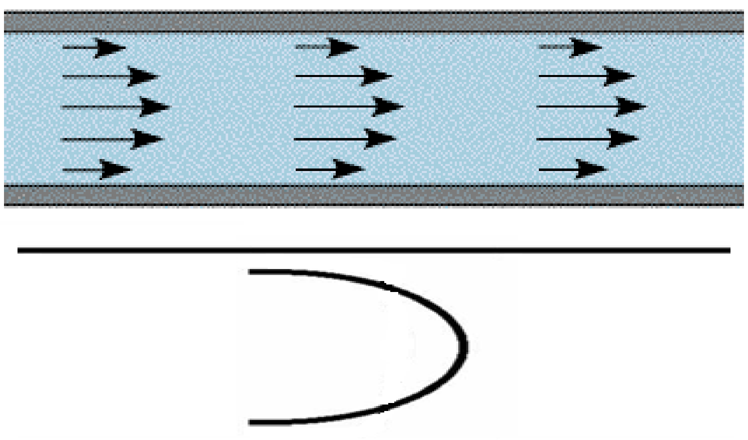
Temperature dependence of crudes



Average flow depending on flow profile

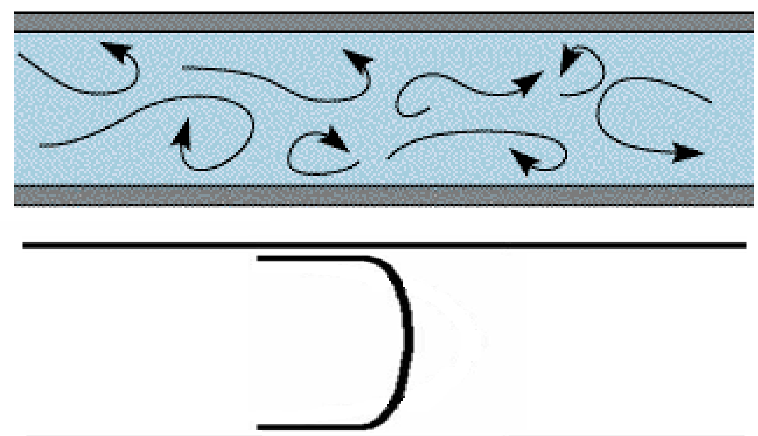
Example 8”	Flow [m3/h]	Viscosity [cSt]	Formula	Reynolds
Minimum	100	90	$R_e = \frac{vxD}{\mu}$	980
Maximum	1.000	180		19.600

Laminar



Parabolic flow profile
Re < 2.000

Turbulent



Flat flow profile
Re > 8.000

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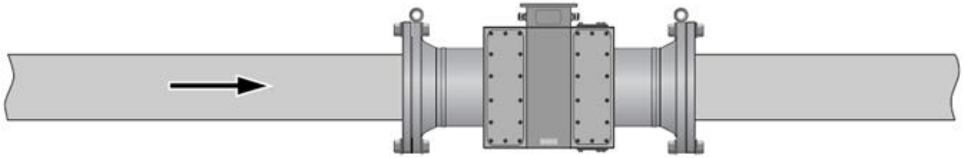
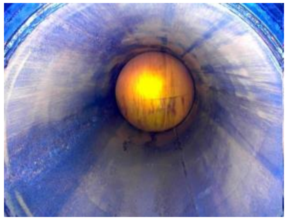
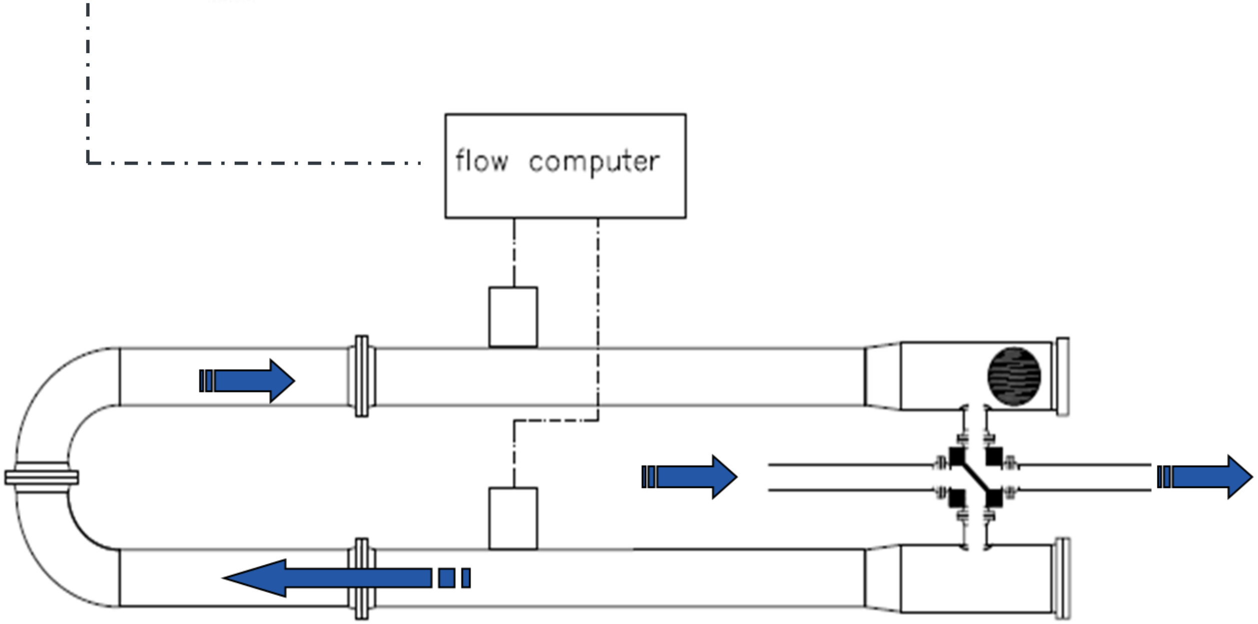
Calibration on ball prover



Pulse output of flowmeter





Traceable volume from ball prover

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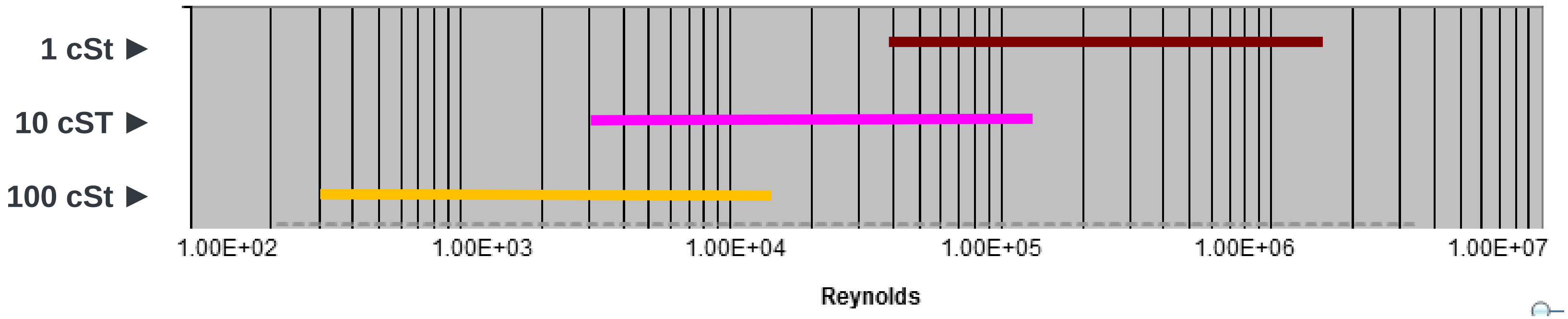
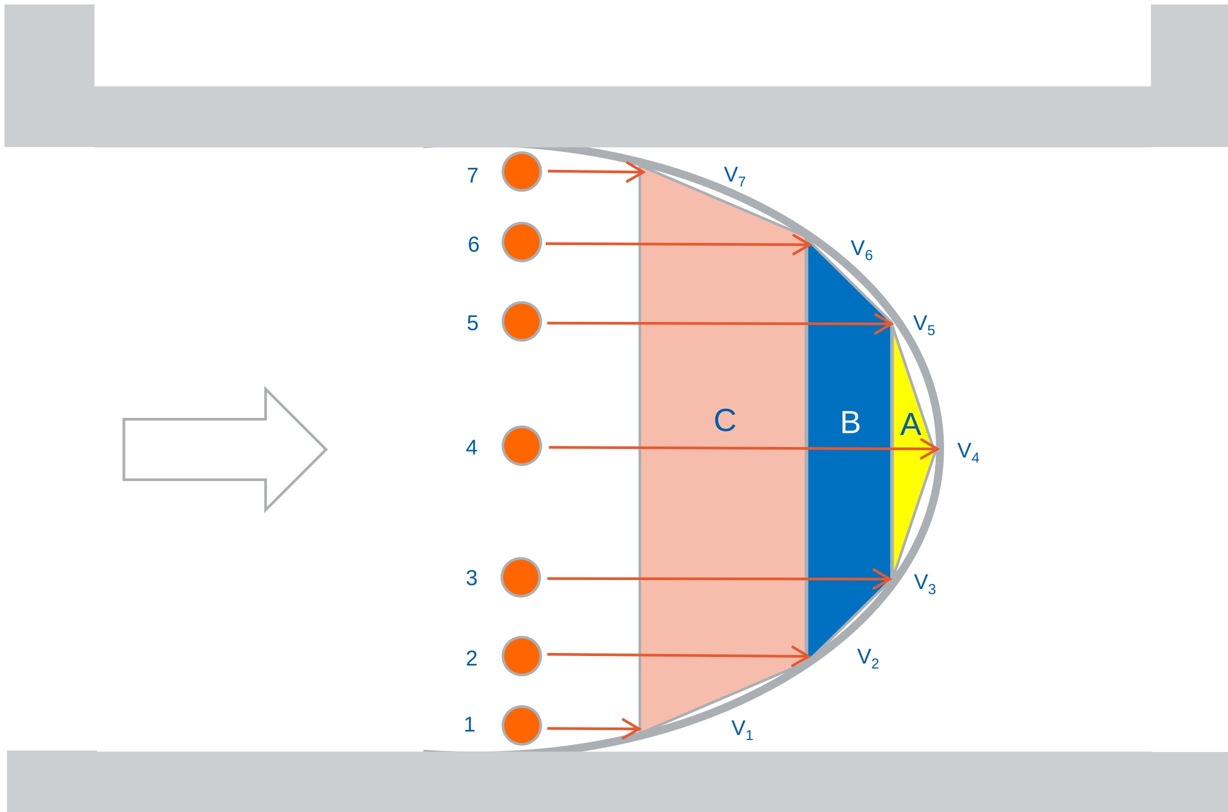
Reynolds calibration

Example 8”	Flow [m3/h]	Viscosity [cSt]	Formula	Reynolds
Minimum	100	90	$R_e = \frac{vxD}{\mu}$	980
Maximum	1.000	180		19.600



Profile recognition



$$A = \frac{V_3 + V_5}{V_4} \qquad B = \frac{V_3 + V_5}{V_2 + V_6} \qquad C = \frac{V_2 + V_6}{V_1 + V_7}$$

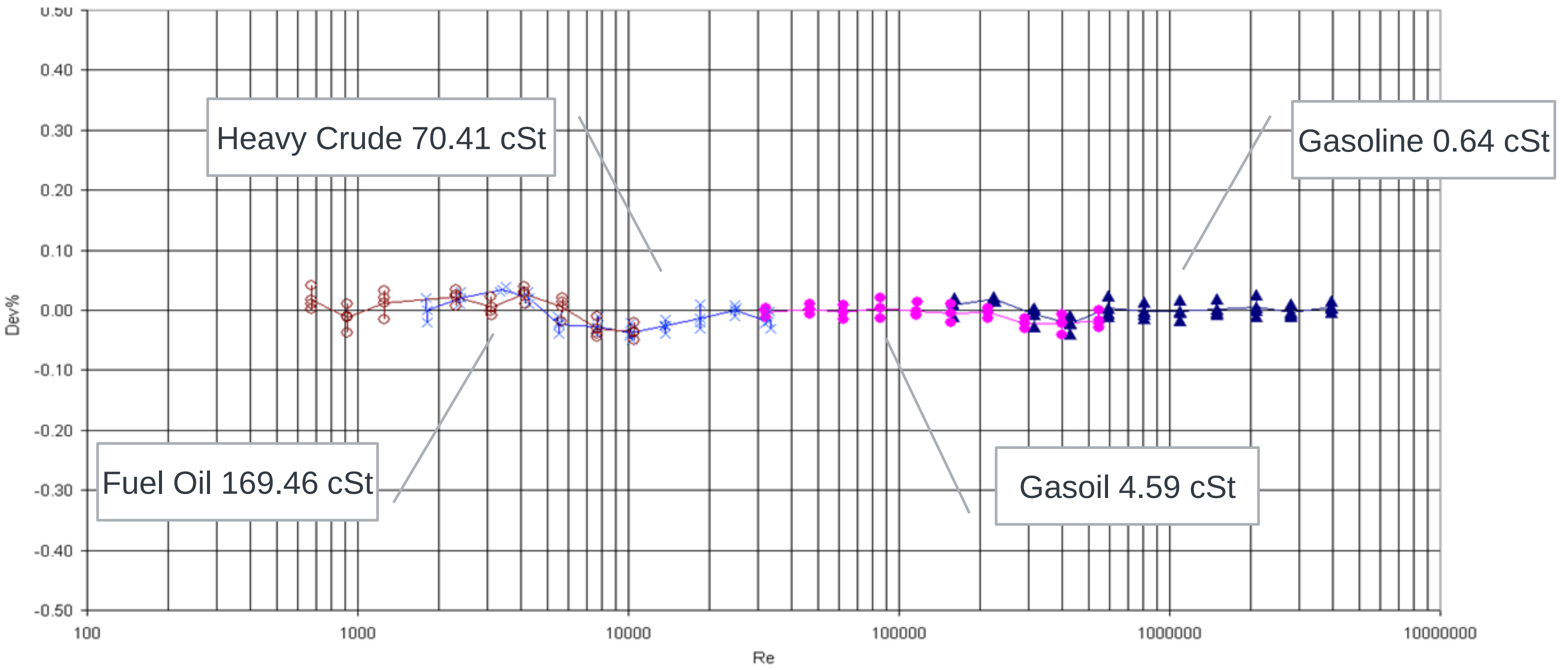
Profile / correction table

	Liquid	A	B	C	Correction Factor
1	1 cSt	1.89000	1.20170	1.40265	1.0085
2		1.88154	1.23608	1.42368	1.0103
3		1.87623	1.25442	1.43472	1.0117
4		1.86880	1.26340	1.44298	1.0113
5		1.86963	1.26954	1.45138	1.0099
6		1.87738	1.27446	1.46956	1.0084
7		1.88163	1.28102	1.47368	1.0071
8		1.88679	1.29230	1.48328	1.0049
9	10 cSt	1.88880	1.29350	1.49327	1.0047
10		1.89120	1.29430	1.50312	1.0045
11		1.88480	1.29900	1.51523	1.0034
12		1.88462	1.29987	1.52378.	1.0032
13		1.87780	1.30404	1.53370	1.0016
14		1.87500	1.30600	1.54845	1.0014
15		1.87310	1.30750	1.56321	1.0012
16		1.87310	1.31580	1.57298	1.0000
17	100 cSt	1.88480	1.29900	1.51523	1.0039
18		1.88462	1.29987	1.52378.	1.0032
19		1.87780	1.30404	1.53370	1.0016
20		1.87500	1.30600	1.54845	1.0019
21		1.87310	1.30750	1.56321	1.0012
22		1.87315	1.31580	1.57298	1.0008
23		1.87901	1.30650	1.56980	1.0012
24		1.87310	1.31700	1.58023	1.0003

A = 1.89120
B = 1.29430
C = 1.50312

30 x per second !

Reynolds correction
Final result on multiple products



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Calibration of ultrasonic flow meters

Correction of the meter reading is based on profile recognition and therefor only depending on Reynolds.

Calibrating the flowmeter across the applicable Reynolds range garantees a good performance on different fluids in the field.

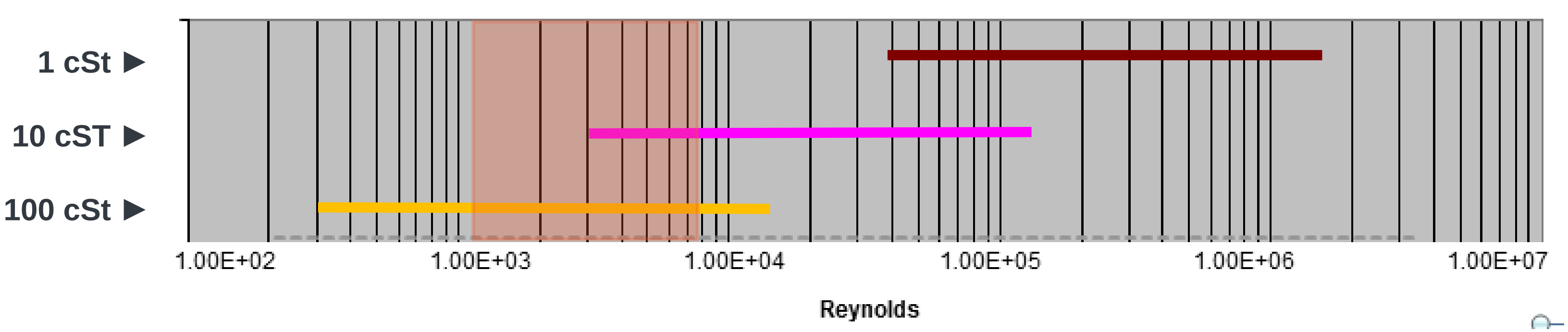
Flow rate versus viscosity and Reynolds

	18 m3/h	37 m3/h	75 m3/h	150 m3/h	300 m3/h	600 m3/h
5 cSt	8490	17400	35400	70700	141000	283000
10 cSt	4240	8720	17700	35400	70700	141000
20 cSt	2120	4360	8840	17700	35400	70700
40 cSt	1060	2180	4420	8840	17700	35400
80 cSt	531	1090	2210	4420	8840	11700
160 cSt	265	545	1110	2210	4420	8840
320 cSt	133	273	553	1110	2210	4420

Calibration with other product then used in the field.

Application 6”				
Example 6”	Flow [m3/h]	Viscosity [cSt]	Formula	Reynolds
Minimum	75	160	$R_e = \frac{vxD}{\mu}$	1110
Maximum	600	160		8840

Calibration 6”				
	Flow [m3/h]	Viscosity [cSt]	Formula	Reynolds
Minimum	45	100	$R_e = \frac{vxD}{\mu}$	907
Maximum	400	100		9070



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Long term stability of ultrasonic flow meters

Performance of a 16 inch flow meter over 4 years

History of the meter

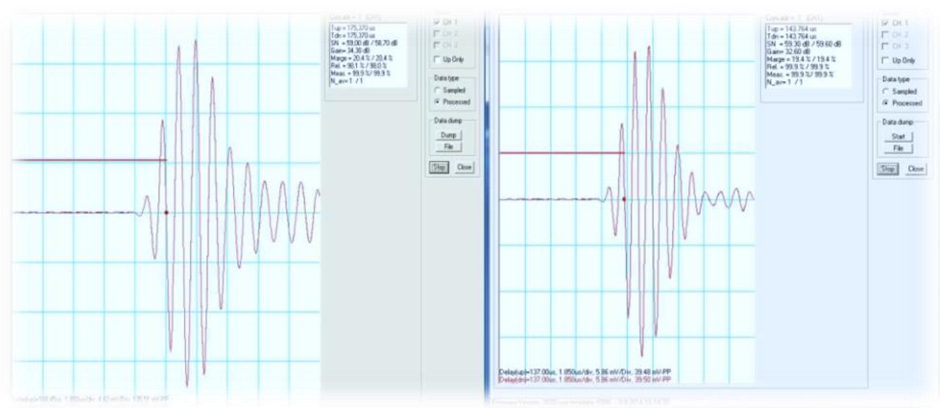
- Initial calibration in 2010
- First re-calibration in 2012
- Second re-calibration in 2014

Check points:

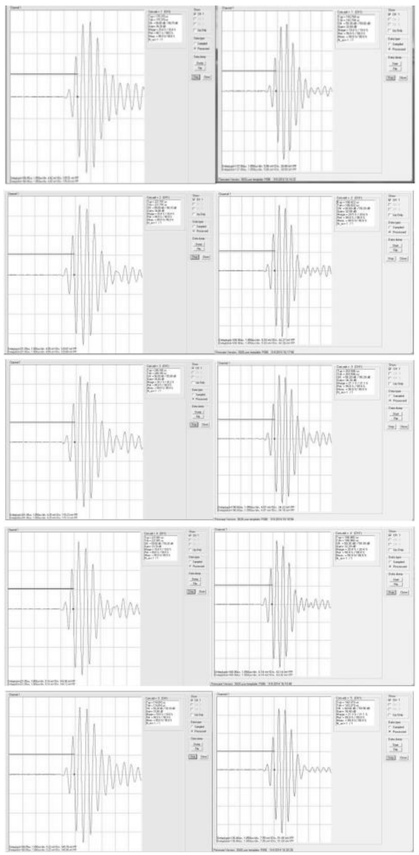
- Ultrasonic signal
- Zero-points
- Overall performance

Long term stability of ultrasonic flow meters

- Signal check under static conditions



2010 2014



Path 1

Path 2

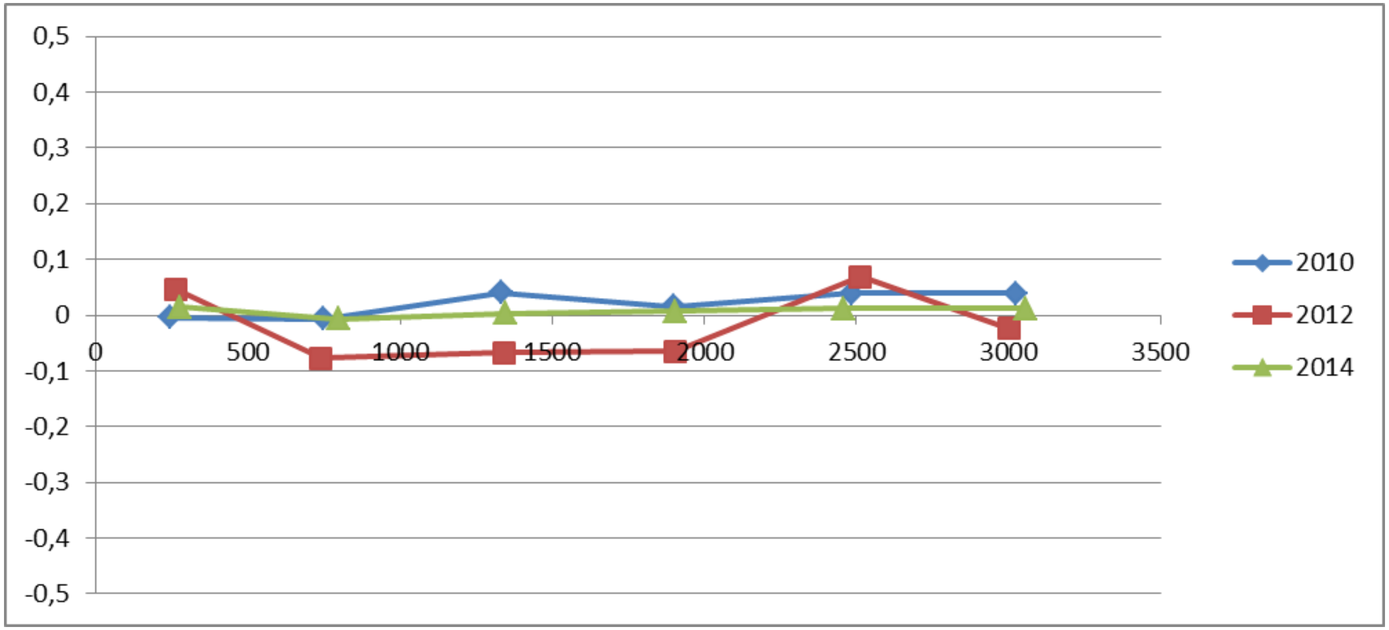
Path 3

Path 4

Path 5

Long term stability of ultrasonic flow meters
16 inch ALTOSONIC V

Calibration performed at SPSE



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Thank you for your attention

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