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And keep you ahead.

Corrections related to operation and calibration of liquid flow meters

NFOGM Temadag 2016

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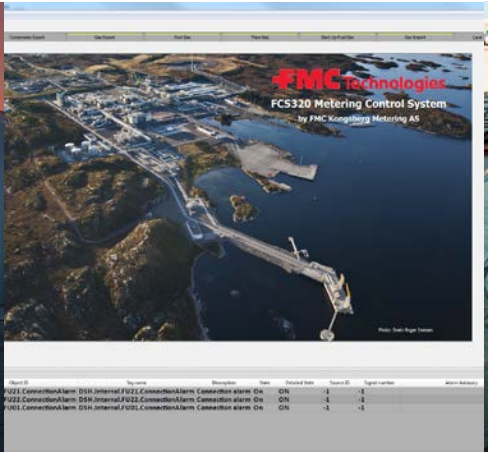



General formulas – Volumetric flow meter

$$q_{v,std} = q_v \cdot C_{tlm} \cdot C_{plm} \cdot C_{tsm} \cdot C_{psm}$$

$$q_v = \frac{Pulses/hour}{K\_factor}$$

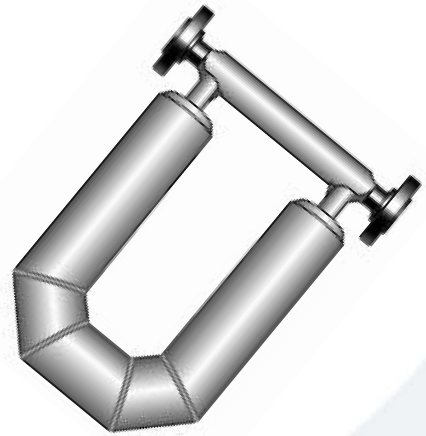
$q_{v,std}$	= Standard volume flow rate from flow meter (Sm^3/h)
q_v	= Actual volume flow rate from flow meter (m^3/h)
C_{tlm}	= Correction for the temperature effect on liquid at the meter
C_{plm}	= Correction for the pressure effect on liquid at the meter
C_{tsm}	= Correction for the temperature effect on steel of the meter
C_{psm}	= Correction for the pressure effect on steel of the meter
K_{factor}	= Calibration factor for flow meter (pulses/m^3)

General formulas – Mass flow meter

$$q_{v,std} = \frac{q_m}{\rho_{std}} = \frac{q_m}{\rho} \cdot C_{tlm} \cdot Cp_{lm}$$

$$q_m = \frac{Pulses/hour}{K\_factor}$$

$q_{v,std}$	= Standard volume flow rate from flow meter (Sm^3/h)
q_m	= Mass flow rate from flow meter (kg/h)
ρ_{std}	= Density of liquid at standard conditions (1.01325 bara, 15 °C)
ρ	= Operating density
C_{tlm}	= Correction for the temperature effect on liquid at the meter
C_{plm}	= Correction for the pressure effect on liquid at the meter
K_{factor}	= Calibration factor for flow meter (pulses/kg)



Correction factors for liquid USM flow measurement

$$q_{v,std} = \frac{Pulses/hour}{K\_factor} \cdot C_{tlm} \cdot C_{plm} \cdot C_{tsm} \cdot C_{psm}$$

C_{tlm} = temperature effect on liquid at the meter

C_{plm} = pressure effect on liquid at the meter

C_{tsm} = temperature effect on steel of the meter

C_{psm} = pressure effect on steel of the meter

$K_{\_factor}$ = Calibration factor for flow meter (p/m^3)

C_{tlm} – temperature effect on liquid at the meter

API MPMS Ch. 11.1.54:

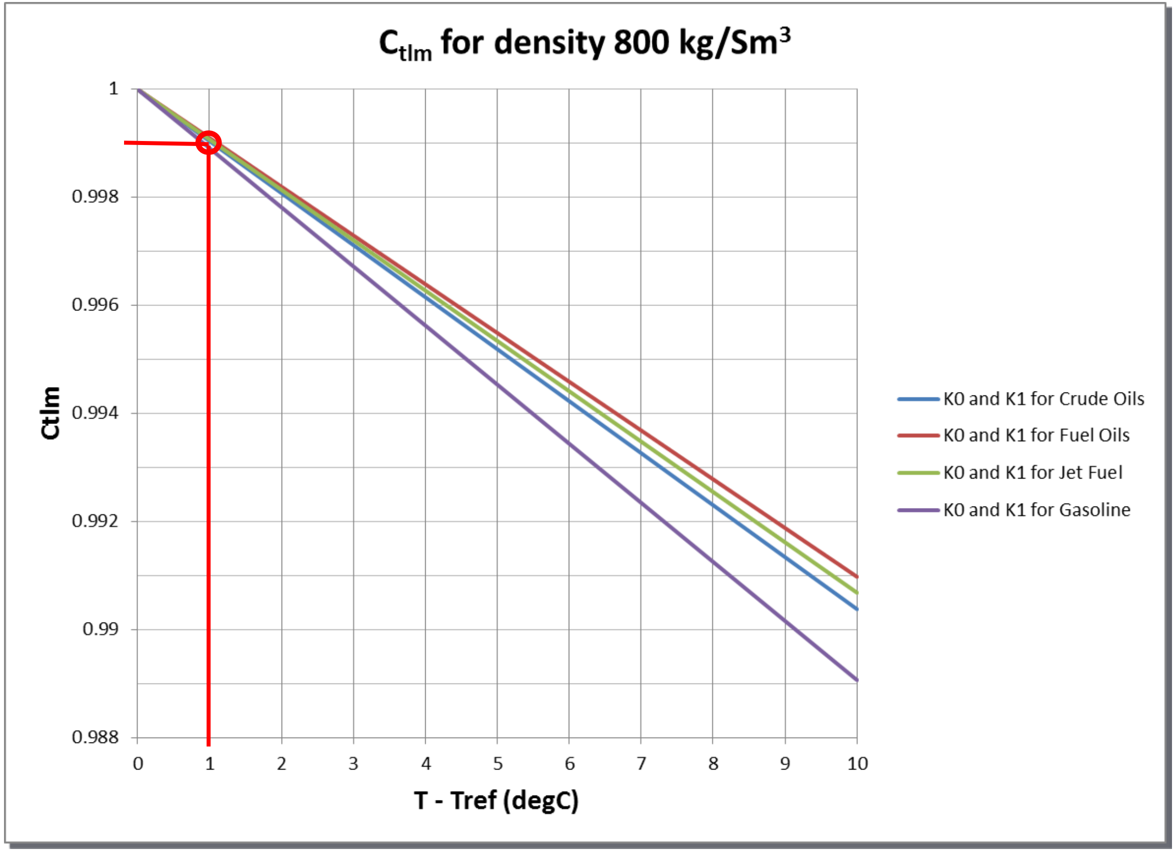
$$C_{tlx} = e^{-\alpha\Delta T - 0.8\alpha^2\Delta T^2}$$

$$\alpha = \frac{K_0}{\rho_{ref}^2} + \frac{K_1}{\rho_{ref}}$$

Hydrocarbon Liquid	K_0	K_1
Crude Oils	613.9723	0.0
Fuel Oils	186.9696	0.4862
Jet Fuel	594.5418	0.0
Gasoline	346.4228	0.4388

C_{tlm} – temperature effect on liquid at the meter

For a typical crude oil, a temperature **increase** of **1 °C** generates an **increased volume** of approximately **0.1%.**



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C_{plm} – pressure effect on liquid at the meter

API MPMS Ch. 11.2.1M:

$$Cplx = \frac{1}{1-\left(P - P_{vp}\right)\cdot F \cdot 100}$$

$$F = \frac{e^{\left(A+B\cdot T + (C+D\cdot T)\left(\frac{1000}{\rho}\right)^2\right)}}{1000000}$$

T = temperature (°C)

ρ = reference density (kg/Sm^3)

The most common used equation for C_{plm} valid for density from 638 to 1074 [kg/Sm^3].

Name	Description
A	-1.6208
B	0.00021592
C	0.87096
D	0.0042092

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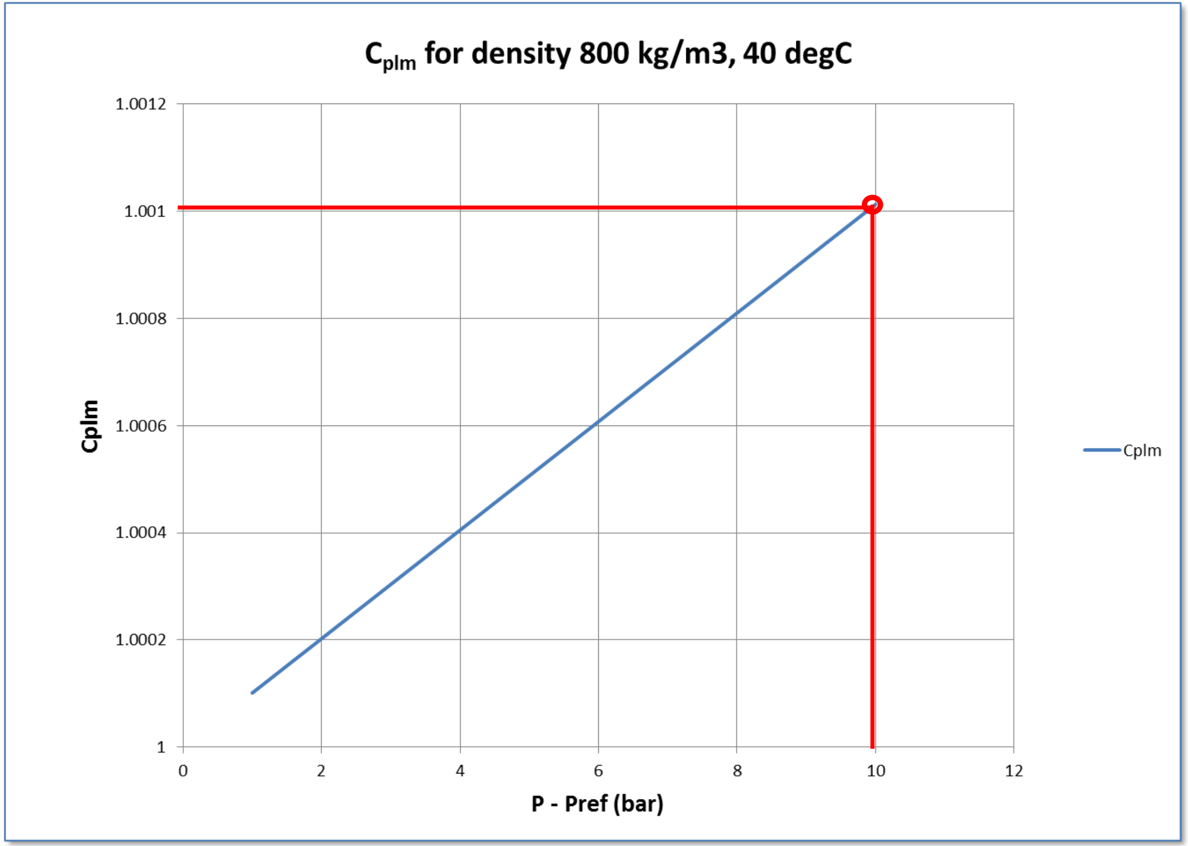
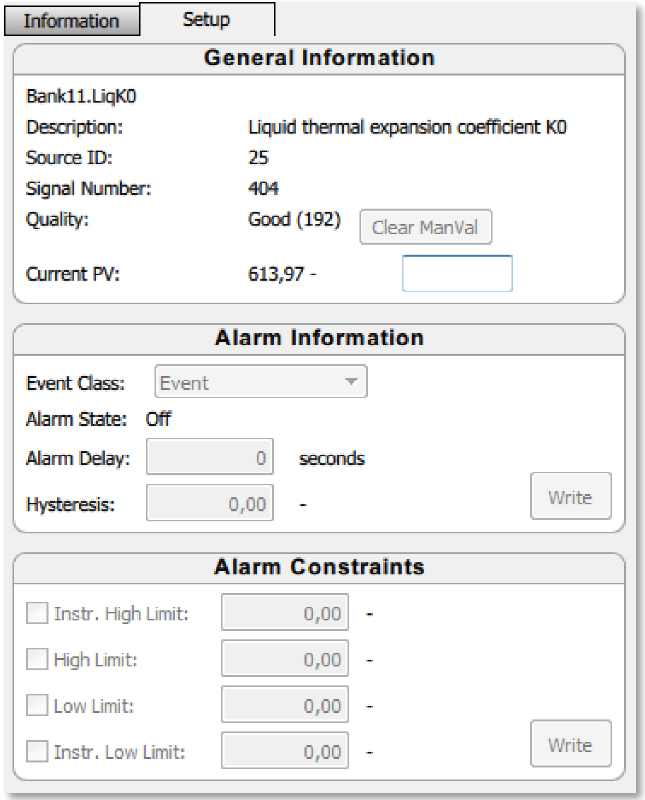
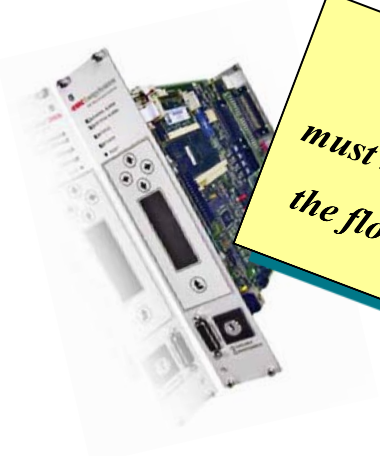
C_{plm} – pressure effect on liquid at the meter



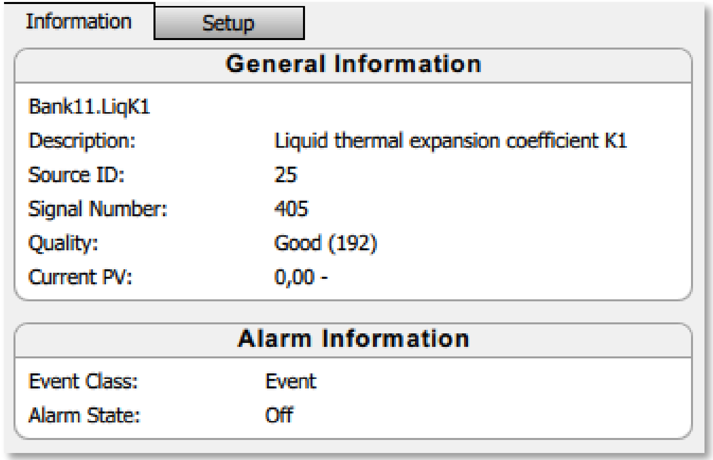
For a typical crude oil, a pressure **increase** of **10 bar** generates a **reduced volume** of approximately **0.1%.**

Data entry for C_{tlm} and C_{plm}





K_0 and K_1 must be entered into the flow computer



Parameter report for C_{tlm} and C_{plm}

Physical Data		
Liquid thermal expansion coefficient K0	[-]	613.9723
Liquid thermal expansion coefficient K1	[-]	0.0000
Liquid vapour pressure	[barg]	0.0000
Liquid shrinkage factor	[-]	1.0000

Correction parameters must be available on flow computer parameter report

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C_{tsm} – temperature effect on steel at the meter

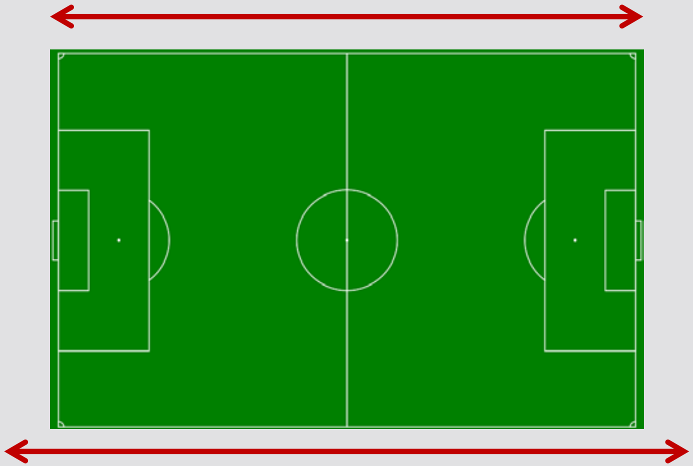
C_{tsm} – temperature effect on steel at the meter

Linear thermal expansion coefficient (α)

Material	α (m/m/K)
Carbon steel	1.2×10^{-5}
Stainless steel AISI 316	1.6×10^{-5}
Duplex	1.3×10^{-5}

Example:
A 100 m steel rail expands 12 mm when temperature increases 10 degrees.

100.000 m at 20 °C



100.012 m at 30 °C

C_{tsm} – temperature effect on steel at the meter

Ultrasonic flow meters

ISO 12242:

Cubical!

$$C_{tsm} = (1 + \alpha \cdot \Delta T)^3$$

$$C_{tsm} \approx 1 + 3\alpha \cdot \Delta T$$

α = Linear thermal expansion coefficient (/K)

ΔT = T – Tcal (K)

References:

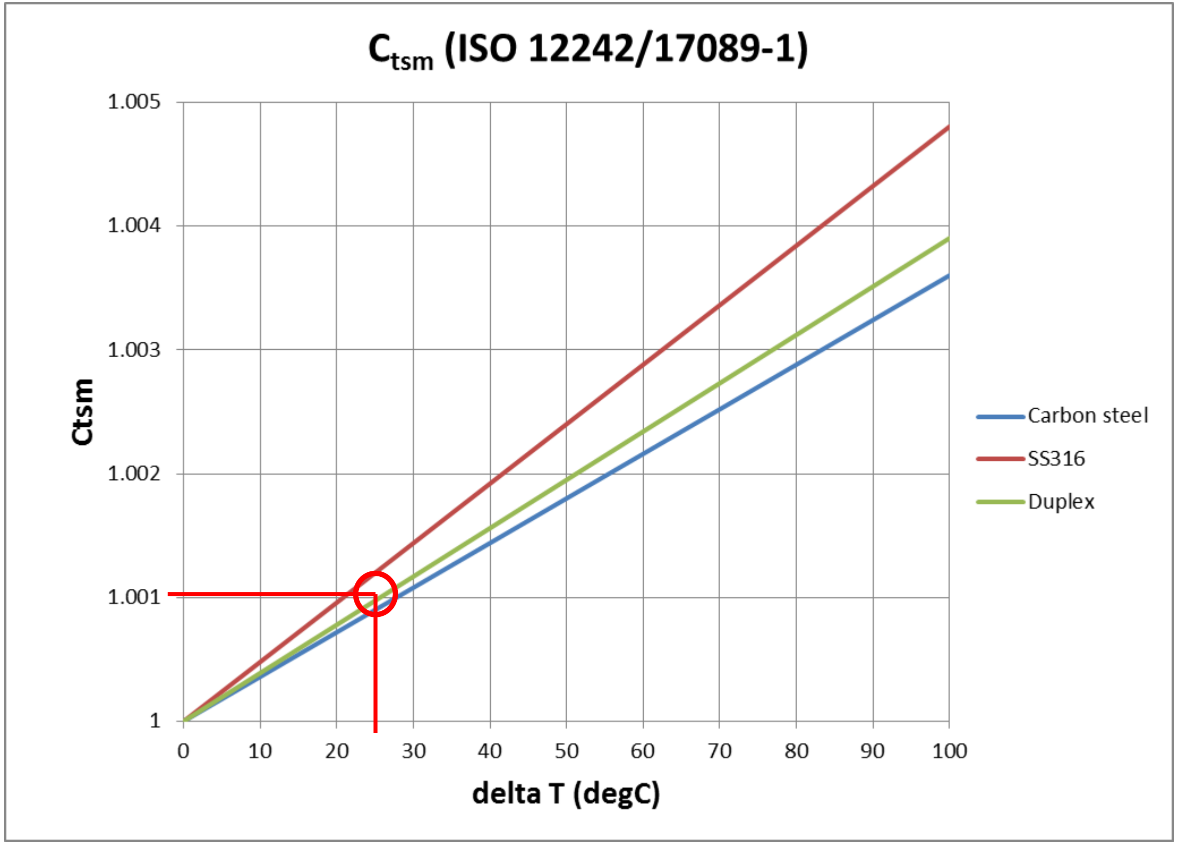
ISO 12242*: Measurement of fluid flow in closed conduits - Ultrasonic meters for liquid*

ISO 12242 refers to ***ISO 17089-1*** *method for pressure and temperature correction of flow meter body*

C_{tsm} – temperature effect on steel at the meter

Ultrasonic flow meters

The relative volume correction for thermal expansion of the flow meter body is approximately **0.1%** if the temperature is increased by **25 °C**.



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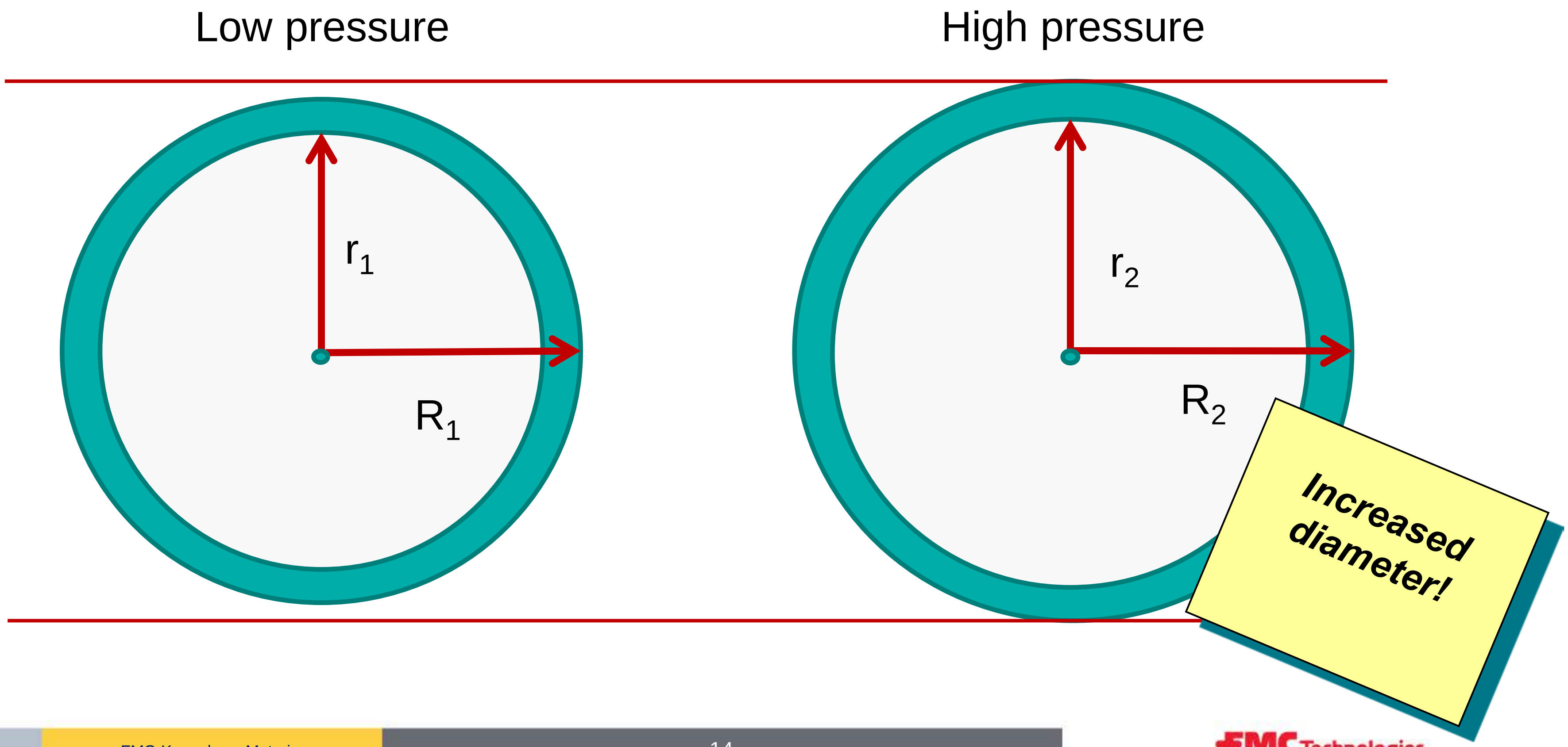
C_{psm} – pressure effect on steel at the meter



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C_{psm} – pressure effect on steel at the meter

Ultrasonic flow meters

ISO 12242 ⇒ ISO 17089-1:

General formula:

$$K_P = \left(\frac{d_1}{d_0}\right)^2 \cdot \left(\frac{l_1}{l_0}\right)^2 = (1+\frac{\Delta r}{r})^4 \approx 1 + 4 \cdot \frac{\Delta r}{r}$$

Open pipe

«Barrel»

$K_{Pne} > K_{Pce}$

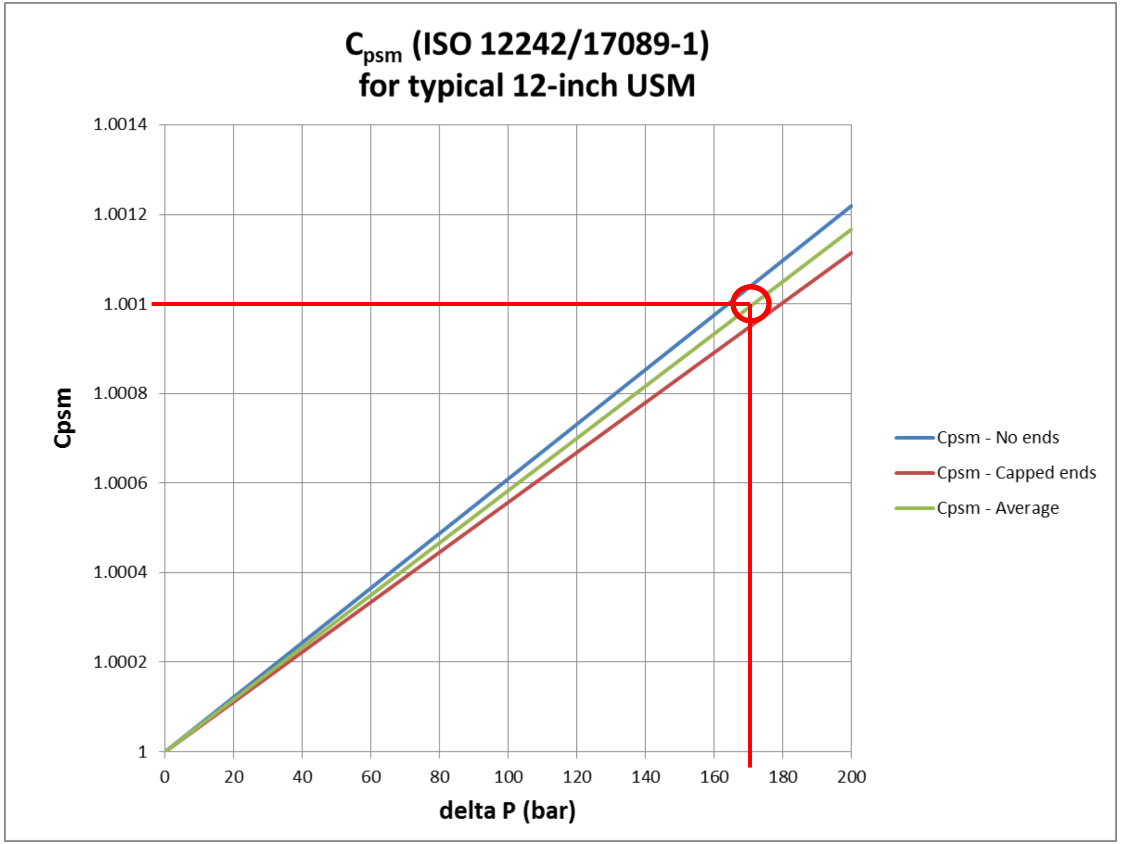
ISO 17089 uses K_P instead of C_{PSM} for pressure correction factor in the meter

No ends	Capped ends	Average
$K_{Pne} = 1 + 4 \cdot \left(\frac{R^2 + r^2}{R^2 - r^2} + \mu\right) \cdot \frac{\Delta P}{E}$	$K_{Pce} = 1 + 4 \cdot \left(\frac{R^2(1+\mu) + r^2(1-2\mu)}{R^2 - r^2}\right) \cdot \frac{\Delta P}{E}$	$K_{Pav} = \left(\frac{K_{Pne} + K_{Pce}}{2}\right)$

µ (Poisson ratio) = 0.3

E (Modulus of elasticity or Young's modulus) = 2 x 10^6 bar (typical)

C_{psm} – pressure effect on steel at the meter



Ultrasonic flow meters

Example:

The relative volume correction for pressure expansion of the 12-inch flow meter body is approximately **0.1%** if the temperature is increased by **170 bar**.

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Summary – C_{tlm}, C_{plm}, C_{tsm}, C_{plm} for USM

- What gives **0.1% volume correction**?

Ctlm	Cplm	Ctsm	Cplm
1 °C	10 bar	25 °C	170 bar

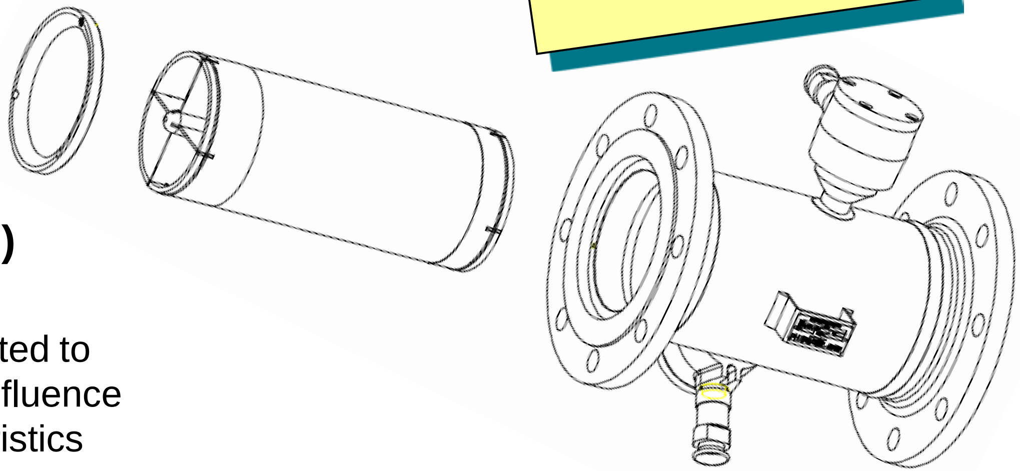
- Example shown for typical crude oil (800 kg/m3) and 12-inch USM

C_{tsm} and C_{psm} for turbine flow meters

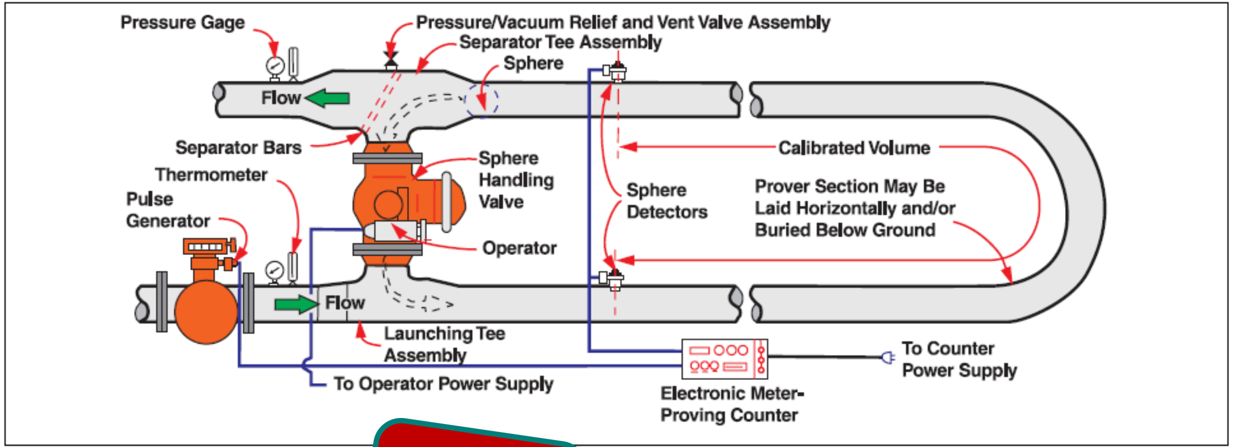
$$Volume = \frac{Pulses * Ctsm * Cpsm}{K_{factor}}$$

- **Pressure correction (C_{psm})**
  - Insertion tube for pressure compensation
  - **C_{psm} = 1 (typically)**
- **Temperature correction (C_{tsm})**
  - Rotor blades will be affected
  - Temperature changes are related to viscosity changes which will influence on the turbine meter characteristics
  - **C_{tsm} = 1 (typically)**

Always calibrate turbine flow meters at operating conditions!



C_{tsp} and C_{psp} for pipe volume prover



API MPMS Ch. 12.2.1:

Cubical!

$$C_{tsm} = 1 + 3\alpha \cdot \Delta T$$

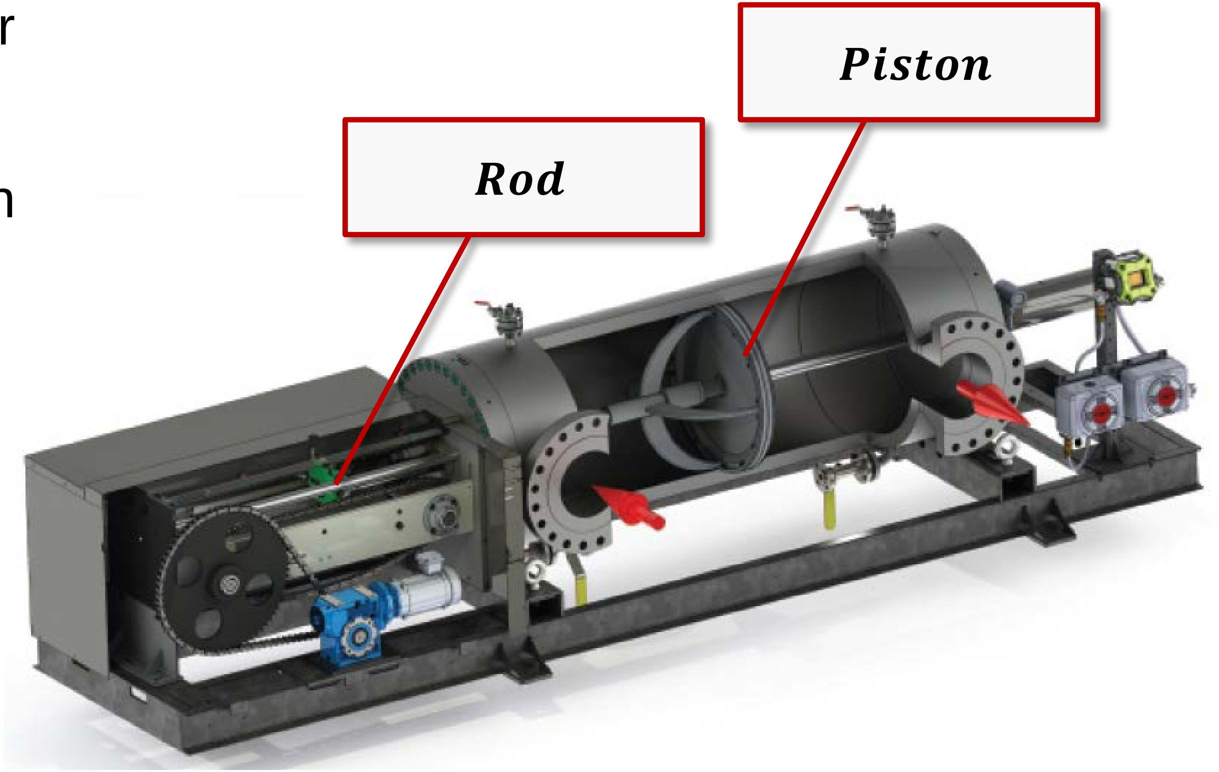
$$C_{psp} = 1 + \frac{\Delta P \cdot D}{E \cdot WT}$$

ΔT	bar	Temperature increase from reference
α	m/m/K	Linear thermal expansion coefficient
ΔP	bar	Pressure increase from reference
D	m	Internal diameter of prover pipe
E	bar	Prover steel elasticity module
WT	m	Wall thickness of prover pipe

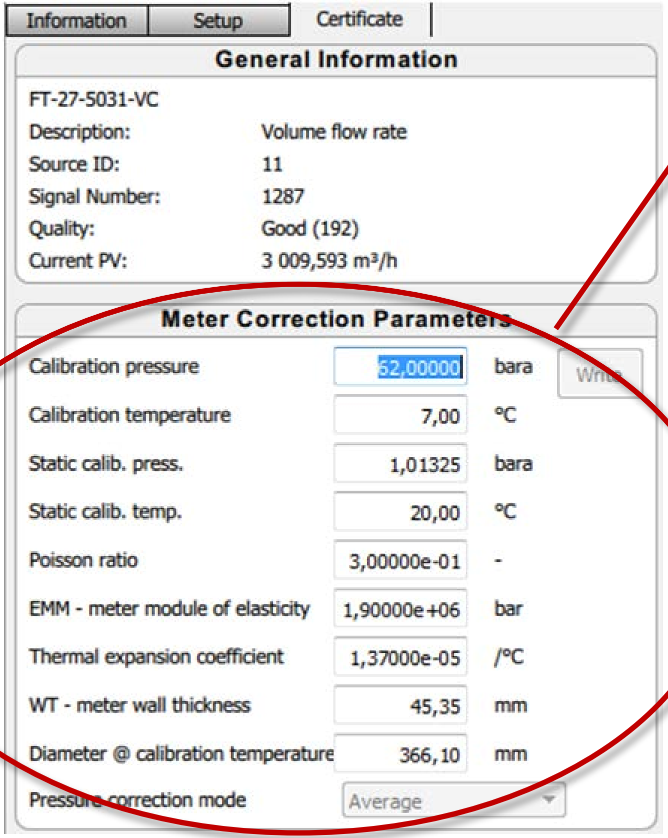
C_{tsp} and C_{psp} for compact provers

- Separate C_{tsp} for area (squared) and for rod (linear) as piston and rod may have different thermal expansion coefficients

- C_{psp} as for pipe volume prover



Data entry for C_{tsm} and C_{psm} parameters


Information | Setup | Certificate

General Information

FT-27-5031-VC

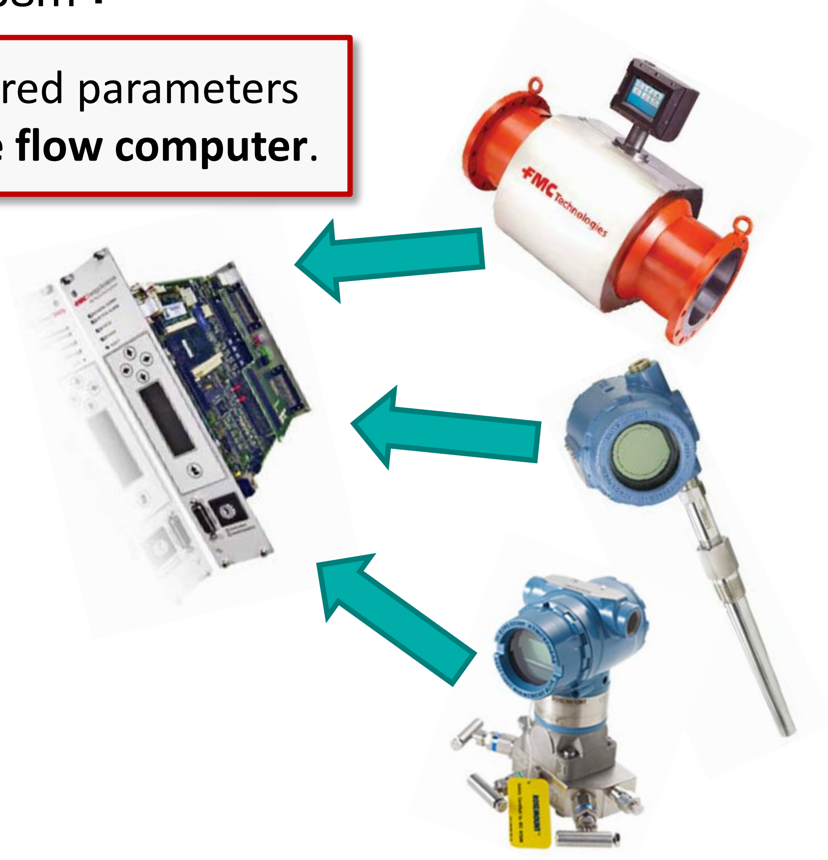
Description:	Volume flow rate
Source ID:	11
Signal Number:	1287
Quality:	Good (192)
Current PV:	3 009,593 m³/h

Meter Correction Parameters

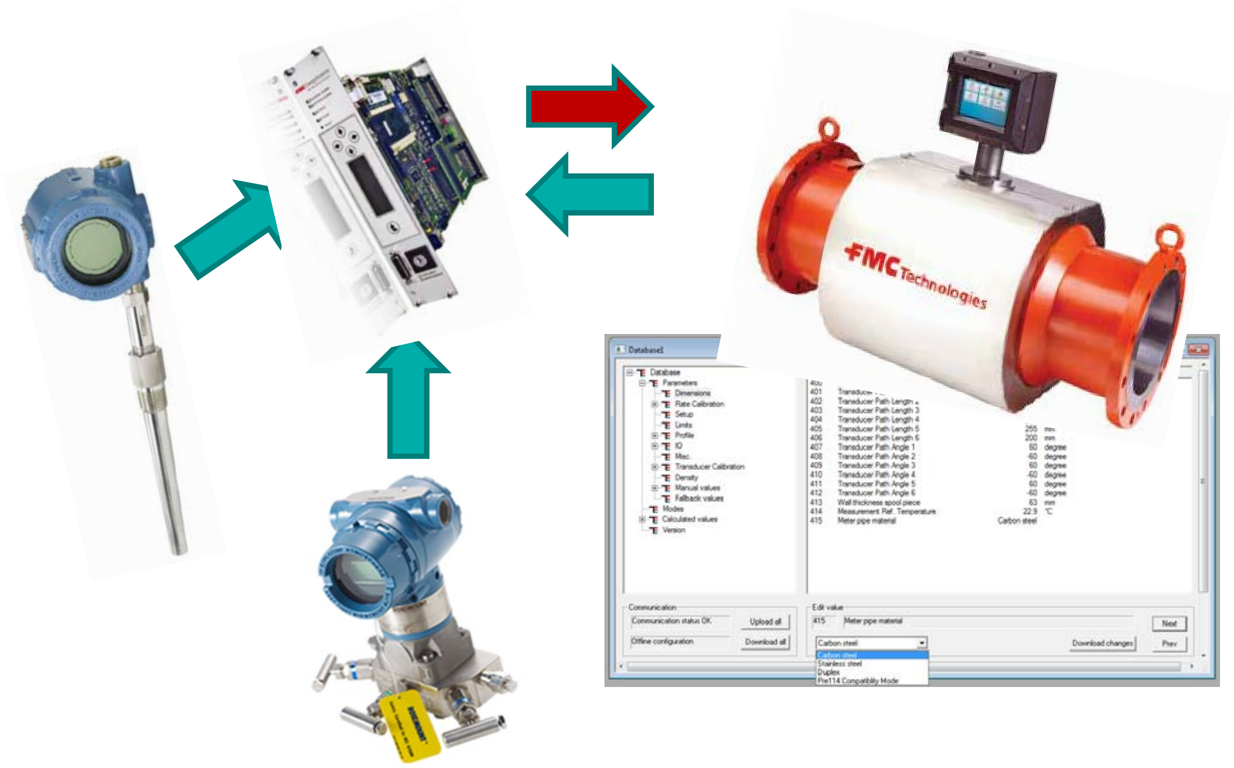
Calibration pressure	52,00000	bara
Calibration temperature	7,00	°C
Static calib. press.	1,01325	bara
Static calib. temp.	20,00	°C
Poisson ratio	3,00000e-01	-
EMM - meter module of elasticity	1,90000e+06	bar
Thermal expansion coefficient	1,37000e-05	/°C
WT - meter wall thickness	45,35	mm
Diameter @ calibration temperature	366,10	mm
Pressure correction mode	Average	

Write

Required parameters
in the flow computer.



Data entry for C_{tsm} and C_{psm} parameters



- For some flow meters the corrections may be done in the flow **meter** itself.

- *But then **flow meter needs to know the operating pressure and temperature!***

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C_{tsm} and C_{psm} during flow calibration

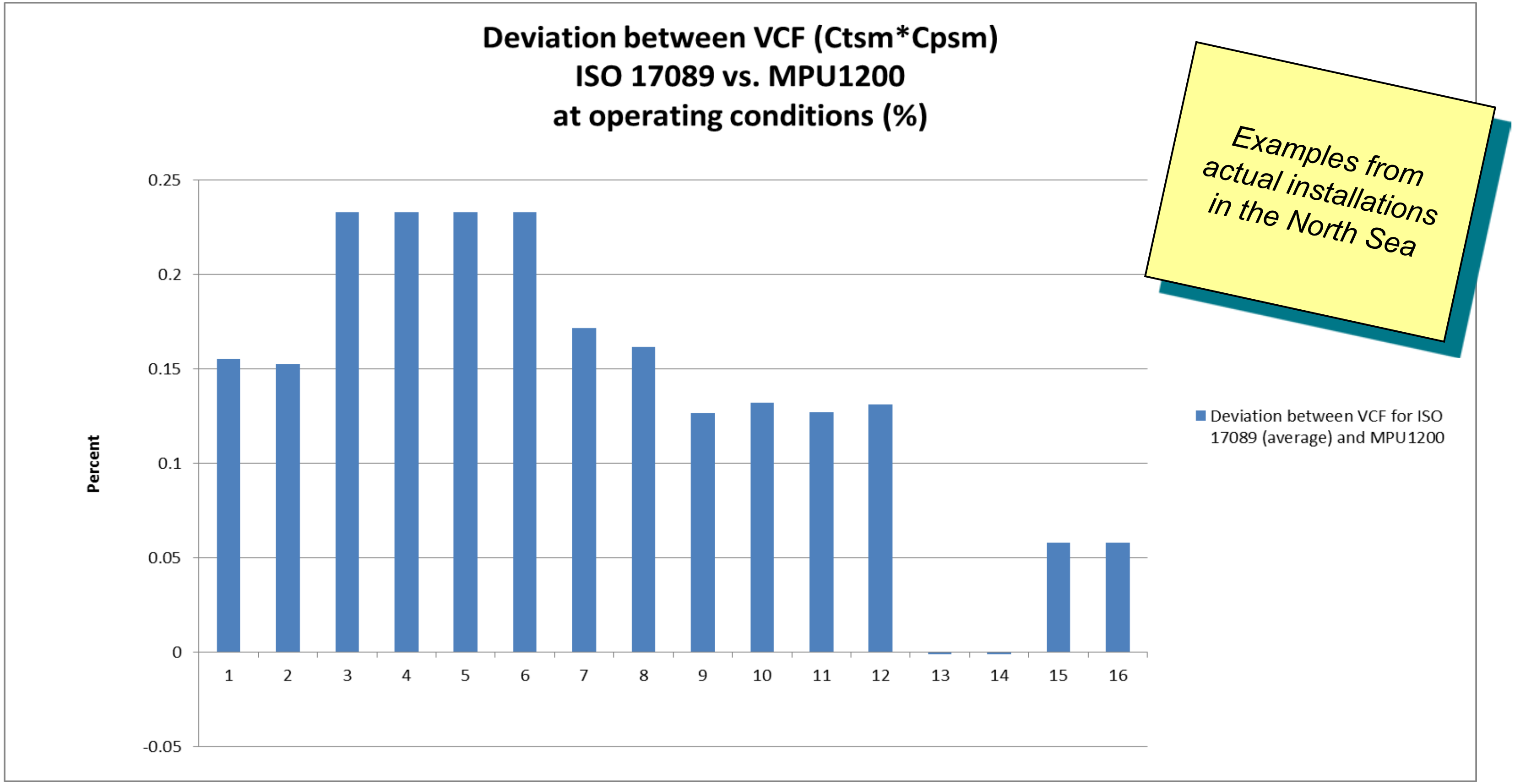
<u>New method:</u>

- Three-stage calculation for corrections in accordance with ISO 17089-1, Annex E
- Pressure and temperature **correction for body expansion must be turned off in the USM during flow calibration**
- Keep pressure and temperature correction turned off in the USM during operation in the field

Step	VCF = Ctsm*Cpsm	Calculation of correction
1	VCF_1	Static to dynamic calibration
2	VCF_2	Static to field conditions
3	$VCF_3 = \frac{VCF_2}{VCF_1}$	Dynamic calibration to field conditions

May risk **deviation from reference outside recommended limits** during flow calibration!

C_{tsm} and C_{psm} - ISO 17089 vs. MPU1200

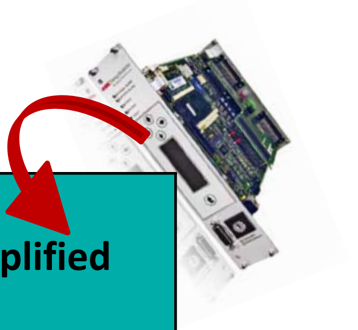


Parameter report for C_{tsm} and C_{psm}

ISO17089 Meter Correction Parameters - Stream 01 A		
Meter calibration pressure	[bara]	62.00000
Meter calibration temperature	[°C]	7.00
Meter poisson ratio	[-]	3.00000E−01
EMM - meter module of elasticity	[bar]	1.90000E+06
Thermal expansion coefficient	[/°C]	1.37000E−05
WT - meter wall thickness	[mm]	45.35
Inner pipe diameter @ calibration temperature	[mm]	366.10
Pressure correction mode		Average

Correction parameters must be available for inspections and audits on flow meter parameter report or on flow meter configuration print-out.

ISO 17089 detailed vs. simplified method

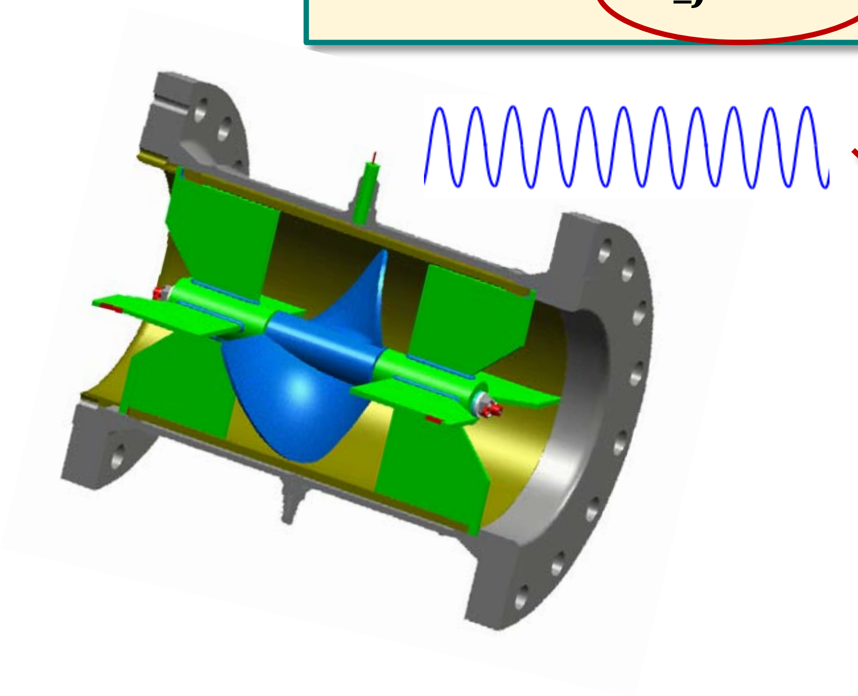


Correction	Detailed	Simplified
Temperature correction	Yes	Yes
Radial pressure correction – no ends condition	Yes	Yes
Radial pressure correction – capped ends conditions	Yes	Yes
Axial pressure correction	Yes	No
Body style effect, Ks (proximity to flanges)	Yes	No
Transducer port temperature correction	Yes	No
Transducer port pressure correction	Yes	No

For 12 inch meters operating at 150 barg pressure the difference is typically ***less than 0.01%.***

K-factor

$$q_{v,std} = \frac{Pulses/hour}{K\_factor} \cdot C_{tlm} \cdot C_{plm} \cdot C_{tsm} \cdot C_{psm}$$



$$K_{factor} = \frac{pulses}{m^3}$$

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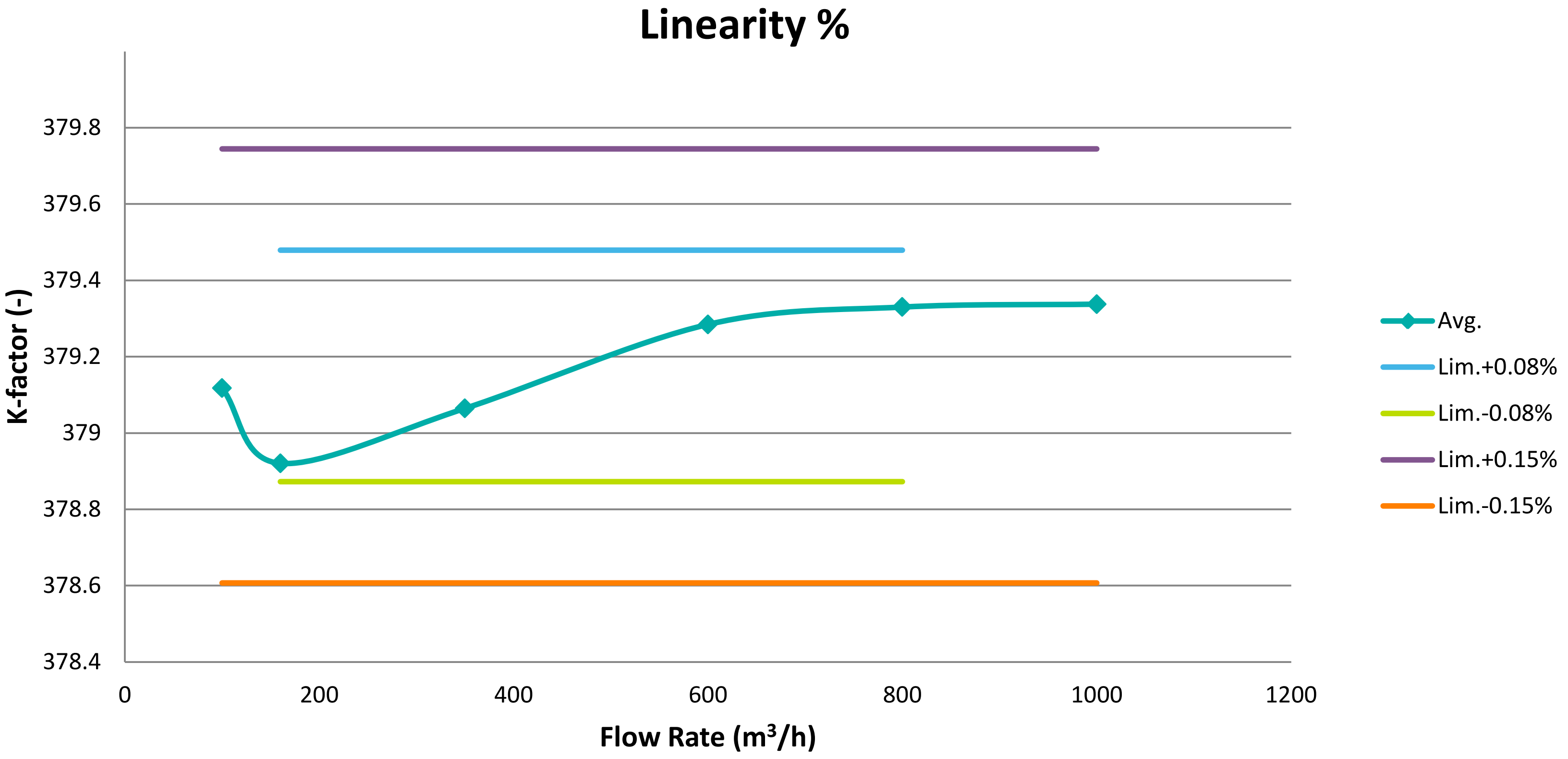
K-factor Calibration Curve - Example



Calibration – Flow meter correction factors

K-factor

- Determined for each flow rate
- Number of pulses per volume or mass unit (pulses/kg or pulses/m^3)

$$Volume = \frac{Number\ of\ pulses}{\boldsymbol{Actual\ K\_factor}}$$

Meter factor (MF)

- Determined for each flow rate
- Correction factor (-) for multiplication with flow meter output
- Must know **nominal K-factor**!

$$Volume = \boldsymbol{MF} \times \frac{Number\ of\ pulses}{\boldsymbol{Nominal\ K\_factor}}$$

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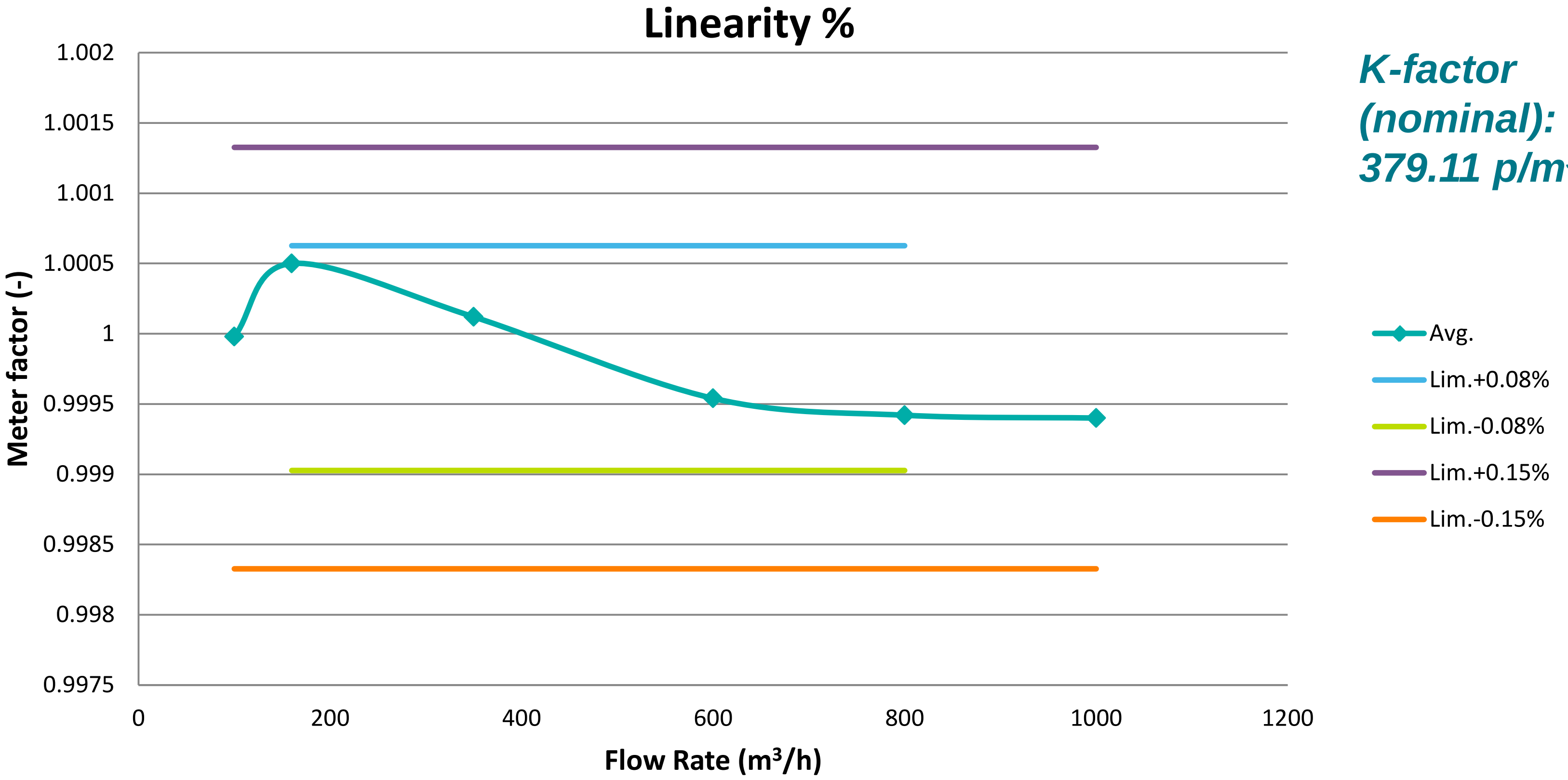
Meter Factor Calibration Curve - Example



K-factor (nominal): 379.11 p/m^3

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Flow Calibration Certificate – Example Turbine

FAURE HERMAN

...nction du débit (m3/h)

Repère	K facteur (Kf)	
33FE9600	0,379110	imp / litre

Nominal KF

Réf. de l'étalon : 91.8021

Volume étalon...

Repère du banc...

Client : ...

Produit :	Fuel-Oil (FOD)	
...sité @ 20°C :	4,00	mm²/s
...vol. @ 15°C :	834,2	kg/m^3
...nde client :	X	

N° commande FH	N° Test
11000364	

Deviation (%) =

$$\frac{Indicated\ flow - Reference\ flow}{Reference\ flow}$$

Meter factor =

$$\frac{1}{1 + [\frac{deviation(\%)}{100}]}$$

K-factor =

$$\frac{Nominal\ Kfactor}{Meter\ factor}$$

Débit moy.	993,0	806,1	601,9	349,5	159,1	103,5
Viscosité	2,77	2,63	[illegible]	[illegible]	[illegible]	[illegible],68
F moy. Hz	104,6	84,9	[illegible]	[illegible]	[illegible]	[illegible]0,9
MF moy.	0,9994	0,9994	0,[illegible]	[illegible]	[illegible]	[illegible]0000
Err.moy. %	0,061	0,057	[illegible]	[illegible]	[illegible]	[illegible]001
Kf Moy.	0,3793	0,3793	0,[illegible]	[illegible]	[illegible]	[illegible]3791
Rép.%	0,028	0,017	[illegible]	[illegible]	[illegible]	[illegible]024

← Flow Rate (m3/h)

← Meter Factor

← Error

← K-factor

Calibration – Linearizing

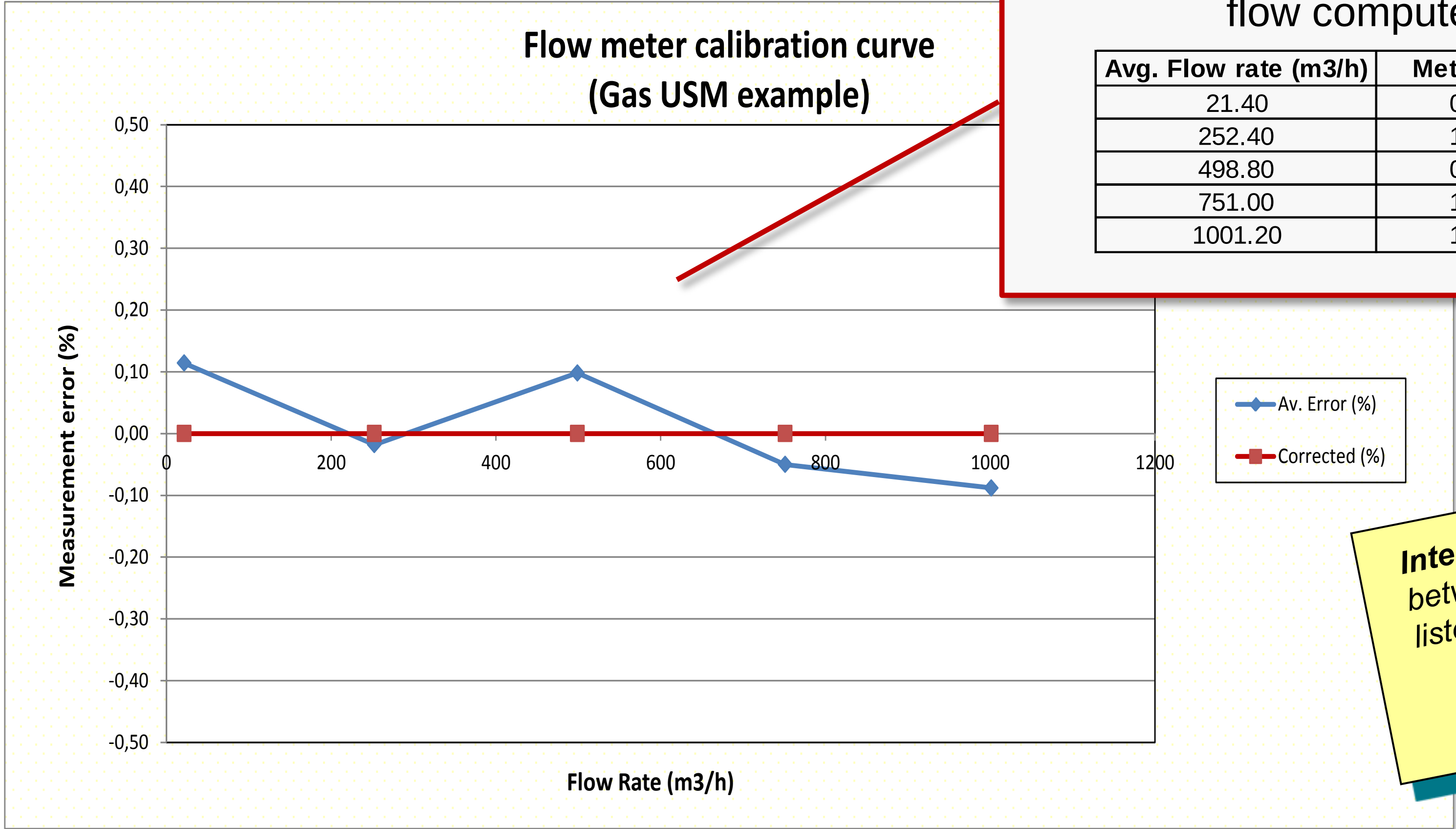


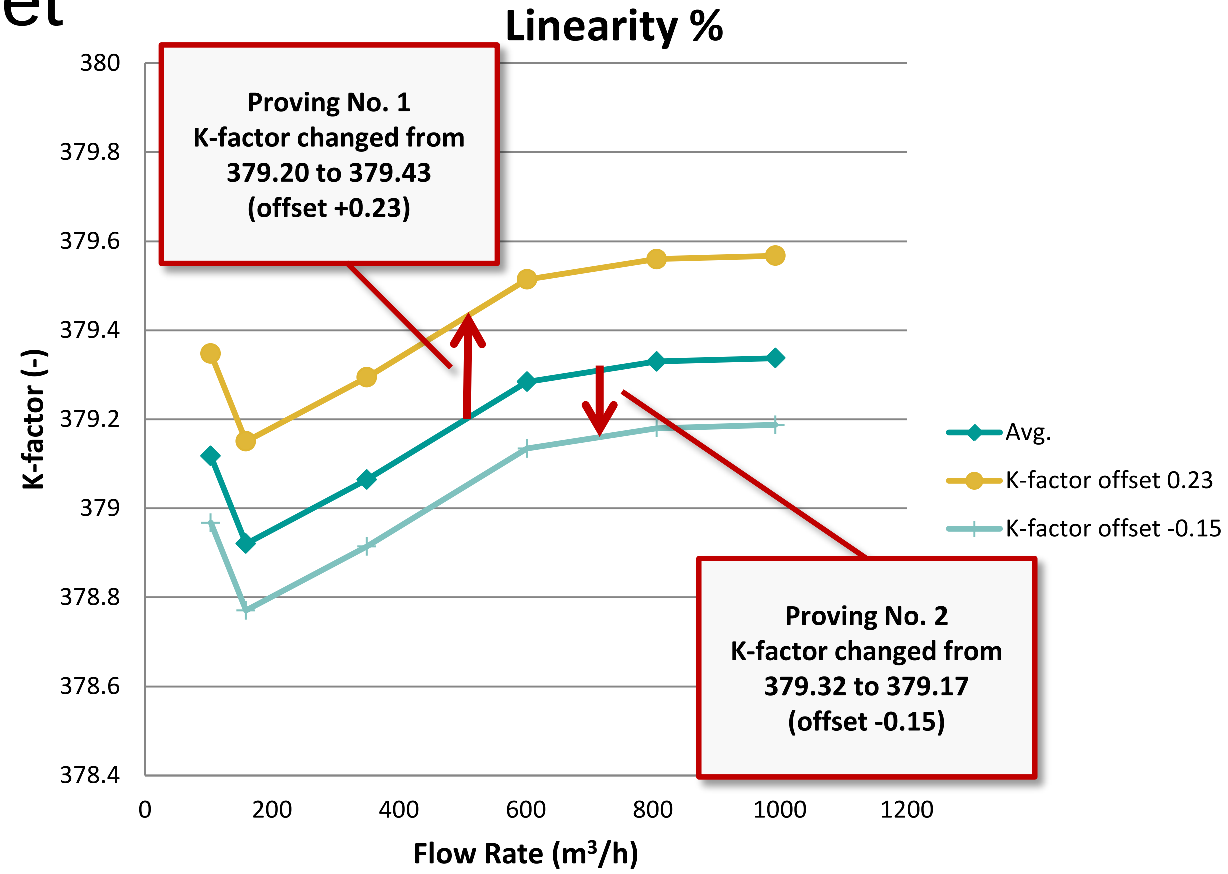
Table entered into flow computer:

Avg. Flow rate (m3/h)	Meter factor (-)
21.40	0.998861
252.40	1.000180
498.80	0.999021
751.00	1.000500
1001.20	1.000881

Interpolation *between the listed flow rates*

K-factor offset

- Linearizing curve established at accredited flow laboratory
- The **curve (shape) is kept unchanged** for the flow meter
- Single point onsite proving generates a **K-factor offset which shifts the curve up or down**



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Calibration – Linearizing options

Flow computer data entry options:

1. K-factor (p/m^3) against indicated flow rate (m^3/h)
2. Meter factor (-) against indicated flow rate (m^3/h)
3. Deviation (%) against indicated flow rate (m^3/h) **NEW!**

4. K-factor (p/m^3) against Reynolds number (-)
5. Meter factor (-) against Reynolds number (-)
6. Deviation (%) against Reynolds number (-) **NEW!**

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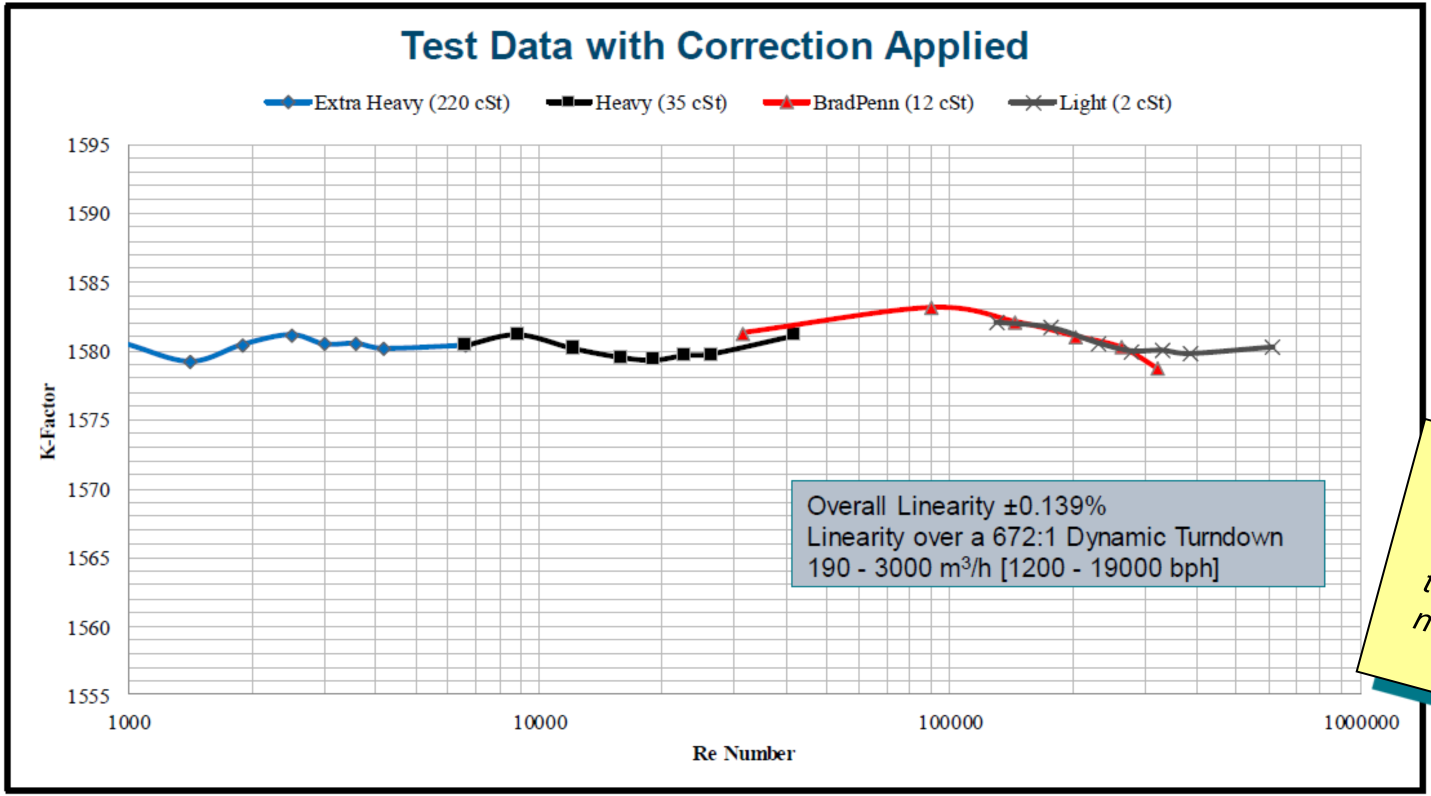
Calibration – Linearizing w.r.t. Reynolds number



$$R_e = \frac{\rho v d}{\mu}$$

ρ = density (kg/m³)

v = velocity (m/s)

d = diameter of pipe (m),

μ = viscosity (Pa.s)

Re < 2000 flow is Laminar.

Re > 4000 flow is Turbulent.

Must know the **viscosity** in order to calculate the Reynolds number

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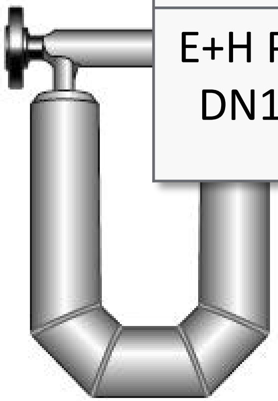
Coriolis meters

Pressure and temperature correction for Coriolis flow meters?

- No standardized method
- Built-in temperature sensor and correction
- Sensitive to pressure
- Fixed pressure input?
- Online pressure correction?



Coriolis flow meter	Pressure effect on mass flow rate (%/bar)
MicroMotion CMF400 (6-inch)	-0.016
E+H Promass 84F DN150 (6-inch)	-0.009

10 bar pressure increase gives approx. **0.1%** lower mass flow

Questions or comments

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