IMPROVING THE ACCURACY OF CEMS BY MEANS OF MULTIPATH ULTRASONIC FLOWMETER

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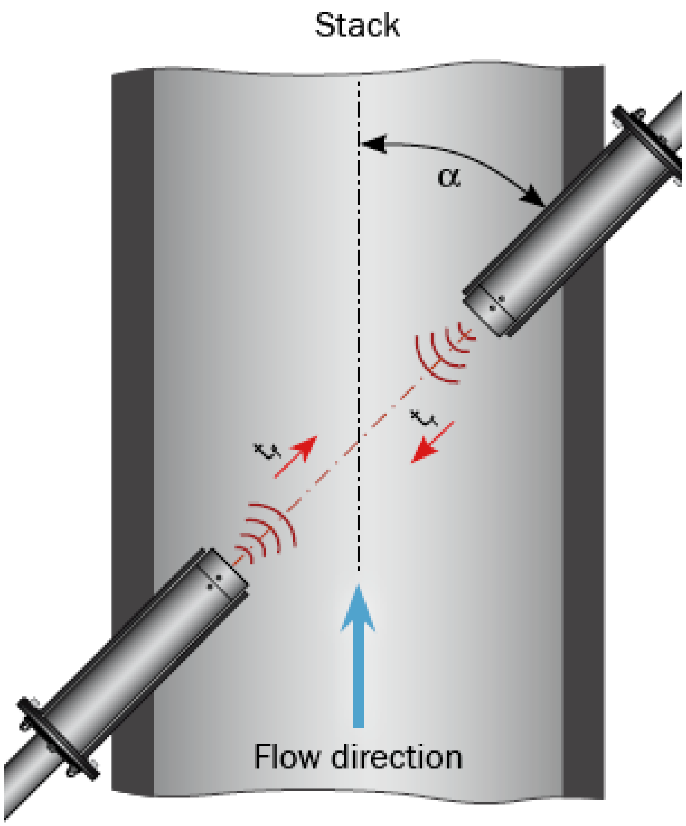
20. April 2015

ULTRASONIC FLOW METER
MEASUREMENT PRINCIPAL



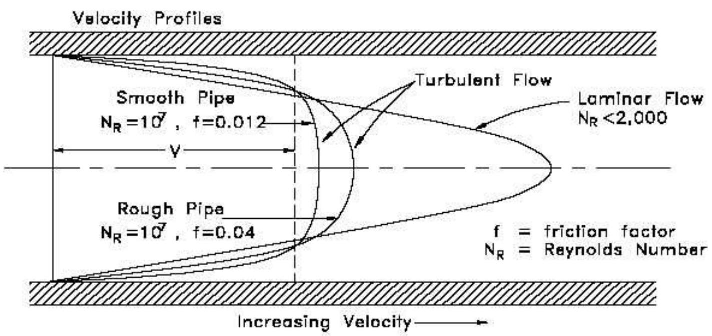
$$t_{AB} = \frac{L}{c + v_p \cos(\alpha)} \qquad t_{BA} = \frac{L}{c - v_p \cos(\alpha)}$$

$$v_p = \frac{L}{2\cos(\alpha)}\left(\frac{1}{t_{AB}} - \frac{1}{t_{BA}}\right)$$

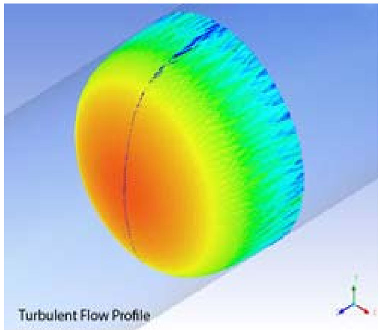
$$Q_V = k \cdot \frac{\pi}{4} \cdot D^2 \cdot v_p$$

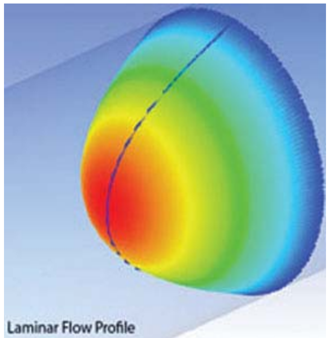
v_p	-	average velocity on measuring path
t_{AB}.t_{BA}	-	transit times
L	-	length of measuring path
D	-	diameter
α	-	installation angle to flow axis
c	-	speed of sound
k	-	calibration factor

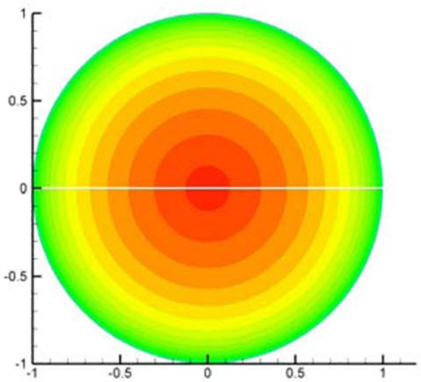
ULTRASONIC FLOW METER
MEASUREMENT PRINCIPAL



picture: nuclearpowertraining.tpub.com

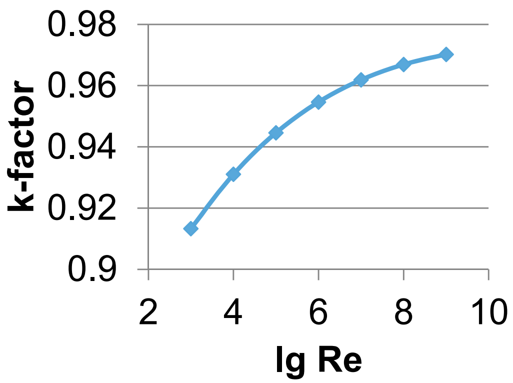




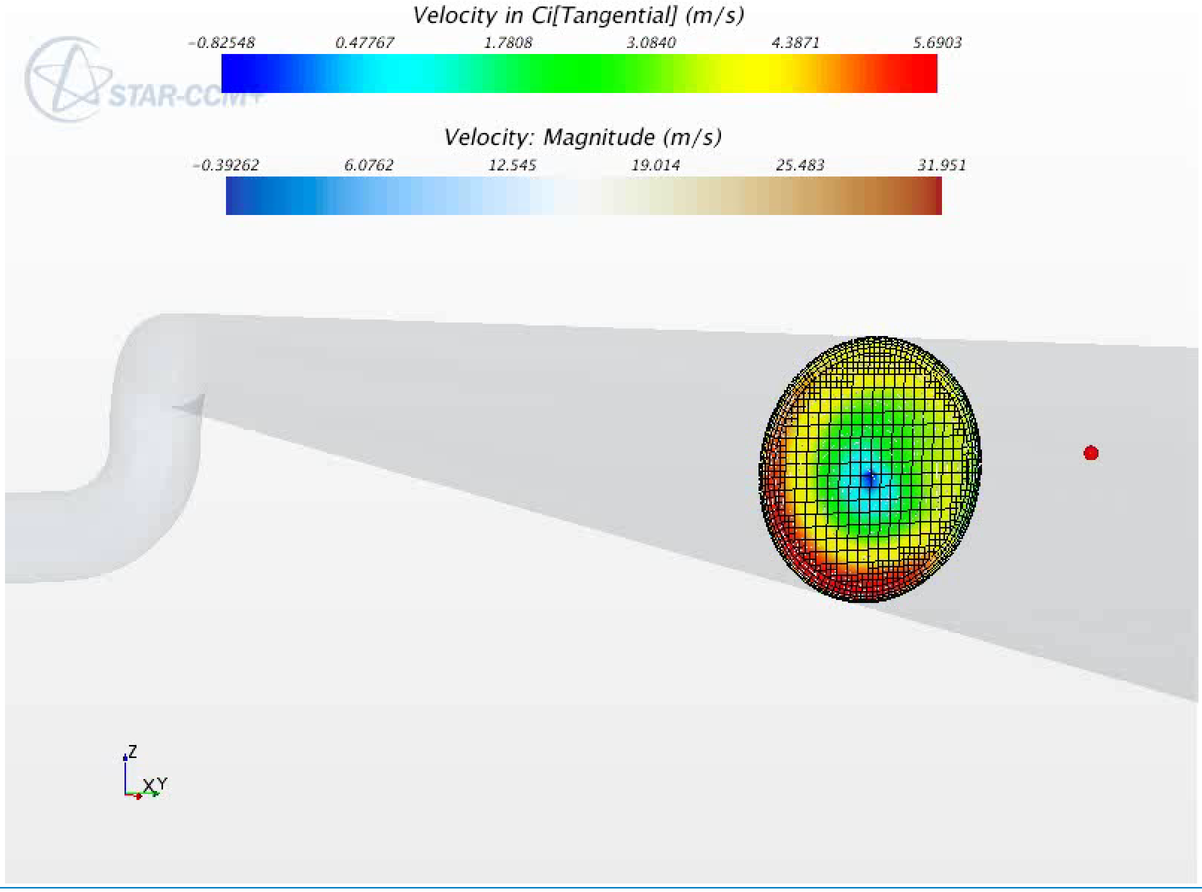


$$v_A = k \cdot v_p$$

$$k = \frac{2}{R} \frac{\int_0^R v(r) \cdot r \, dr}{\int_0^R v(r) \, dr}$$

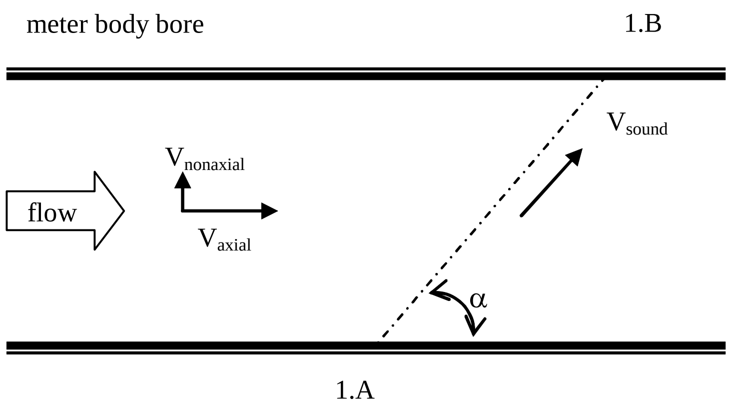


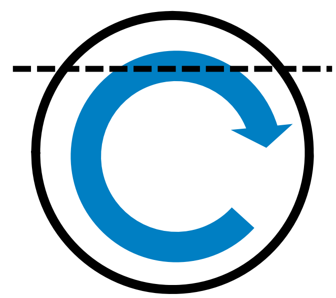
UNCERTANTY CONSIDERATIONS
FLOW PROFILE



UNCERTAINTY CONSIDERATIONS
FLOW PROFILE

- Swirl adds a velocity component!





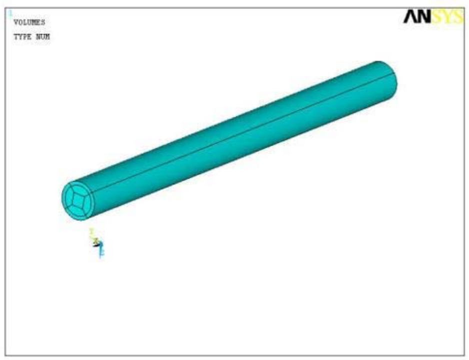
$$t_{AB} = \frac{L}{c + v_p \cos(\alpha)}$$

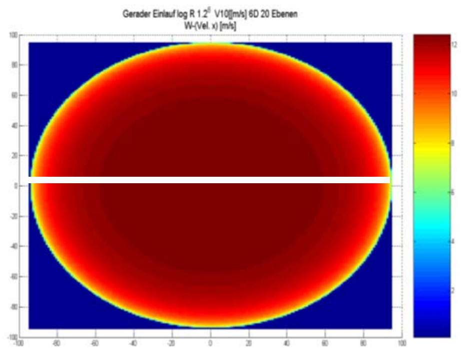
$$t_{BA} = \frac{L}{c - v_p \cos(\alpha)}$$

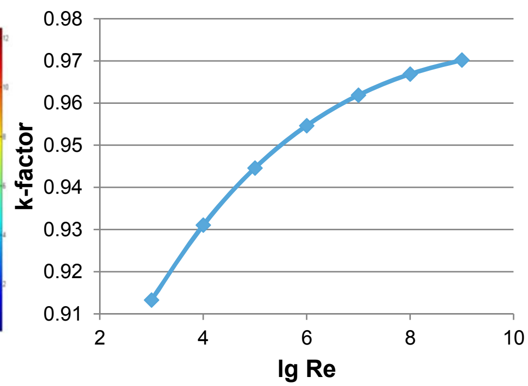
$$t_{AB} = \frac{L}{v_{sound} + \cos(\alpha) \cdot (v_{axial} + v_{\text{nonaxial}} \cdot \tan(\alpha))}$$

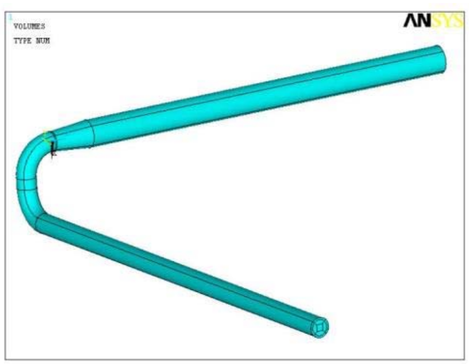
$$t_{BA} = \frac{L}{v_{sound} - \cos(\alpha) \cdot (v_{axial} + v_{\text{nonaxial}} \cdot \tan(\alpha))}$$

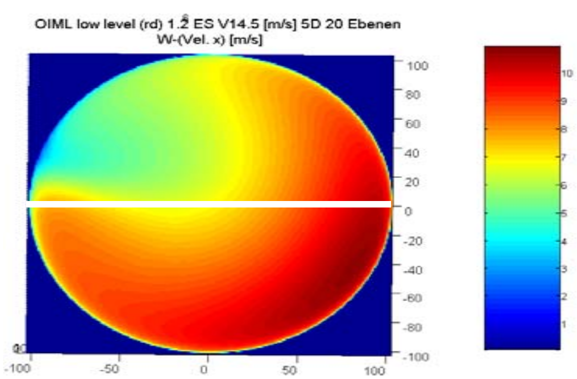
UNCERTANTY CONSIDERATIONS
FLOW PROFILE





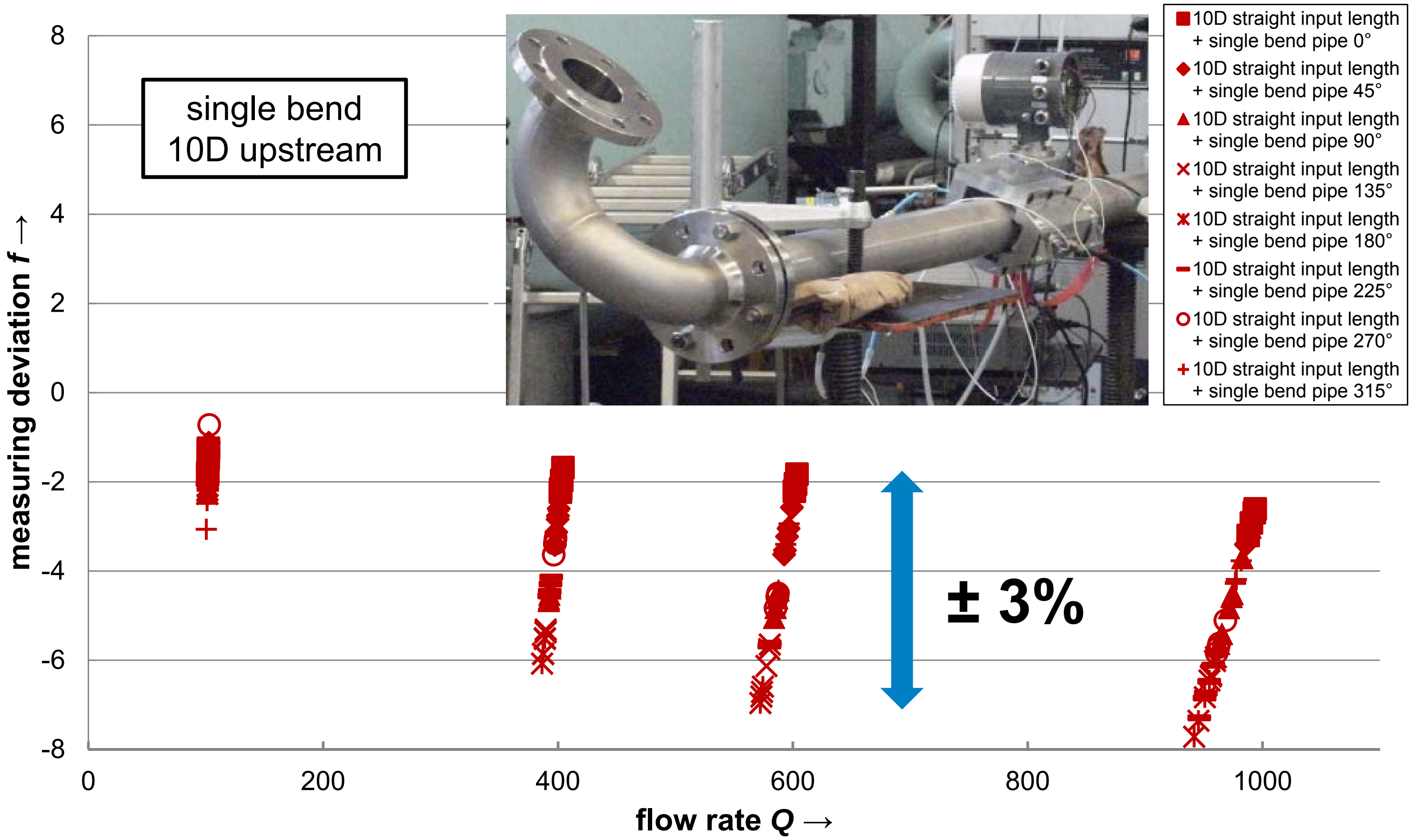




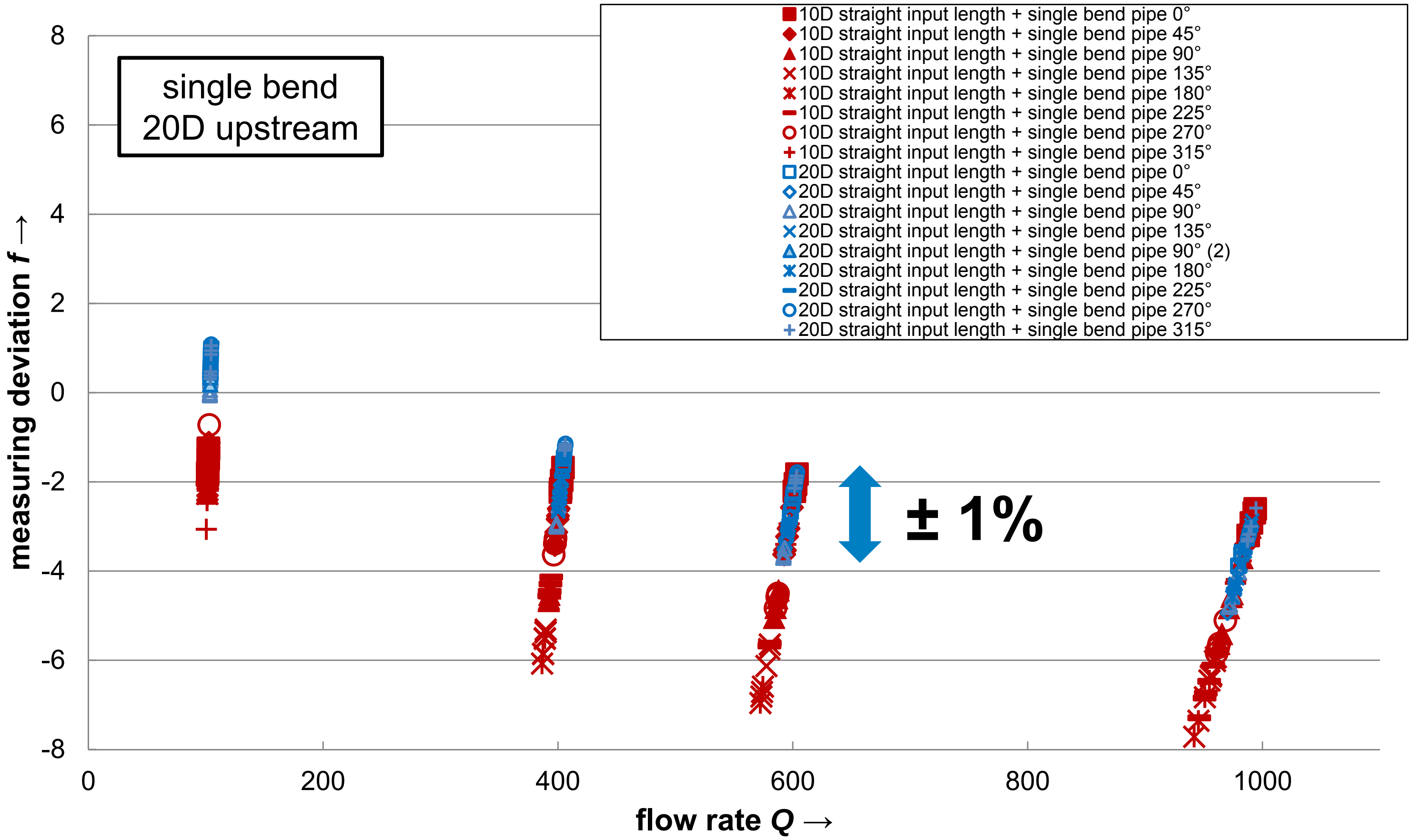


UNCERTAINTY CONSIDERATIONS
INVESTIGATION SINGLE PATH SYSTEM

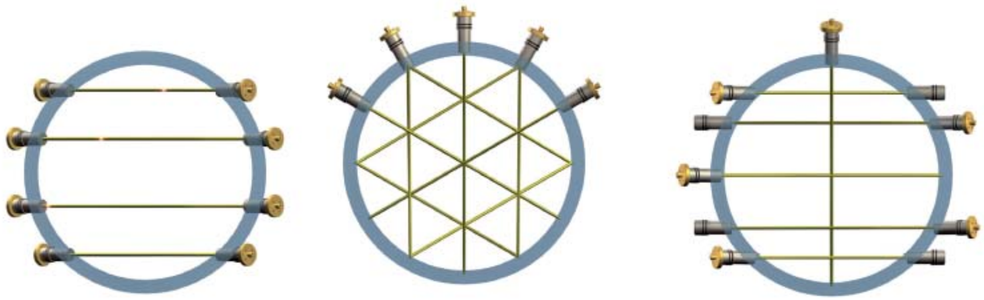
SICK Sensor Intelligence.

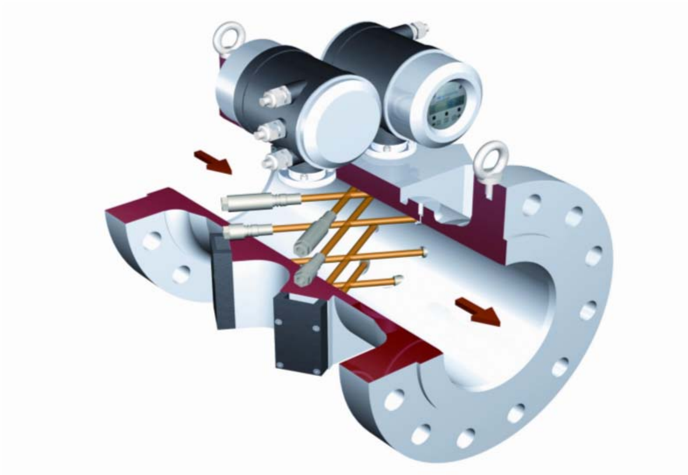


UNCERTAINTY CONSIDERATIONS
INVESTIGATION SINGLE PATH SYSTEM



ULTRASONIC FLOW METER
FISCAL METERING GAS TRANSMISSION





- Size: 2“ to 48“
- Pressure: 100bar
- Dry, clean gas
- Machined meter body
- Accurately measured geometry
- Meters are calibrated at a flow lab

ACCURACY CLASSES

Installation Effects

Class 1.0: less than 0.33%

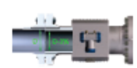
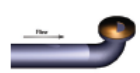
Class 0.5: less tan 0.16%

DOCUMENTS

ISO 17089-1&2.

A.G.A. Report 9

OIML R137

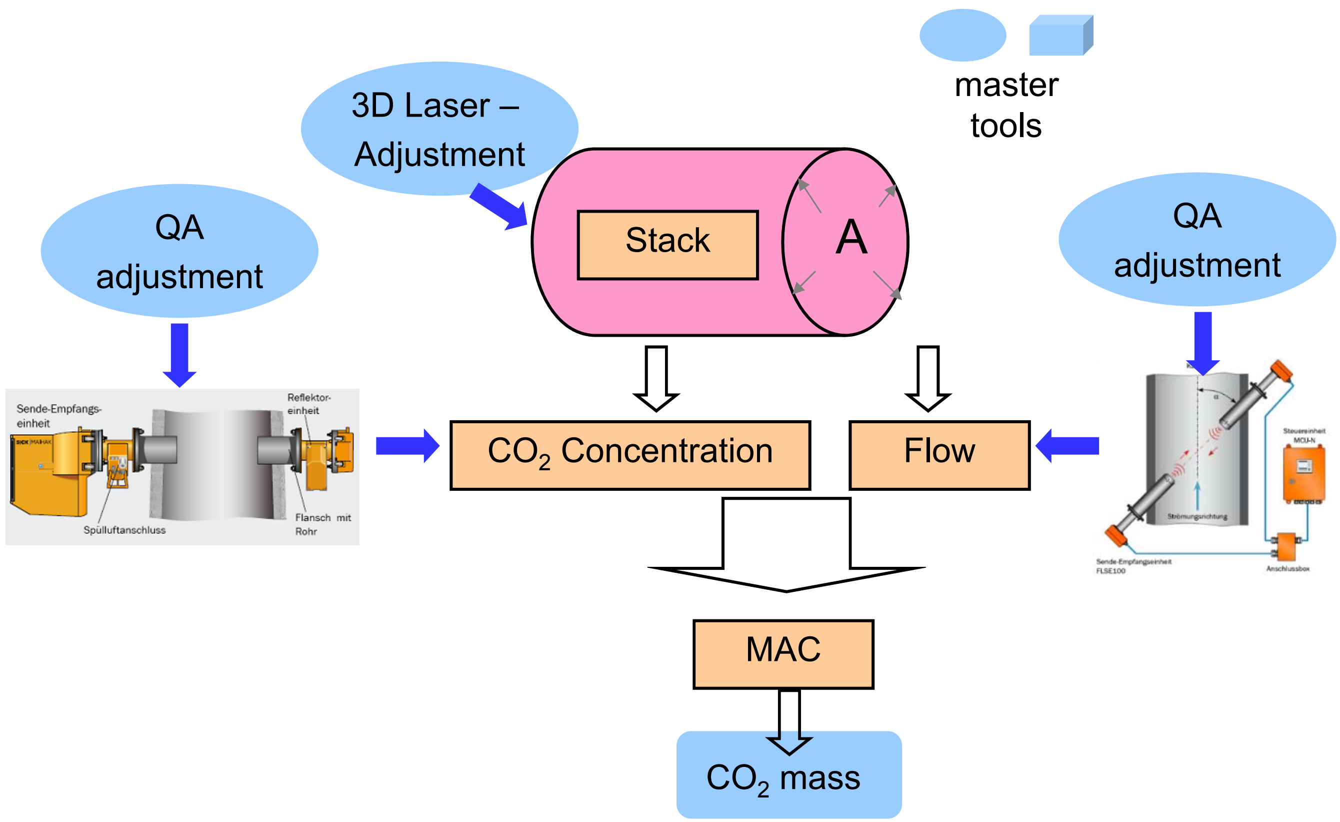
Test		Test conditions	Remarks
a		Reference conditions	approx. 80 D straight line approx. 10 D straight line (see Note)
b		A single 90° bend	radius elbow: 1.5 D
c		Double out-of-plane bend	rotating right; radius elbows: 1.5 D
d		Double out-of-plane bend	rotating left; radius elbows:1.5 D
e		Expander	one step difference of the pipe diameter is applied angle of expansion/reduction part: ≤ 15°
f		Reducer	
g		Diameter step on the upstream flange	approx. +3 % and –3 %
+		Half pipe area plate	image shows first bend in piping and mounting of half-moon plate.

EXAMPLE
PROJECT DIRECT CO2 MONITORING

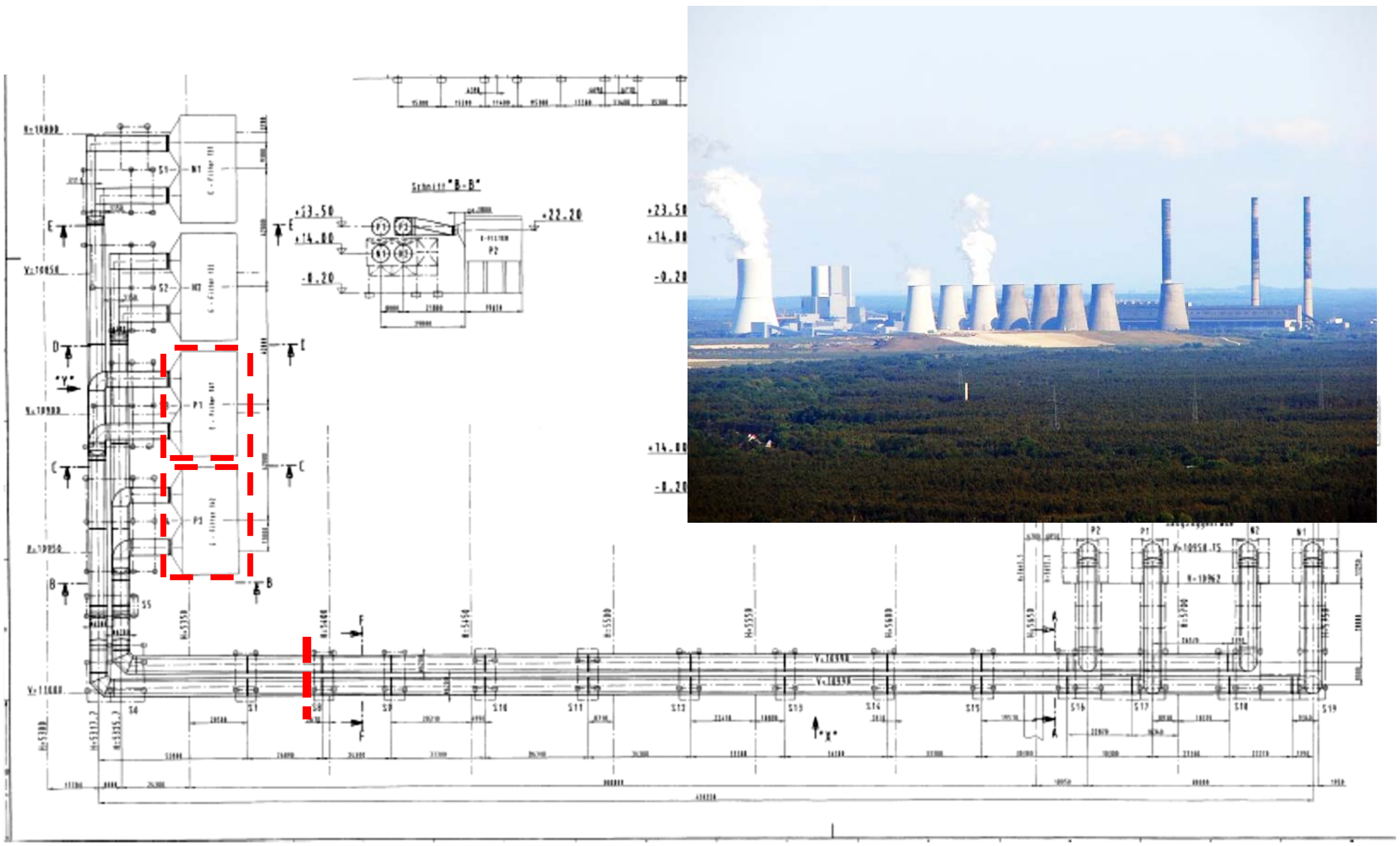
SICK
Sensor Intelligence.

PROJECT DIRECT CO2 MONITORING

SYSTEM OVERVIEW

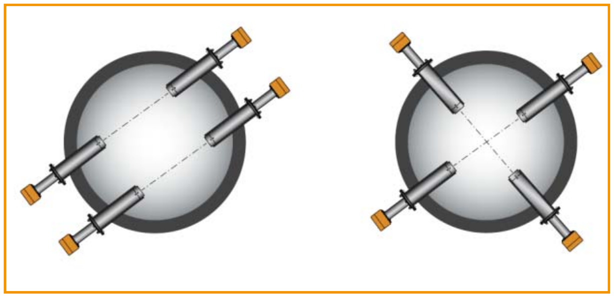


PROJECT DIRECT CO2 MONITORING
INSTALLATION



PROJECT DIRECT CO2 MONITORING
FLOW MEASUREMENT

- Installation FLOWSIC100:
  - Target uncertainty (as found): $U_{k=2} \leq \pm 1.0\%$
  - 2-path system
    - — 60° path angle
    - — Chordal layout, mid radius position



  - Upstream of the flue gas scrubber
  - T = 165°C (330°F)
  - Inner diameter 6200mm (20.34ft)
  - approx. 5D downstream of a 90°-bend with guiding plates

- Validation by
  - an extended measurement traverse at real conditions
  - Comparison with thermo-dynamic model calculation

PROJECT DIRECT CO2 MONITORING
ADJUSTMENT TIME MEASUREMENT

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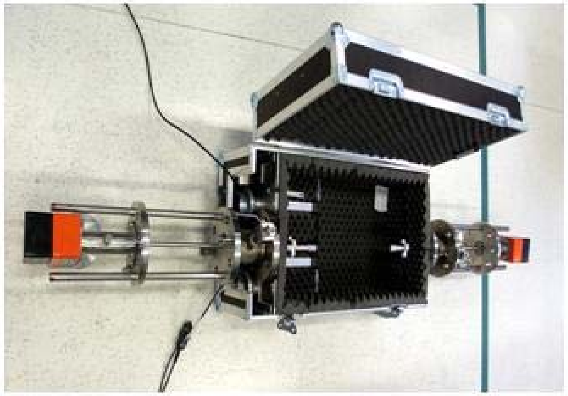
Zero flow check and SOS-check

Each device passed a zero-flow and a speed of sound check to reduce the manufacturing uncertainty

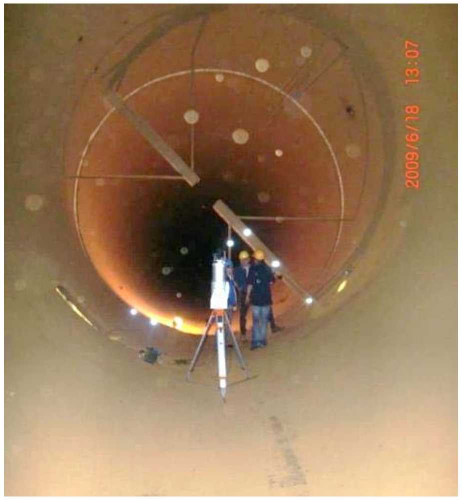


	U (k=2)
Time difference / µs	0.5
Time absolute / µs	2.8

PROJECT DIRECT CO2 MONITORING
GEOMETRY PARAMETER

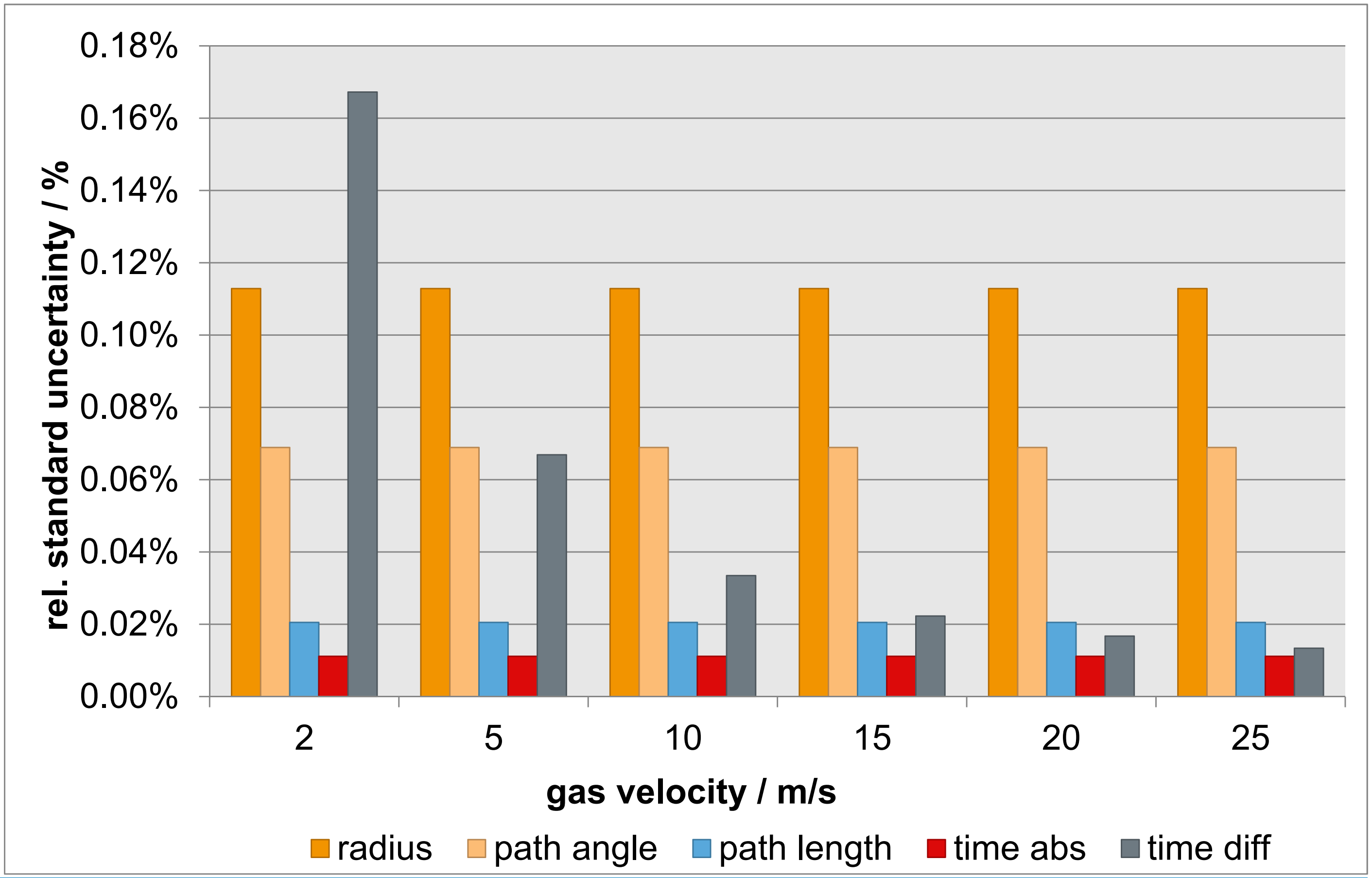
- 3D laser scanner on site for precise measurement of
  - Diameter.
  - Path length and
  - Path angle

Parameter (N2)	value	u
Radius / mm	3102	7
Path length 1 / mm	6135	5
Path length 2 / mm	6177	5
Path angle 1 / °	57.66	0.1
Path angle 2 / °	57.63	0.1



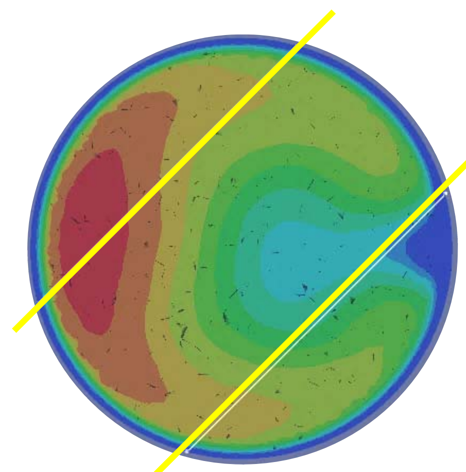
- 0.1° error @ 60° path angle → 0.3% velocity error

PROJECT DIRECT CO2 MONITORING
UNCERTAINTY CONTRIBUTIONS

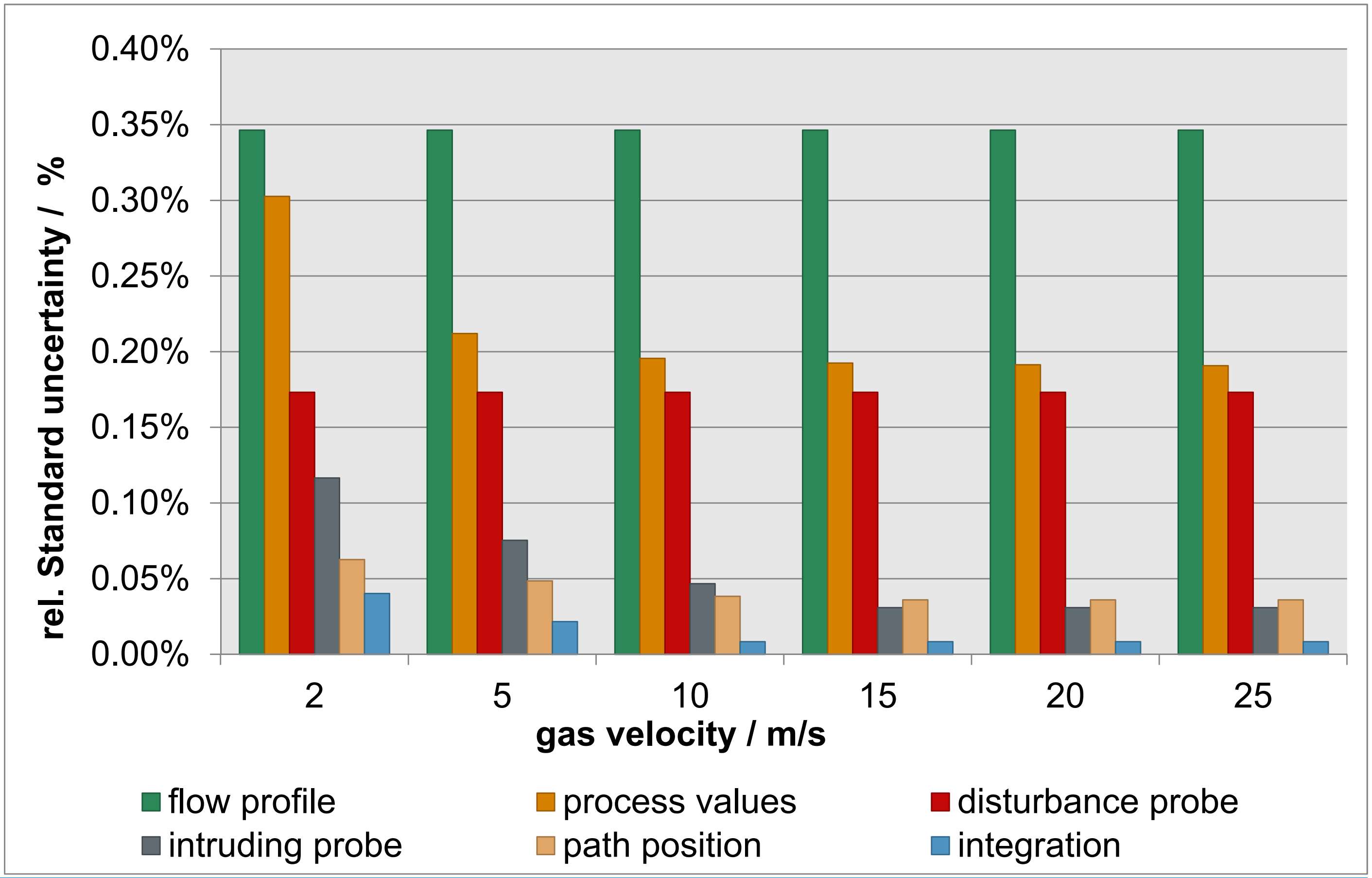


PROJECT DIRECT CO_2 MONITORING
COMPUTATIONAL FLUID DYNAMICS

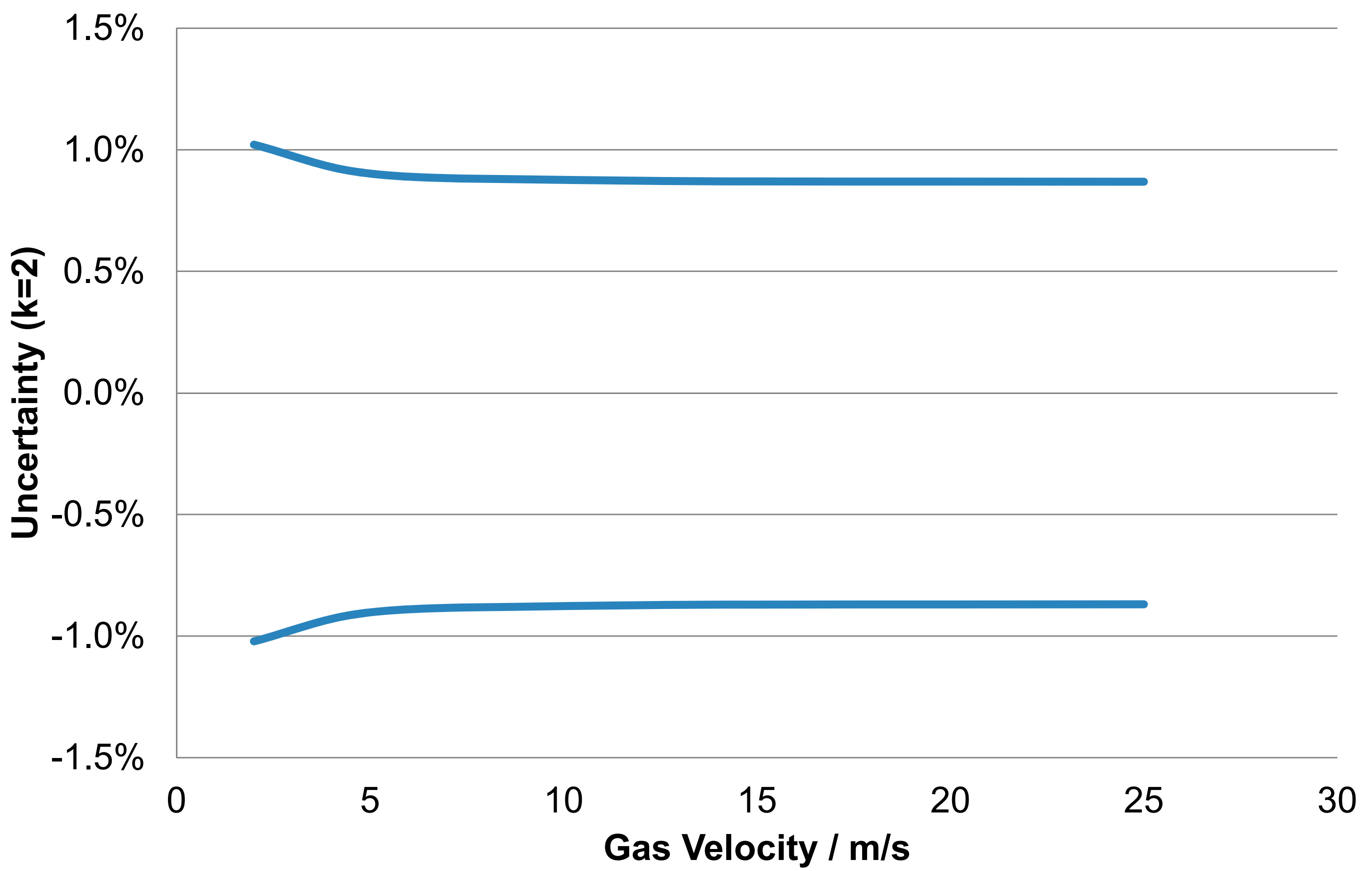
- Virtual adjustment: theoretically defined calibration function based on CFD calculations
- „Virtual calibration“ of the flow meter $k = m \cdot x + n$
- „Worst Case analysis“ – rotation of the flow profile ±0.6%



PROJECT DIRECT CO2 MONITORING
UNCERTAINTY CONTRIBUTION



PROJECT DIRECT CO2 MONITORING
EXPECTED UNCERTAINTY FLOW MEASUREMENT



PROJECT DIRECT CO2 MONITORING

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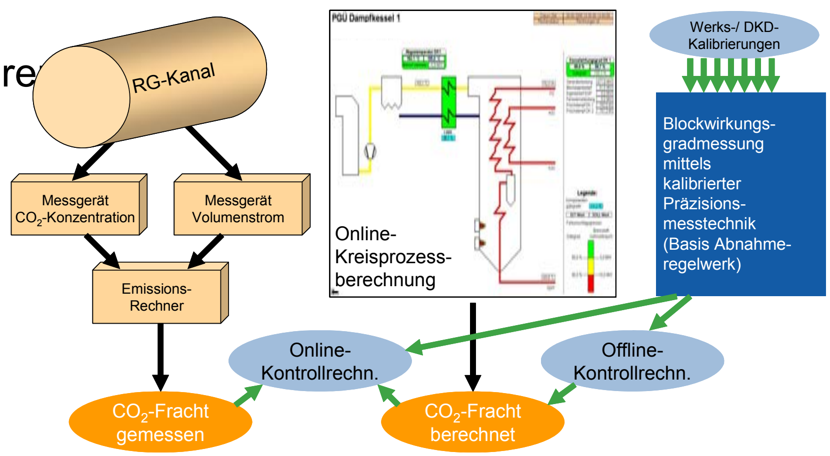
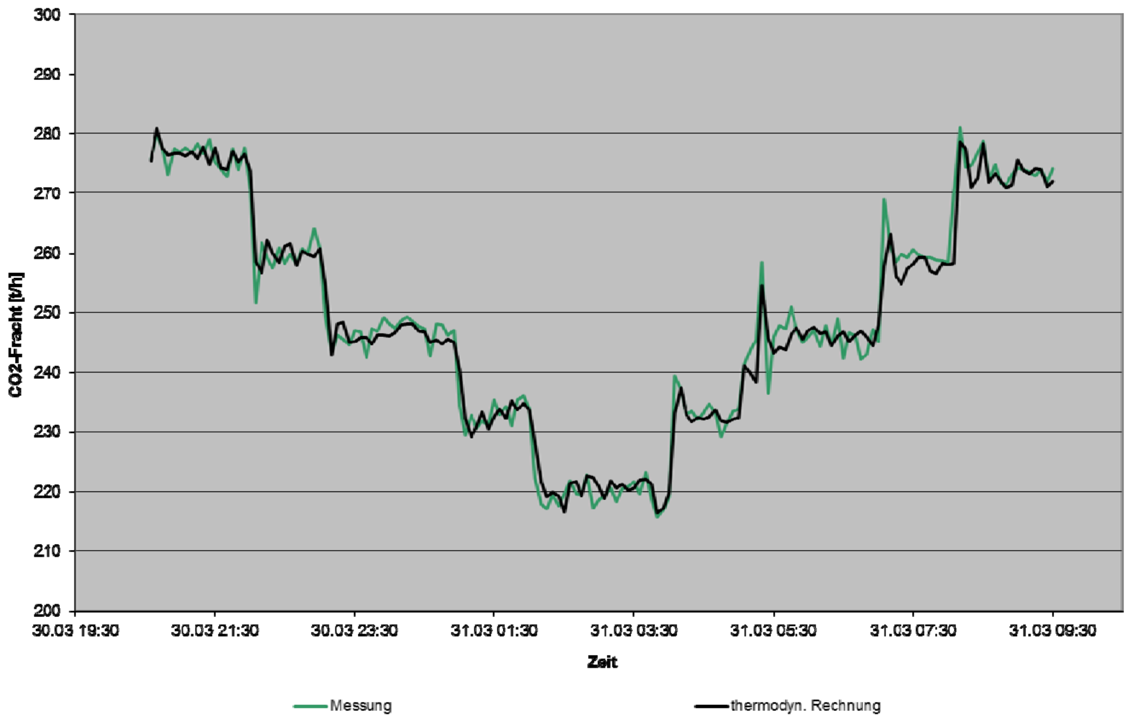
- (1) continuous thermo-dynamic calculation
  - Process measurement
  - Model of the thermodynamic cycle
- (2) Mass balance analysis
  - Mass of burned coal
  - Chemical analysis the coal
- (3) extended traverse test measure
  - Acceptance inspection



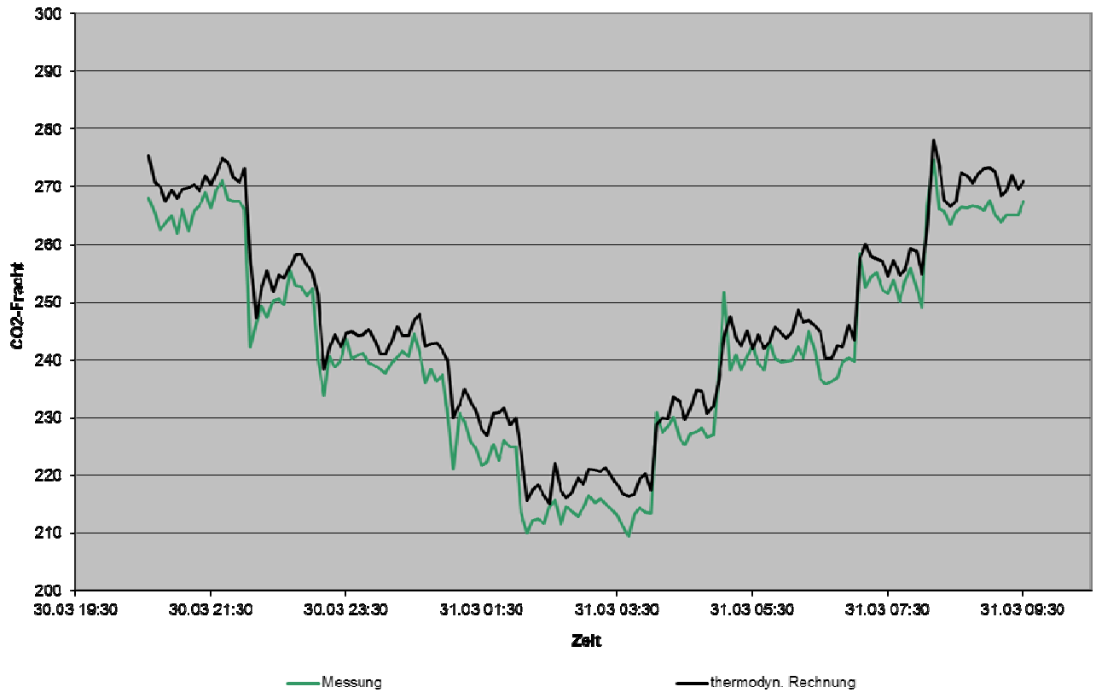
THERMODYNAMIC MODEL CALCULATION
UNIT N1

- Average deviation $\Delta = 0.1\%$
- sigma: $\sigma = \pm 1.4\%$



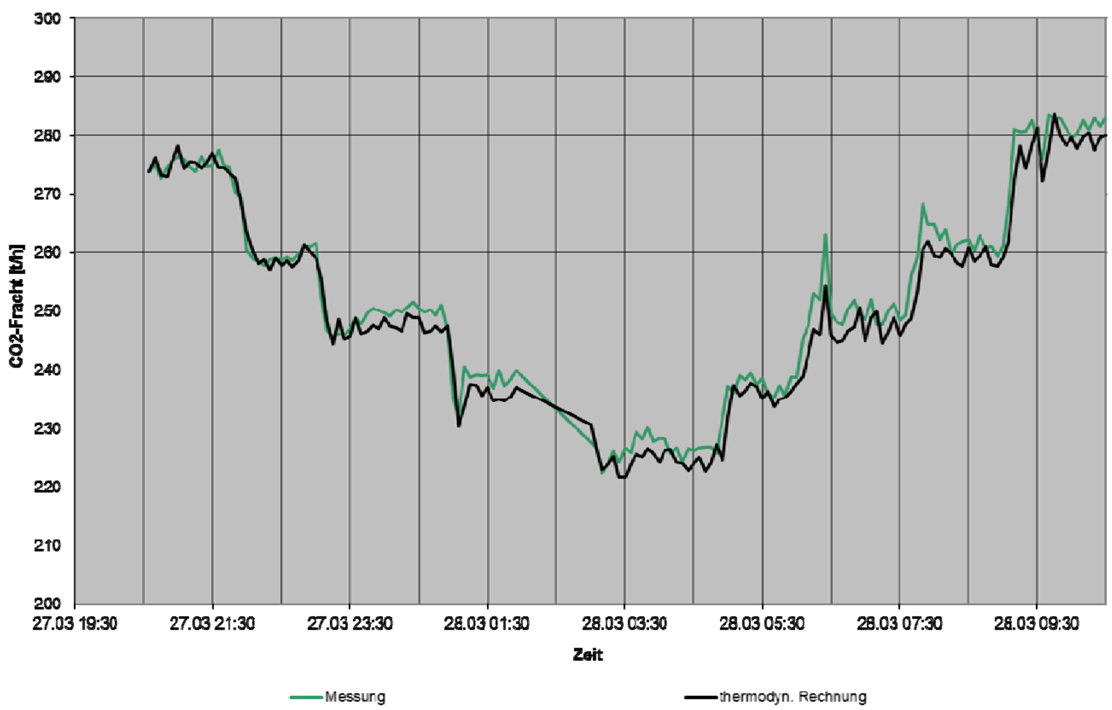
THERMODYNAMIC MODEL CALCULATION
UNIT N2

- Average deviation: Δ = -1.85%
- Sigma: σ = ±1.1%



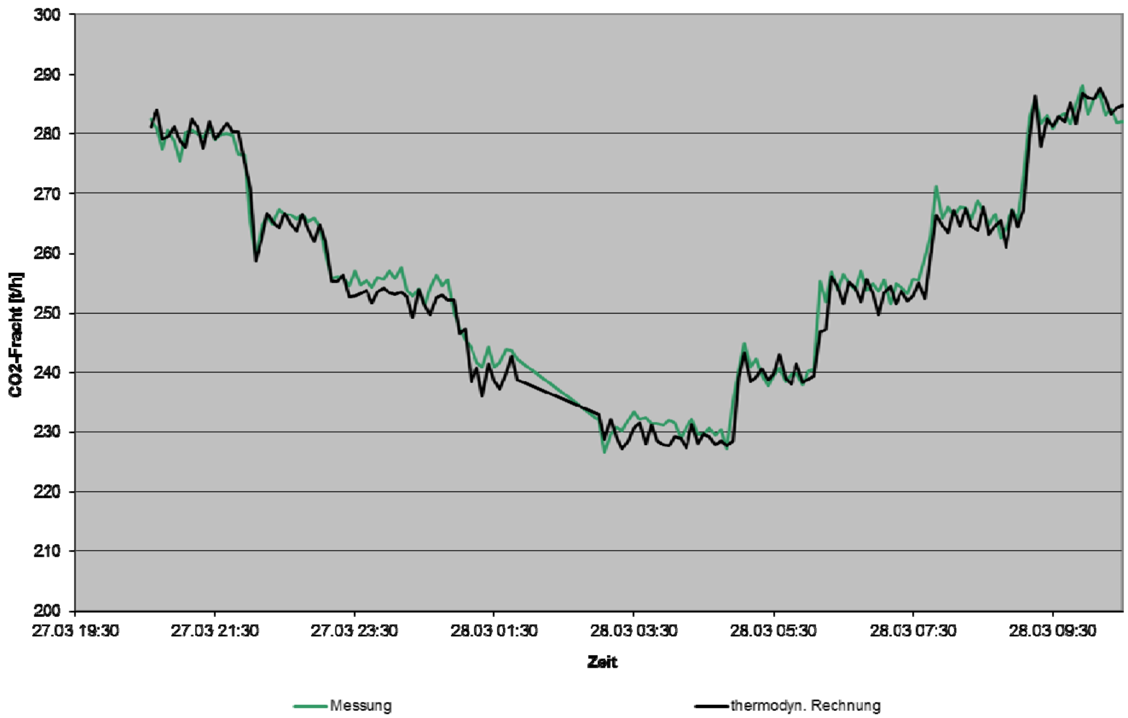
THERMODYNAMIC MODEL CALCULATION
UNIT P1

- Average deviation: Δ = 0.81%
- Sigma: σ = ±1.0%



THERMODYNAMIC MODEL CALCULATION
UNIT P2

- Average deviation: $\Delta = 0.49\%$
- Sigma: $\sigma = \pm 1.0\%$



RESULTS
TOTAL CO2 MASS DIFFERENCES

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method	Period	Unit N1	Unit N2	Unit P1	Unit P2
Total mass balance (U: 1.5%)	2 month	0.80%			
Thermo dynamic model calculation (U: 1.5%)	1st month	-0.10%	1.85%	0.81%	0.49%
	2nd month	0.50%	2.50%	1.20%	0.50%
Extended Traverse (U: 1.3 .. 2.2%)	Single test	-0.14%	1.86%	0.75%	0.47%

SUMMARY

- CEMS:
  - Measurement uncertainty of better than 1.5% is realistic for direct CO_2 monitoring
  - Verification uncertainty is at the same level!

- Recommendations for the Ultrasonic flow meter
  - Install with max. possible straight upstream length
  - Reduce the uncertainty by multi path layout (≥ 2path)
  - Use CFD analysis
    — to find an optimized path layout (if you have the freedom)
    — And/or calculate a “dry” calibration function
  - Do precise geometry measurement, especially
    — Path angle
    — Diameter

MANY THANKS FOR YOUR ATTENTION.