MEAS-6-22

“High-Pressure Calibration of Turbine/USMs with an Inert Gas”

PRCI 2019 Winter TC Meeting
6 Feb 2019

Emmelyn Graham
Objectives

- Assess the feasibility of using inert gas as a calibration medium for ultrasonic and turbine meters.
- Develop method to transfer calibration in inert gas to natural gas.
Milestone 1 – Review & Modelling

Task 1.1 Mathematical Model
• Review literature to determine impact of different gas properties on performance of turbines & USMs
• Build model to predict effects of different gas properties (focus on nitrogen) to use as calibration gases for turbines & USMs

Task 1.2 Correction Model
• Develop correction model to transform the results from an inert gas calibration to meter data that is representative for a natural gas application. This would allow a natural gas certificate based on an inert gas calibration.

Task 1.3 PRCI Database & Protocol
• Access to standard test protocol developed by PRCI and database for capturing calibration data & diagnostics. This will be used to collect and standardise data from testing.
Milestone 2 – Detailed Test Plan

Task 2.1 Develop test plan – initial stage (1)
• Develop detailed test plan based on the data from Task 1.

Task 2.2 Develop test plan – refinement (2)
• Final test matrix to be agreed

Task 2.3 Develop test plan – final stage (3)
• Selection and provision of suitable flow meters, pipework & adapters

Milestone 3 – Flow Testing

Task 3.1 Testing in Natural Gas at FORCE
Task 3.2 Testing in Nitrogen Gas at NEL

Milestone 4 – Evaluation & Analysis
Milestone 5 – Final Report
• Literature review is complete
  – Reviewed nearly 80 documents

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<th>Link</th>
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Comments:
- Good background on USM principles
- Mention on fluid property effects on VoS (P, T, dens, comp)
- Gas properties should not have significant impact on performance
- Re will affect pipe profile and path curvature
- CO2 may attenuate signal
- Calibrations should be as close to operational Re as possible
- If manual input of gas properties required, manufacturer should state sensitivity on performance
- Nitrogen as a reference gas is mentioned
- Similar to 1 but less detail
- No mention of Reynolds
- Comparison of turbine and USM at PTB and NIST
- Re used to characterise both meters
- For USM (4-path), individual paths compared
- VoS not required for gas velocity—It is used for diagnostics
- Calculation of average velocity often part of proprietary software algorithms
- Measurement of transit time key measurement
- VoS more sensitive to temperature and composition than pressure
- VoS sensitive to composition
- Majority of users use flow conditioners
- Similar to 4
- Additional info on dynamic diagnostics
- Says if flow diagnostics similar to calibration diagnostics, good indicator that calibration
Literature on USMs

- Reynolds numbers will be high during the tests (fully turbulent flow)
  - USM behaviour becomes more linear & profile changes flatten out.
  - Fluid effects are less likely to influence results, than with e.g. laminar liquids.
- For Re > 10 000 for same Re with different T,P, viscosity – meter exhibits similar behaviour
- USMs can account for Re through profile factor corrections. Sophisticated computational techniques are used to determine corrections that are hidden in the USM “black-box”. Calculation of average velocity is part of these proprietary software algorithms.
- Without knowing the ‘black-box’ methodology it is largely impossible to determine any extra uncertainty, or even how good the method is at correcting the changes due to Reynolds number
- Re effects different for different types of meters

\[
\bar{v} = \frac{L}{2 \cos \theta} \cdot \frac{\Delta t}{t_{ab} t_{ba}} = \frac{L^2 \Delta t}{2 x t_{ab} t_{ba}}
\]
• Past work has shown that using different gases at different conditions may not have a significant impact on meter performance and differences are likely to be within facility uncertainties.

• USMs have multiple diagnostic parameters and some of these will be affected by the gas type, e.g. velocity of sound (VoS) and gain

• VoS not used for gas velocity calculations but is sensitive to T, P & composition

• Recommended to match on density and Re
Update on USM modelling & testing

- 4” USM is provided by Emerson
  - Received information last week on meter to progress modelling & correction

- 8” USM meter is no longer available for project

- Gasunie is investigating possibility of sourcing 8” USM
- Otherwise Emerson maybe able to provide a meter
Turbine Modelling
Simple Re fit

- 232 psi (16 bar) & 725 psi (50 bar) data
- Doesn’t fit so well at low Re

\[ f_{meas} = a_0 + a_1 \left( \frac{Re}{10^6} \right) + a_2 \left( \frac{Re}{10^6} \right)^2 + a_3 \left( \frac{Re}{10^6} \right)^3 \]
• 232 psi (16 bar) & 725 psi (50 bar)
• Improved fit

Straatma polynomial model describes the meter deviation versus flow rate:

$$e(Q) = a_0 + a_1 \left( \frac{Re}{Re_{\text{max}}} \right)^p + a_2 \left( \frac{Re}{Re_{\text{max}}} \right)^q + a_3 \left( \frac{Re}{Re_{\text{max}}} \right)^r$$  \hspace{1cm} (3)

Eq. (3) is based on the forces inside a turbine gas meter [3, 4], where:
- $a_0$: offset
- $p = -0.2$: drag force flowing gas and rotor blades, $a_1 < 0$
- $q = -0.33$: boundary layer in the meter annulus, $a_2 > 0$
- $r = -2$: friction in the meter bearing, $a_3 < 0$

![Graph showing the Straatma polynomial model with data points and a fitted line.](image)
Ln(Re) model

- 232 psi (16 bar) & 725 psi (50 bar) data
- Much improved fit

\[ f_{\text{meas}} = a_0 + a_1 \ln(Re) + a_2 [\ln(Re)]^2 + a_3 [\ln(Re)]^3 \]
PTB Model

\[ f_{\text{meas}} = a_0 + a_1 \log\left(\frac{Re}{10^6}\right) + a_2 \left[\log\left(\frac{Re}{10^6}\right)\right]^2 + a_3 \left[\log\left(\frac{Re}{10^6}\right)\right]^3 + a_4 \left[\log\left(\frac{Re}{10^6}\right)\right]^4 + \frac{b_0}{\rho Q_v^2} + \frac{b_1}{\rho Q_v} + c_p \frac{\rho Q_v}{p} \]

**Fluid flow effects**

**Friction effects**

**T&P effects**

\[ \text{Re} \]

\[ \text{Meter deviation (\%)} \]
Simplified PTB model

- 232 psi (16 bar) & 725 psi (50 bar) data
- Improved fit for different pressures / densities

\[ f_{meas} = a_0 + a_1[ln(Re)] + a_2[ln(Re)]^2 + a_3[ln(Re)]^3 + a_4[ln(Re)]^4 + \frac{b}{\rho Q_v^2} \]
Simplified PTB model

\[ f_{meas} = a_0 + a_1 [\ln(Re)] + a_2 [\ln(Re)]^2 + a_3 [\ln(Re)]^3 + a_4 [\ln(Re)]^4 + \frac{b}{\rho Q_v^2} \]
Simplified PTB Model

\[ f_{meas} = a_0 + a_1 \log \left( \frac{Re}{10^6} \right) + a_2 \left[ \log \left( \frac{Re}{10^6} \right) \right]^2 + a_3 \left[ \log \left( \frac{Re}{10^6} \right) \right]^3 + a_4 \left[ \log \left( \frac{Re}{10^6} \right) \right]^4 + \frac{b_0}{\rho Q_v^2} + \frac{b_1}{\rho Q_v} + c_p \frac{\rho Q_v}{p} \]
Turbine Correction
Turbine correction method

- From model - match on Re and gas density
- Main difference is the gas viscosity

![Graph showing dynamic viscosity vs pressure for different gases (Gulf Coast, Amarillo, Ekofisk, Nitrogen).]
Turbine correction method

- Meter deviation based on simplified PTB model
Turbine correction method

- Shift or correction from calibration in nitrogen gas (N2) to natural gas (NG) using simplified PTB model

\[ \text{Shift}_{\text{NG-N2}} = a_1 [\ln(Re_{NG}) - \ln(Re_{N2})] + a_2 [\ln(Re_{NG})^2 - \ln(Re_{N2})^2] + a_3 [\ln(Re_{NG})^3 - \ln(Re_{N2})^3] + a_4 [\ln(Re_{NG})^4 - \ln(Re_{N2})^4] \]

Constant NG-N2 diff value = 0.1353
Turbine Testing
Turbine meters

**4-inch turbine meter**
- Provided by NEL
- Manufacturer: Instromet
- Type: SM-RI-X
- Calibrated flow range: 20-400 m³/hr
- Nominal diameter: DN100
- Flange: ANSI 600
- Calibrated: FORCE 2018
- Upstream pipework: 10D
- Downstream pipework: 3D with thermowell

**8-inch turbine meter**
- Provided by Gasunie
- Manufacturer: Instromet/Honeywell
- Type: SM-RI-X-E G250
- Calibrated flow range: up to 2500 m³/hr
- Nominal diameter: DN200
- Flange: ANSI 600
- Calibrated: FORCE 2017
- Upstream pipework: 15D
- Downstream pipework: 3D with thermowell
Orifice run as transfer standard
Turbine testing

- Matching on gas density and Re

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**8" turbine at low pressure**

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### Turbine testing

#### 4" turbine at high pressure

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NG: Natural Gas (NG)
### 4” Turbine at Low Pressure

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<td>24.3</td>
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<td>Vol Flow (m³/hr)</td>
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| Natural Gas (NG) | NG | NG | NG | NG | NG | NG |
| Pressure (bar) | 30 | 30 | 30 | 30 | 30 | 30 |
| Density (kg/m³) | 24.3 | 24.3 | 24.3 | 24.3 | 24.3 | 24.3 |
| Vol Flow (m³/hr) | 50 | 100 | 150 | 150 | 200 | 240 |
| Re            | 1.91E+05 | 3.82E+05 | 5.72E+05 | 5.72E+05 | 7.63E+05 | 9.16E+05 |
Next steps......

• Turbine meters will be tested at FORCE using natural gas
  ▪ 21-22 February 2019

• Witnessed by NEL and Gasunie

• Meters tested at NEL in nitrogen
  ▪ March 2019
Any Questions?

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