Calibrating and operating Coriolis flowmeters with respect to temperature, pressure, viscosity and Reynolds number Effects

Chris Mills, NEL
CONTENTS

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- UK REGULATIONS / ISO 10790
- NEL FACILITIES
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Brief history

- **2006 - 2010**: NEL completed research with Coriolis meters across laminar – turbulent regimes with **viscous oils** and discovered **Reynolds Number effect**
- **2011**: NEL completed research with Coriolis meters for a number of O&G operators at **elevated temperatures**.
- **2012**: NEL formulated a Joint Industrial Project (JIP) exploring influence of **T, P, and viscosity**.
- **2014**: JIP completed and concluded that:
  - calibration under conditions similar to the field required
  - lack of traceable calibration facilities that can operate at elevated temperature, pressure, and viscosity
- **2014 – 2016**: NEL designed & built a new flow loop operating at Elevated P and T (EPAT) & **fully accredited to UKAS**
- **2016 - present**: This presentation focus now on NEL experiences and ‘**Calibrating and operating Coriolis flowmeters**’
Current regulations

- **UK Oil & Gas Authority (OGA) Guidelines**

  6.5.4 **Temperature and Pressure Compensation**

  Where a flow meter is operated at a temperature and pressure different from that at which it was calibrated, an offset in meter performance may be expected.

  Where temperature and/or pressure compensation routines are applied, these must be agreed in advance with OGA. The relevant calculations must be traceable and auditable.

  6.10 **Coriolis Meters**

  6.10.1 **Meter Calibration**

  The meter must be flow calibrated over its full operating range prior to its installation.

  At this, and subsequent, calibrations the conditions (pressure, temperature) should be as close as possible to the anticipated operating conditions, and the calibration medium should be as representative as possible.

  Calibration against a mass flow standard will result in a lower calibration uncertainty.

  6.10.6 **Installation Effects**

  Where the meter is removed and recalibrated at a remote facility, the effects of any differences between the in-service process conditions (pressure, temperature, viscosity) must be considered.

  Unless otherwise agreed with OGA, the pressure, temperature and viscosity of the calibration fluid should be representative of the anticipated operating conditions.

  The use of generic pressure, temperature and/or viscosity correction factors must be agreed with OGA.
What about the Coriolis ISO Standard?

4.3.5 Temperature effects

A change in oscillating tube(s) temperature will affect the properties of the oscillating tube(s), and thus will influence the measurement of the fluid process by the Coriolis flowmeter. A means of compensation for this temperature effect is usually incorporated in the transmitter.

Users are advised to discuss temperature effects with their suppliers. At the time of writing of this Standard, temperature was ongoing scientific research.

4.3.6 Pressure effects

Static pressure changes can affect the measurement of the fluid process by the Coriolis flowmeter, the extent of the measurement affect shall be specified by the manufacturer.

4.3.8 Viscosity effects

Higher viscosity fluids may draw energy from the Coriolis flowmeter excitation system, particularly at the start of flow. This phenomenon may cause the sensor tube(s) to momentarily stall during start up.

There is not any data in the public domain (when this standard was being updated) that relates calibration to different fluid viscosities.
What about the Coriolis ISO Standard?
Elevated Pressure & Temperature (EPAT) Facility
Elevated Pressure & Temperature (EPAT) Facility

<table>
<thead>
<tr>
<th>Item</th>
<th>Spec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Pressure:</td>
<td>100 bar g</td>
</tr>
<tr>
<td>Minimum Pressure:</td>
<td>4 bar g</td>
</tr>
<tr>
<td>Pressure Control:</td>
<td>+/- 0.5 Bar</td>
</tr>
<tr>
<td>Maximum Temperature:</td>
<td>80 °C</td>
</tr>
<tr>
<td>Minimum Temperature:</td>
<td>20 °C</td>
</tr>
<tr>
<td>Temperature Control:</td>
<td>+/- 0.5 °C</td>
</tr>
<tr>
<td>Maximum Flow:</td>
<td>100 l/s</td>
</tr>
<tr>
<td>Minimum Flow:</td>
<td>0.5 l/s</td>
</tr>
<tr>
<td>Fluid Density:</td>
<td>0.810 kg/l</td>
</tr>
<tr>
<td>Maximum Fluid Viscosity:</td>
<td>6 cP</td>
</tr>
<tr>
<td>Minimum Fluid Viscosity:</td>
<td>2 cP</td>
</tr>
<tr>
<td>Test Section Pipe Size:</td>
<td>1 – 10 inch OD</td>
</tr>
<tr>
<td>Test Section Pipe Length:</td>
<td>10 metres</td>
</tr>
<tr>
<td>Measurement Uncertainty:</td>
<td>± 0.08 (k=2)</td>
</tr>
</tbody>
</table>
National Standards Oil Flow Facility

- **Primary:**  Gravimetric system (± 0.05%, k = 2)
- **Secondary:** PD reference meter (± 0.05%, k = 2)
# National Standards Oil Flow Facility

<table>
<thead>
<tr>
<th>Item</th>
<th>Spec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Pressure:</td>
<td>6 bar g</td>
</tr>
<tr>
<td>Pressure Control:</td>
<td>+/- 0.2 Bar</td>
</tr>
<tr>
<td>Maximum Temperature:</td>
<td>50 °C</td>
</tr>
<tr>
<td>Minimum Temperature:</td>
<td>5 °C</td>
</tr>
<tr>
<td>Temperature Control:</td>
<td>+/- 0.5 °C</td>
</tr>
<tr>
<td>Maximum Flow:</td>
<td>200 l/s</td>
</tr>
<tr>
<td>Minimum Flow:</td>
<td>0.04 l/s</td>
</tr>
<tr>
<td>Fluid Density:</td>
<td>0.750 – 0.890 kg/l</td>
</tr>
<tr>
<td>Maximum Fluid Viscosity:</td>
<td>2000 cP</td>
</tr>
<tr>
<td>Minimum Fluid Viscosity:</td>
<td>1 cP</td>
</tr>
<tr>
<td>Test Section Pipe Size:</td>
<td>1 – 12 inch OD</td>
</tr>
<tr>
<td>Test Section Pipe Length:</td>
<td>20 metres</td>
</tr>
</tbody>
</table>
# Schedule of Accreditation

**Issued by**: United Kingdom Accreditation Service  
**2 Pine Trees, Chertsey Lane, Staines-upon-Thames, TW18 3HR, UK**

**TUV SUD Ltd**  
Trading as NEL

**Issue No:** 030  
**Issue date:** 25 August 2017

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**NEL Division**  
East Kilbride  
Glasgow  
Scotland  
G75 0QF

Accredited to ISO/IEC 17025: 2005

Calibration performed at the above address only

## DETAIL OF ACCREDITATION

<table>
<thead>
<tr>
<th>Measured Quantity Instrument or Gauge</th>
<th>Range</th>
<th>Calibration and Measurement Capability (CMC) Expressed as an Expanded Uncertainty (k=2)</th>
<th>Remarks</th>
</tr>
</thead>
</table>
| Hydrocarbons Quantity (mass or volume)| 0.5 l/s to 100 l/s | 0.080 % | Conditions: Mineral oil, viscosities between 1.5 cSt and 10 cSt  
Temperatures 20 °C to 80 °C  
Pressures 4 bar(g) to 93 bar(g) |
| Hydrocarbons Flowrate (mass or volume)| 0.002 l/min to 100 l/s  
100 l/s to 200 l/s | 0.050 %  
0.090 % | Conditions: Kerosine and gas oil substitutes and mineral oils viscosities between 1.2 cSt & 30 cSt  
Temperatures 5 °C to 60 °C  
Pressures 0 bar(g) to 9 bar(g) |
| Hydrocarbons Quantity and Flowrate (mass)| 0.04 l/s to 100 l/s  
100 l/s to 150 l/s | 0.050 %  
0.25 % | Conditions: oil viscosities between 30 cSt and 500 cSt  
Temperatures 5 °C to 60 °C  
Pressures 0 bar(g) to 8 bar(g) |
| Hydrocarbons Quantity and Flowrate (volume)| 0.04 l/s to 150 l/s | 0.25 % | Conditions: oil viscosities between 30 cSt and 500 cSt  
Temperatures 5 °C to 60 °C  
Pressures 0 bar(g) to 8 bar(g) |
Customer data

• Calibrated large number of Coriolis meters
  – All manufacturers
  – Variety of sizes and models
  – Models with and without Re No corrections
  – Calibrated across laminar-transition-turbulent regimes
  – Calibrated across a range of pressures and temperatures
  – Models with and without Pressure corrections
Temperature & Pressure

%Err (Ref.Mass)

Ref. Mass Flow, T/hr

Kerosene 20degC 3cSt
Gas Oil 20degC 8cSt
Gas Oil 20degC 8cSt (R)
EXPERIENCE

Temperature & Pressure

![Graph showing temperature and pressure data for different fluids and conditions](image)
Temperature & Pressure

![Graph showing linear pressure effect with data points for different liquids and pressures.]

Legend:
- Kerosene 20degC 3cSt
- Gas Oil 20degC 8cSt
- Gas Oil 20degC 8cSt (R)
- EPAT 25degC 10bar.g
- EPAT 25degC 20bar.g
- EPAT 25degC 40bar.g
Customer data

Linear Pressure Effect

Pressure compensation possible

\[ y = -0.0083x + 0.0201 \]
\[ R^2 = 0.9956 \]
**NEL RECOMMENDATION**

Calibration procedure – Temperature & Pressure

1. Zero device at operating temperature and pressure
2. Calibrate device at operating temperature and pressure ‘as found’
3. Additional pressure compensation calibration at ± 10 bar.g to derive (linear) pressure compensation
4. Can then perform an ‘as left’ calibration if required
5. NEL pressure correction is fully traceable and meets OGA Regulations.
VISCOSITY

Coriolis 1 – uncorrected data

Well within Specification

Reference Flowrate (kg/s)

Mass Flowrate Error (%)
Coriolis 1 – uncorrected data

Outside of the Specification

Reference Flowrate (kg/s)

Mass Flowrate Error (%)
Coriolis 1 – uncorrected data

Compensation possible versus Reynolds Number
Coriolis 2 – No ‘Re No correction’ data

Outside the expected specification (WITHOUT CORRECTION)
Compensation possible versus Reynolds Number

VISCOSITY

Coriolis X – No ‘Re No correction’ data
VISCOSITY

Coriolis X – ‘Re No correction’ activated data

![Graph showing Mass Flow Error vs. Ref. Mass Flow for different viscosities (200 cSt, 600 cSt, 1000 cSt, 1500 cSt). The graph indicates that the data points are not fully within specification (WITH CORRECTION ACTIVATED).]
1. Specify Re No range of device
2. Match Re No range with high viscosity fluid at two or more temperatures
3. Zero device at operating temperature / and pressure
4. Calibrate device across Re No range ‘as found’
5. Decide if Reynolds Number effect is significant
6. Can then perform an ‘as left’ calibration if required
7. Calibration is fully traceable and meets OGA Regulations
Meters can be zeroed at T&P but as T drops, P drops significantly.

High viscosity gravimetric calibrations are time consuming. Master Meter has higher uncertainty.

RTD on board Coriolis flowmeters measures tube temperature as opposed to fluid temperature (response lag).

If zeroing at elevated temperature, it is important to allow time for stabilising.

Zero value can change by end of calibration. Possibly due to expansion / contraction of facility with T&P over time.
Key findings

– A Coriolis meter water calibration cannot replicate service conditions and still attain 0.1% meter specification.
– Vendor published pressure corrections are not traceable at present. Can over (or under) correct for pressure.
– Temperature effect is magnitude less than pressure. NOTE: Ambient temperature effects can be significant
– Coriolis meters should not be calibrated at ambient conditions and then deployed to elevated service conditions.
– They should be calibrated close to service conditions and characterised against Re No if high viscosity.
– The performance of Coriolis meters from one vendor to another are not necessarily similar as there are many other variables.
DDAT (NEL Database)

- Collating all calibrations (both master meters & customer)
- Publish the data at conferences and journal papers
- Use customer data to revise Coriolis ISO 10790
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