KUWAIT 3RD FLOW MEASUREMENT TECHNOLOGY CONFERENCE

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A Subsidiary of Kuwait Petroleum Corporation

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The Importance of Calibrating at Service Conditions Pressure, Temperature, and Viscosity Effects

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Agenda

- Overview of the problematic
- Specific installation to address the calibration
- Viscosity Effect (or Reynolds Number) on the Coriolis Response (limited to mass rate)
- Pressure Effect on the Coriolis Response (limited to mass rate)
- Temperature Effect
- Conclusion

Introduction

- Why Pressure, Temperature, and Viscosity are important for Coriolis Meter?

- Let's take Kuwait Crude Oil Production ~2.77MMbpd
- An error of 0.1% in the allocation/measurement is a gain or loss for the seller or the buyer of 2770bpd → ~140k$/day or 50.5MM$/year
- But Trade needs to be fair and equitable for everybody → a specific focus on uncertainty is essential and specially in single phase measurement.

Overview & Statement

- Oil flow meters are often calibrated with water at ambient conditions
- It was assumed that Coriolis are not sensitive to variation in T, P, and Viscosity (I will say: if no test to validate then no doubt!)
- TUV-NEL is a Primary Calibration Facility but also in charge to maintain UK standard
- By 2010, some changes were planned for devices doing allocation (from turbine to Coriolis) and extensive work was done at NEL → demonstrating large errors may result when operated at different P&T conditions.
- For some devices, fixed corrections were applied with little information about the used correction (and lack of traceability)

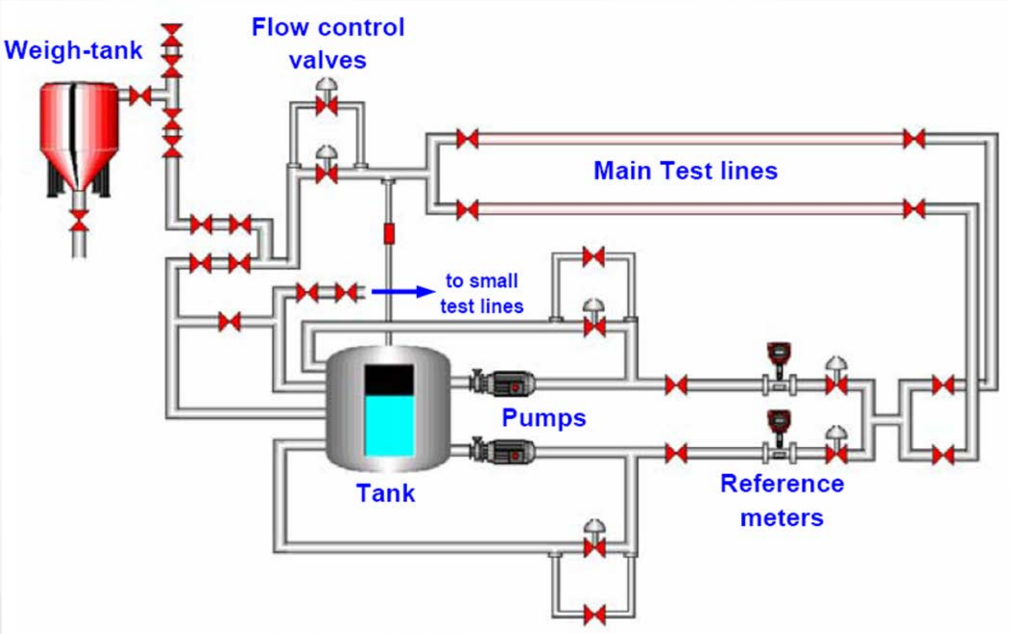
Regulation & Calibration

- For example in UK, the issue is addressed by UK Oil & Gas Authority (OGA) Regulations → the goal is that the UK obtains the maximum economic return from its oil & gas resource
- The OGA Regulations are based on ISO (such as ISO 10790), BSI, and experts, they are the minimum requirement
- From OGA, the uncertainty Value of 0.25% for oil is the minimum objective
- There is therefore a need to calibration flow meters as close as possible to service conditions
- Since 2010, >700 units (80% CORIOLIS) have been going thru single phase calibration.

TUV-NEL Standard Single Phase Oil Test Facility

- UK National Standard:

- Oil viscosity (different fluids):
  - From 1.5 to 1500 cSt at P, T
- Capability:
  - Temperature from 50°F to 158°F [10-70°C]
  - Temp control within ± 1°C
  - Pressure up to 144psia [10 bara]
  - Pres control within ± 0.3 bar
- Pipe sizes from 0.5” to 8”
- Flow rates from 27bpd to 108,700bpd [0.18 to 720m3/h]



- Two References available with an overall uncertainty (facility)
  - ± 0.03% (Gravimetric) [low viscosity] to ± 0.05% [high viscosity]
  - ± 0.08% (Reference meters - Turbines) [Low] ± 0.25% [High]

TUV-NEL Work Carried Out over 5years on Coriolis

- 2011: Establishment of dependency on Elevated Temperature
- 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 is compulsory (full range) and similar fluid (i.e. viscosity)
  - But more important there is a lack of traceable calibration facilities that can operate at elevated temperature, pressure, and viscosity
- 2014 – 2016 NEL designed and built a new flowloop calibration facility operating at Elevated P and T (EPAT) & Fully accredited to UKAS
- 2017: This presentation will focus on results collected from three different Coriolis meters (named Coriolis #1, #2 and #3)

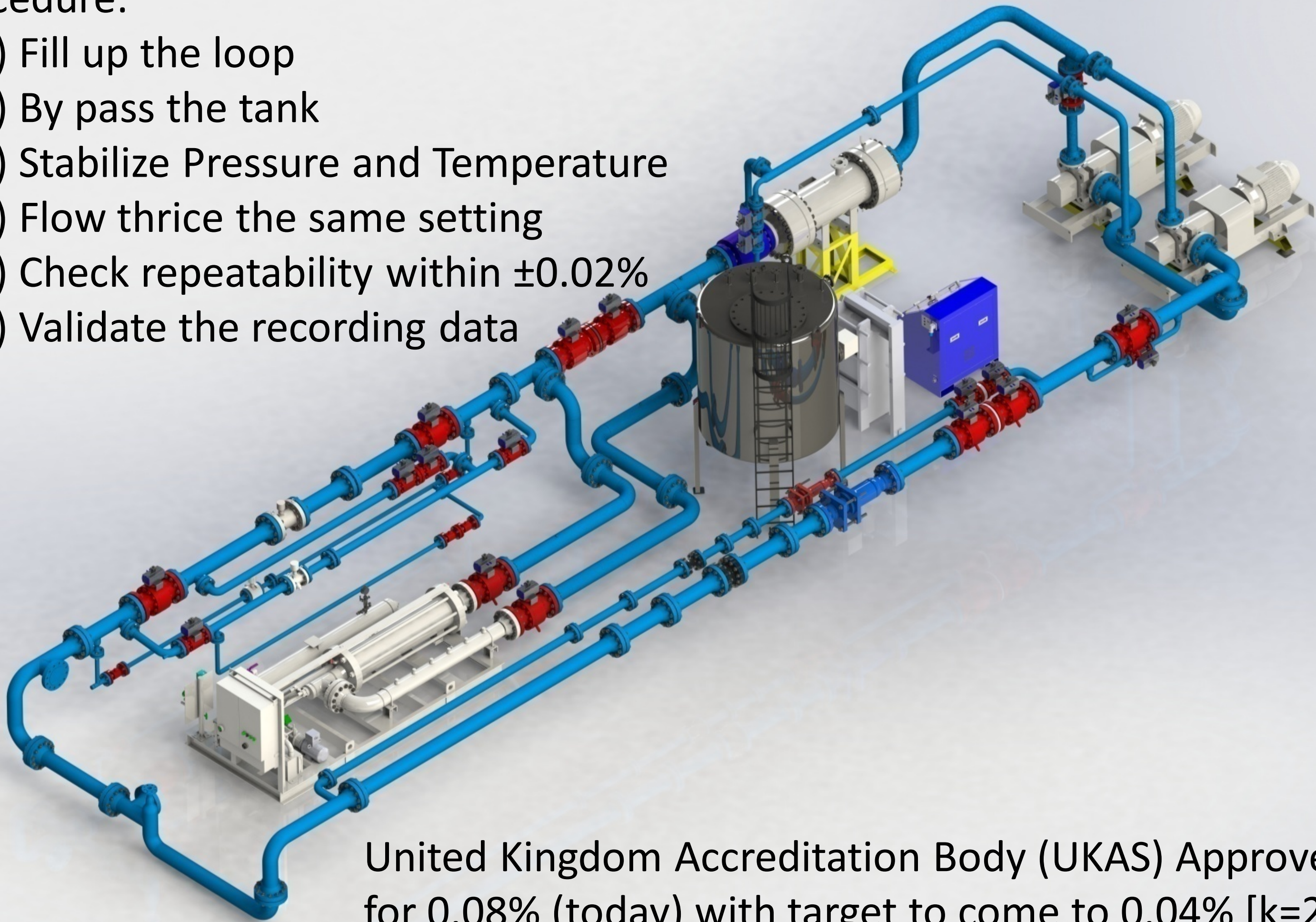
TUV-NEL Elevated P&T Test Facility

- EPAT facility was designed to calibrate liquid flow meters
  - Coriolis meter, Ultrasonic meter…
- Range of conditions:
  - Pressure: 73psia to 1,364psia [4 - 93barg] (stabilization ±0.5bar)
  - Temperature : 68°F to 176°F [20-80°C] (stabilization ±0.2°C)
  - Flow rate: 54bpd to 54,344bpd [0.36-360m^3/h]
- References & Uncertainty:
  - 12" (60 liters) Piston prover is used as a primary reference within 0.025%
  - 1.5", 3", and 6" helicoidal turbine flow meters as secondary reference within 0.080%
- Capability:
  - Viscosity from 1.5 cP to 10 cP at line conditions
  - Standard fluid: 2-7 cP and Density 810kg/m^3 ±0.5% and API 43.2°
  - Nominal pipe sizes from 0.5" to 10"
  - Test section up to 10m

EPAT: A Unique Facility Worldwide

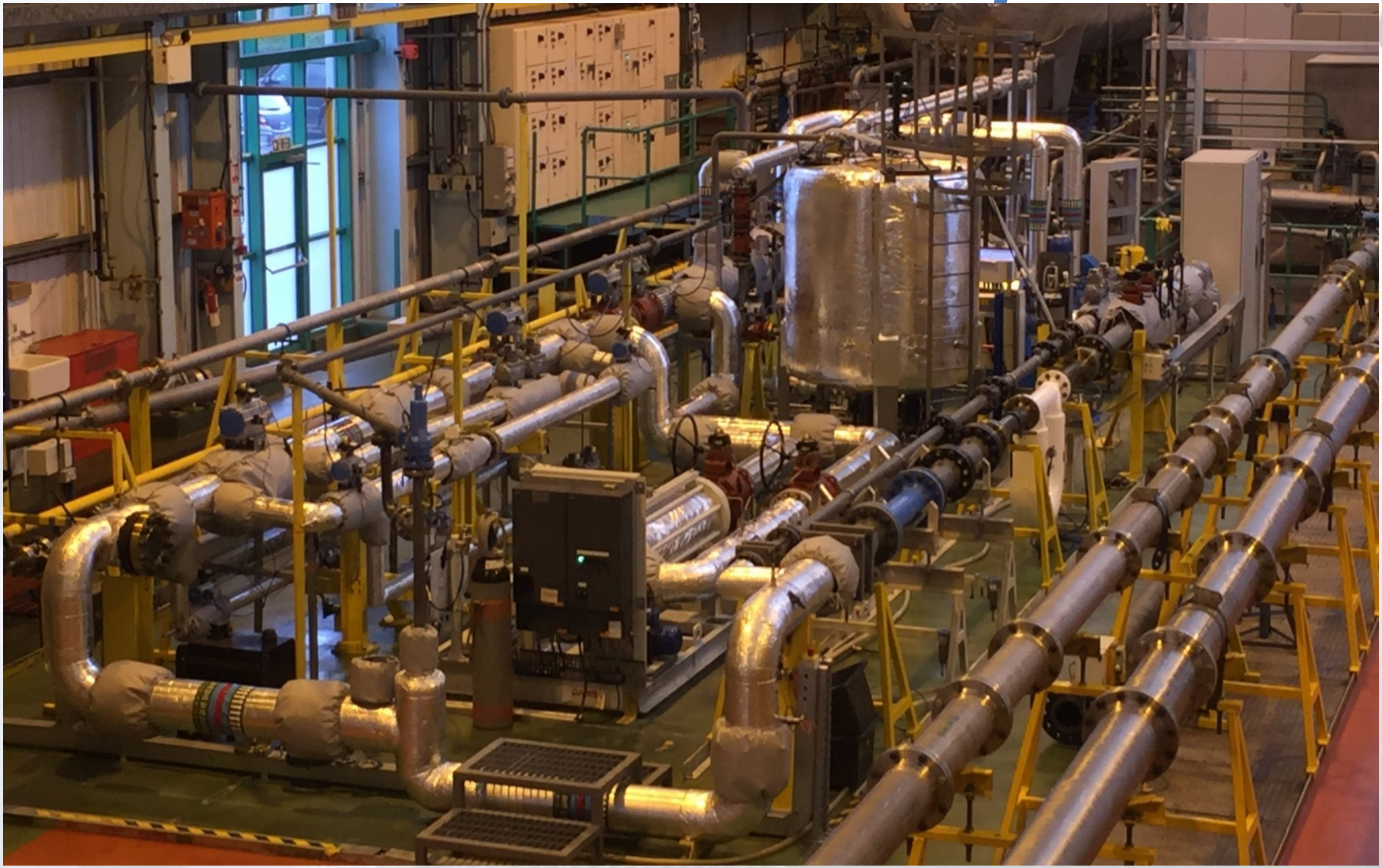
Procedure:

- -1) Fill up the loop
- -2) By pass the tank
- -3) Stabilize Pressure and Temperature
- -4) Flow thrice the same setting
- -5) Check repeatability within ±0.02%
- -6) Validate the recording data



United Kingdom Accreditation Body (UKAS) Approved for 0.08% (today) with target to come to 0.04% [k=2]

TUV-NEL EPAT Test Facility – UKAS



Twin Tube Coriolis#1 and Coriolis#2

INFLUENCE OF VISCOSITY ON CORIOLIS MEASUREMENT UNCERTAINTY

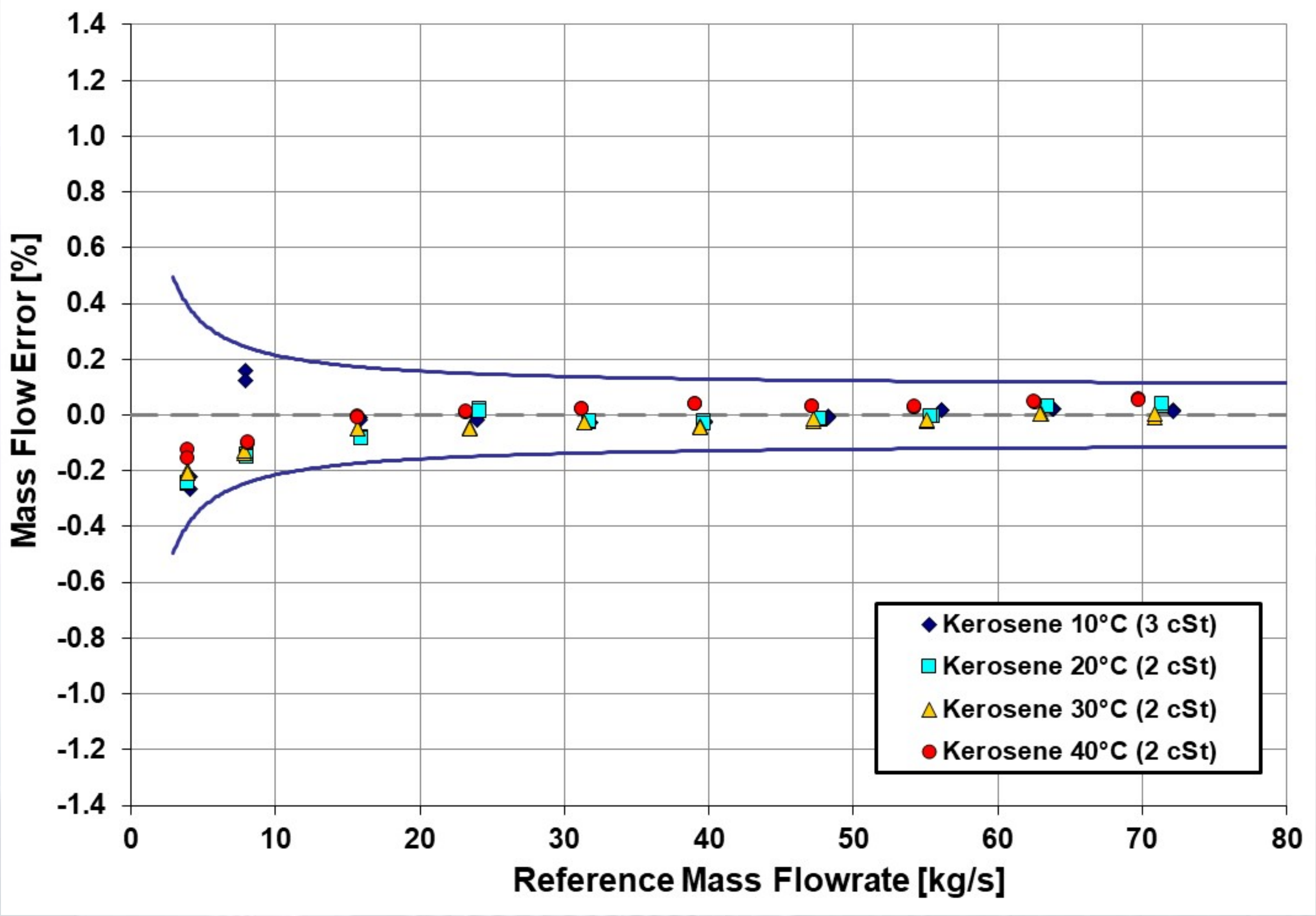
Influence of Viscosity

- Coriolis#1: This device has no correction for viscosity.
- Coriolis#2: This device has a patented Reynolds Number correction. Results will be shown without and with correction activated.

$$\mathrm{Re} = \frac{\rho \cdot u \cdot D}{\mu_k}$$

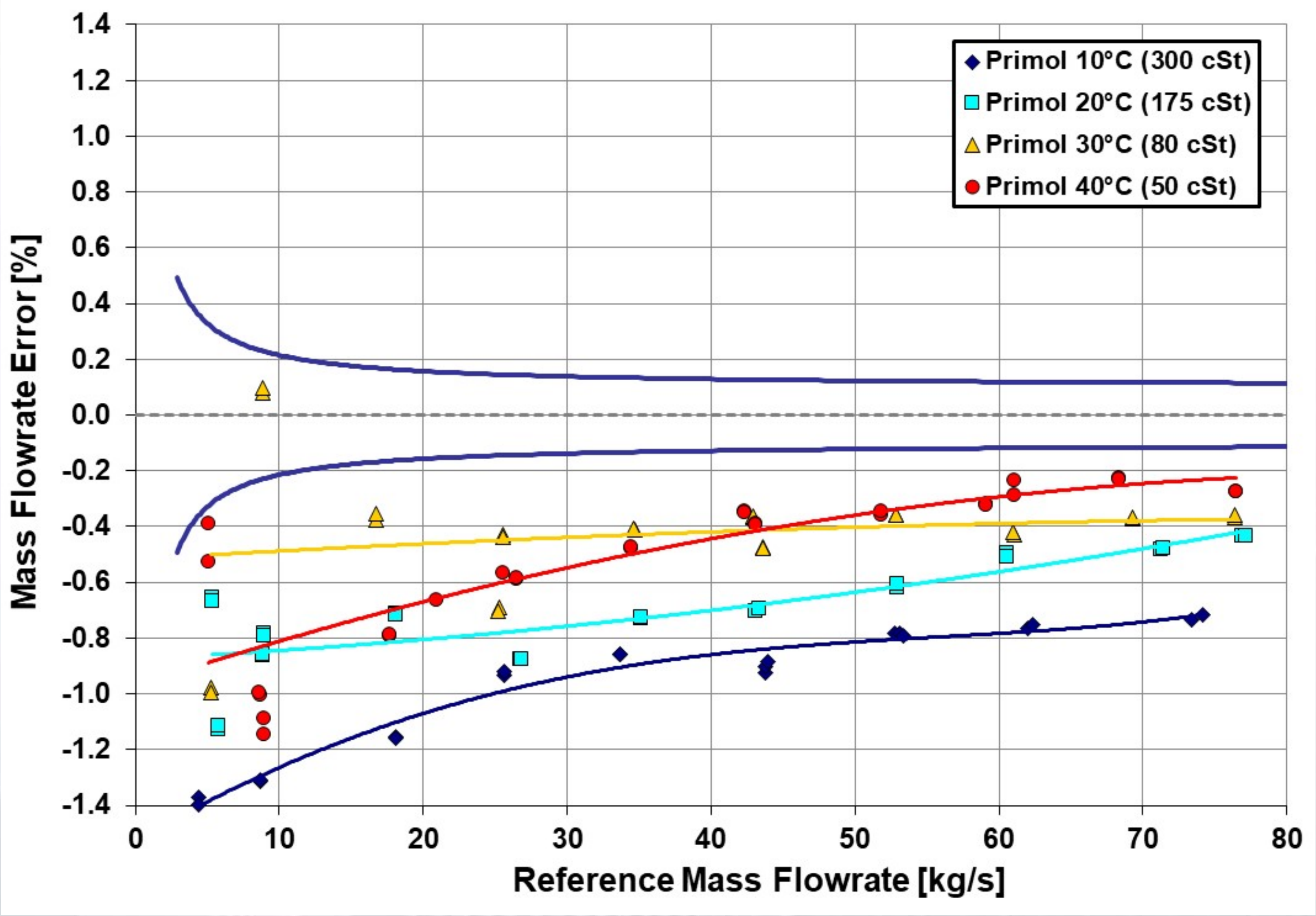
  - ρ Fluid density measure by the Coriolis meter
  - u Fluid velocity calculated from uncorrected mass flowrate & cross section area
  - D Tube diameter
  - μ Kinematic viscosity estimated by the Coriolis meter and torsional movement of one tube

CORIOLIS#1: VISCOSITY EFFECT vs. MASS FLOWRATE [<5cP]



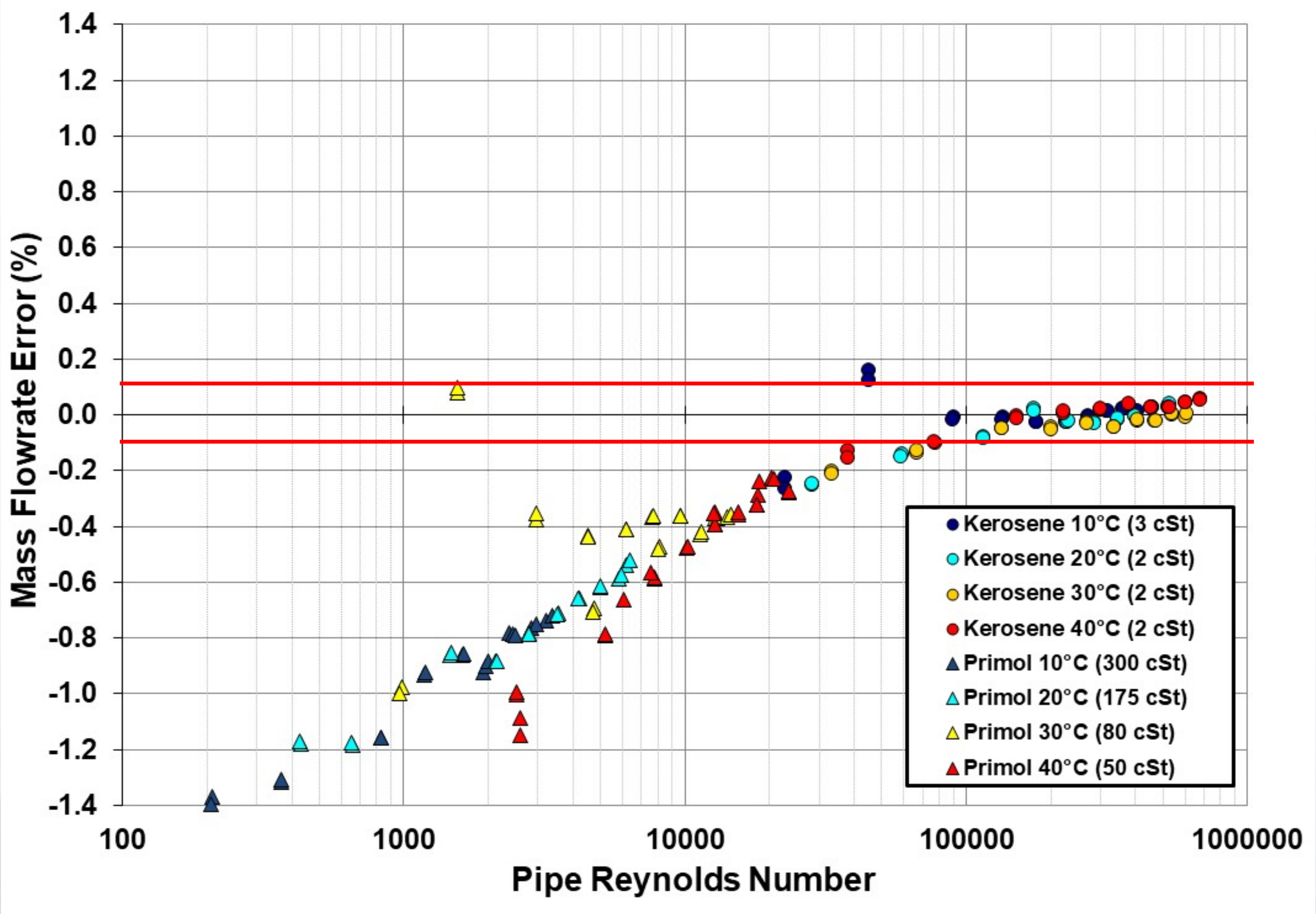
No correction for viscosity (standalone meter)

CORIOLIS#1: VISCOSITY EFFECT vs. MASS FLOWRATE [>50cP]



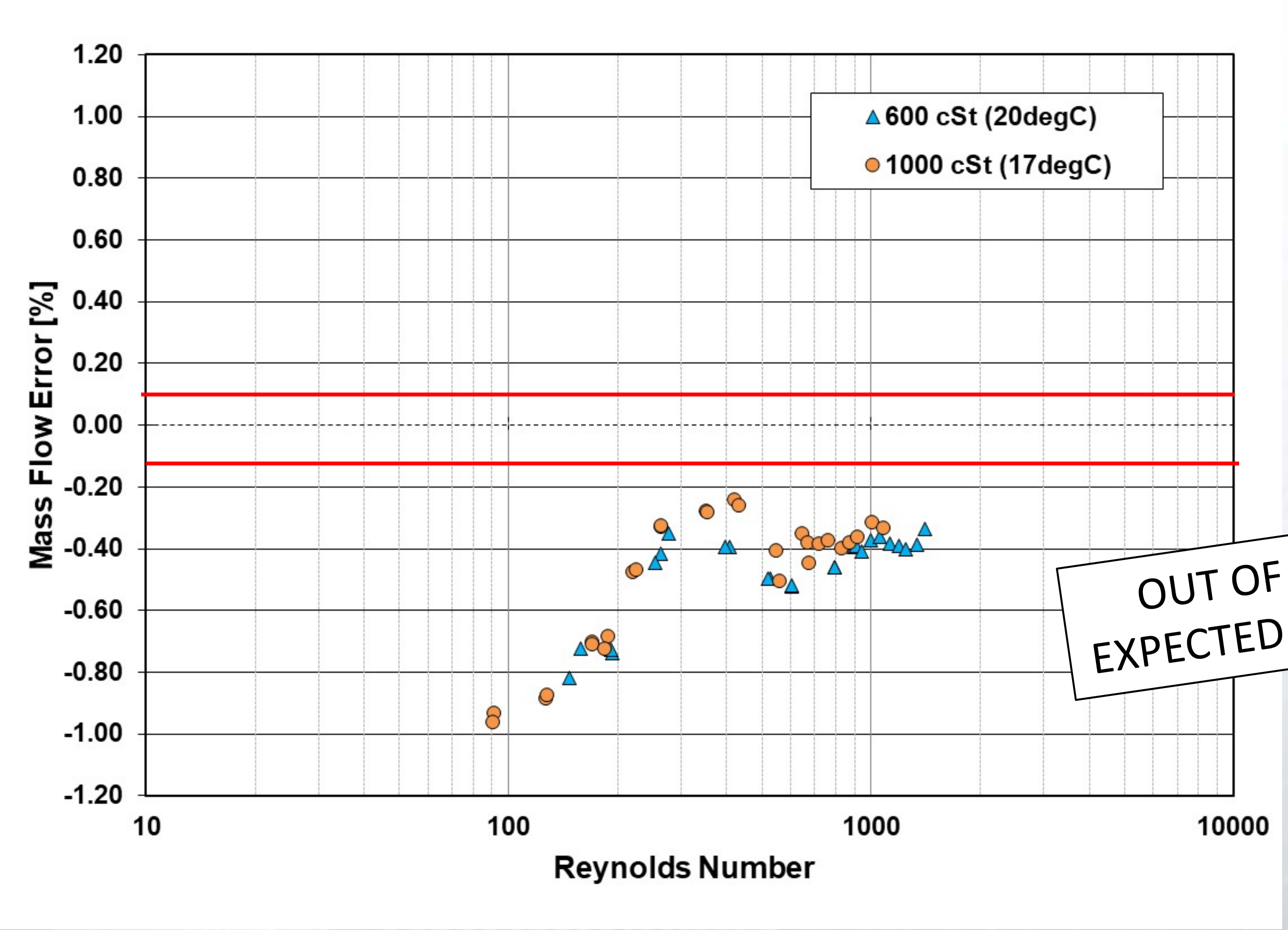
No correction for viscosity (standalone meter)

CORIOLIS#1: MASS FLOW RATE ERROR vs. REYNOLDS NUMBER



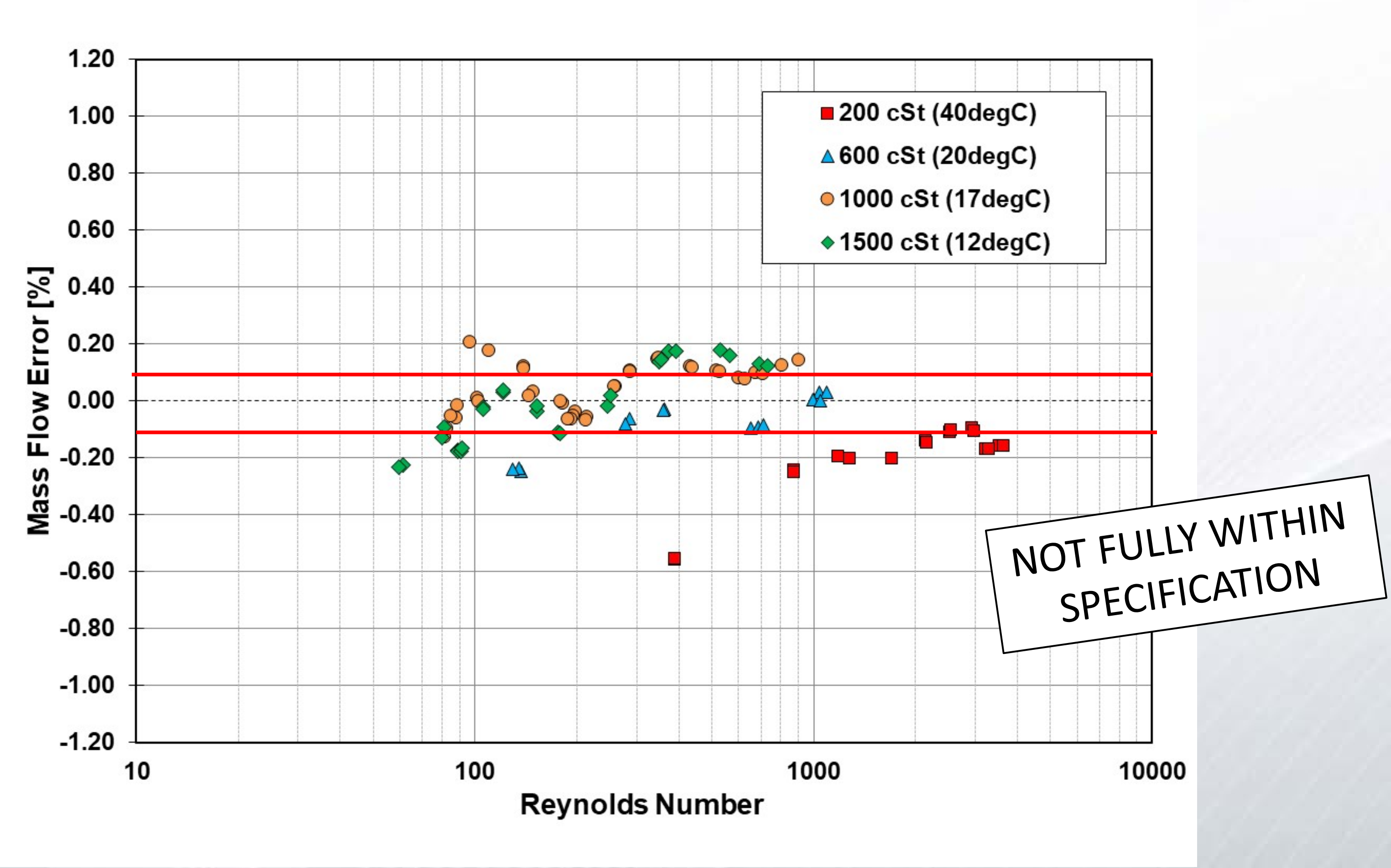
Compensation is possible versus Reynolds Number

CORIOLIS#2: MASS FLOW RATE ERROR vs. REYNOLDS NUMBER



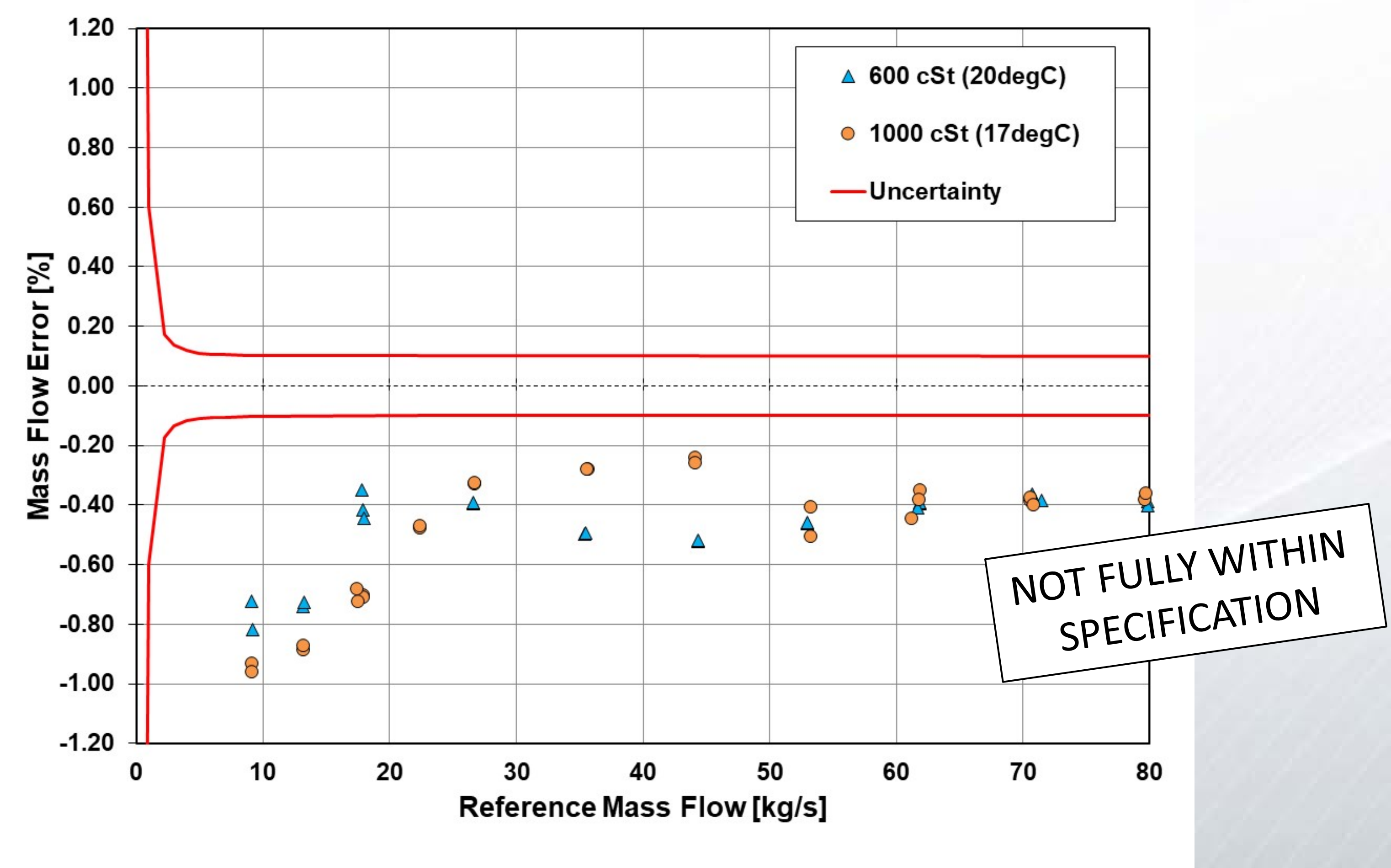
Reynolds correction not activated

CORIOLIS#2: VISCOSITY EFFECT vs. REYNOLDS



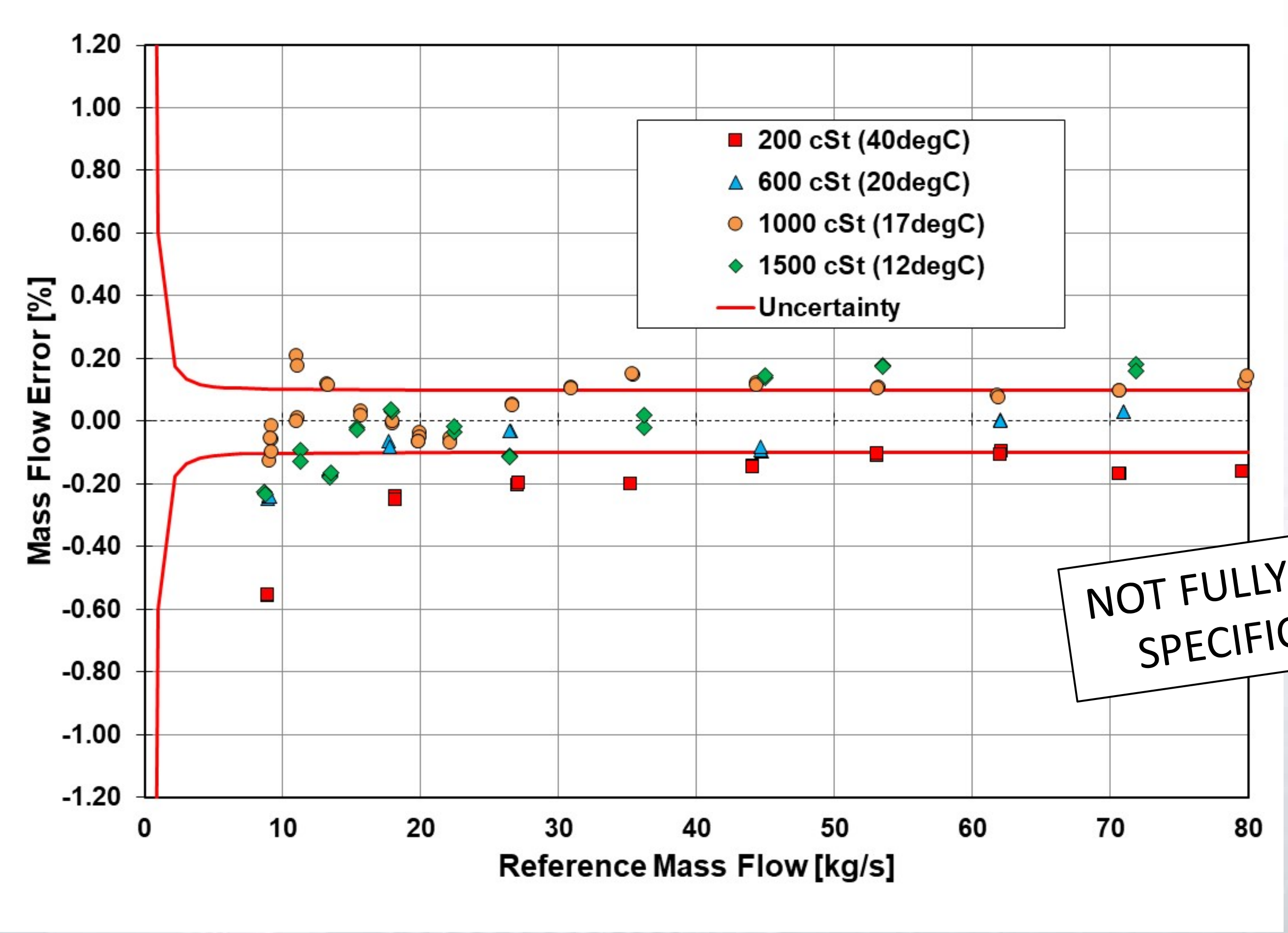
Reynolds correction activated

CORIOLIS#2: VISCOSITY EFFECT vs. MASS FLOWRATE



Reynolds correction not activated

CORIOLIS#2: VISCOSITY EFFECT vs. MASS FLOWRATE



NOT FULLY WITHIN SPECIFICATION

Reynolds correction activated

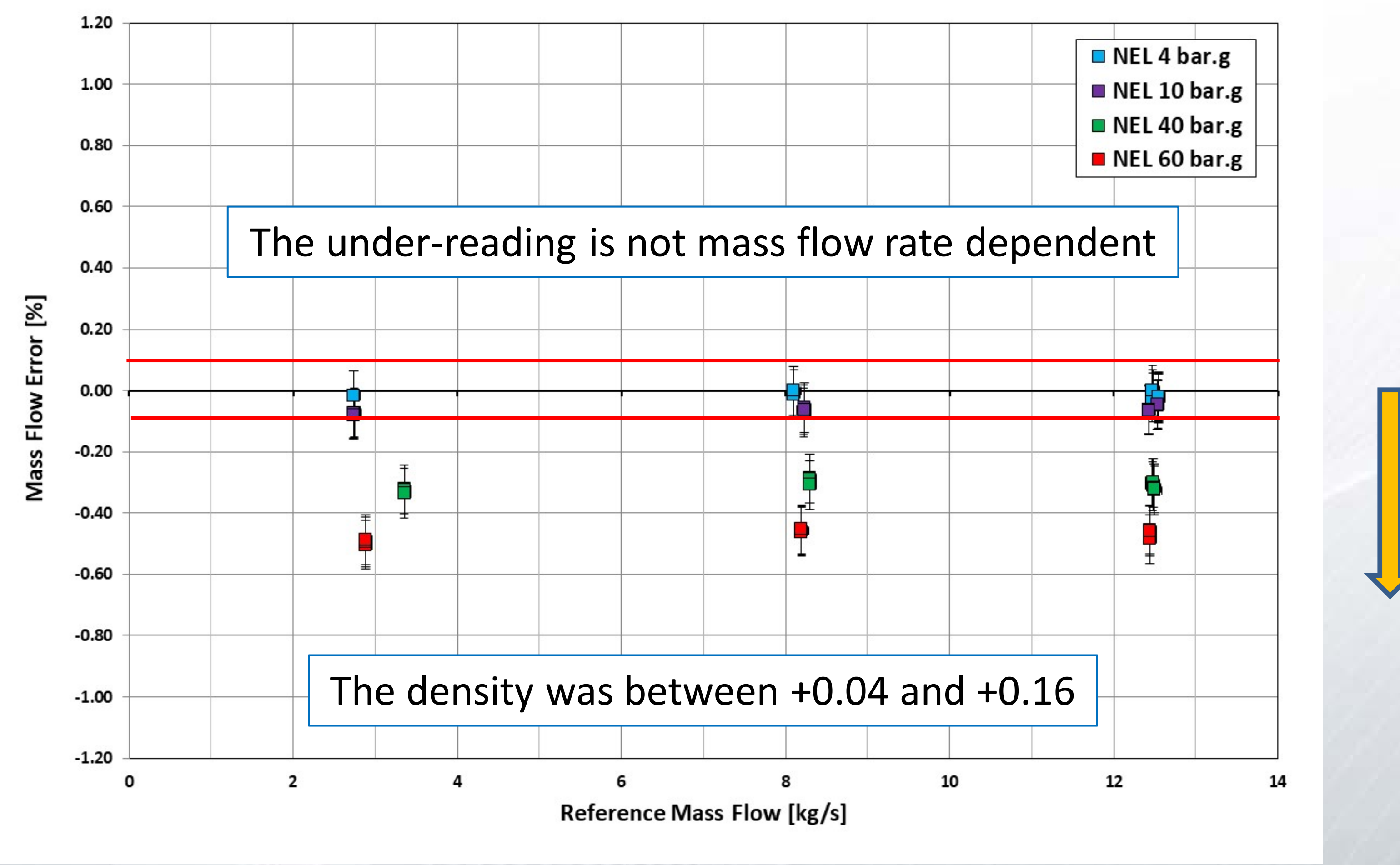
Twin Tube Coriolis#3 Tested in the TUV-NEL EPAT facility

INFLUENCE OF PRESSURE ON CORIOLIS MEASUREMENT UNCERTAINTY

Extensive Tests

- Meter Information:
  - 2in Meter
  - Maximum rate 87.1t/h [24.2kg/s]
  - Mass rate within ±0.1%
  - Density within ±0.5kg/m3
- Protocol of Test
  - Each test run has 3 repeats
  - 4 pressure tests: 4, 10, 40, 60 barg
  - Mass Flow rate from 7.5t/h [2.08kg/s] to 45t/h [12.5kg/s]

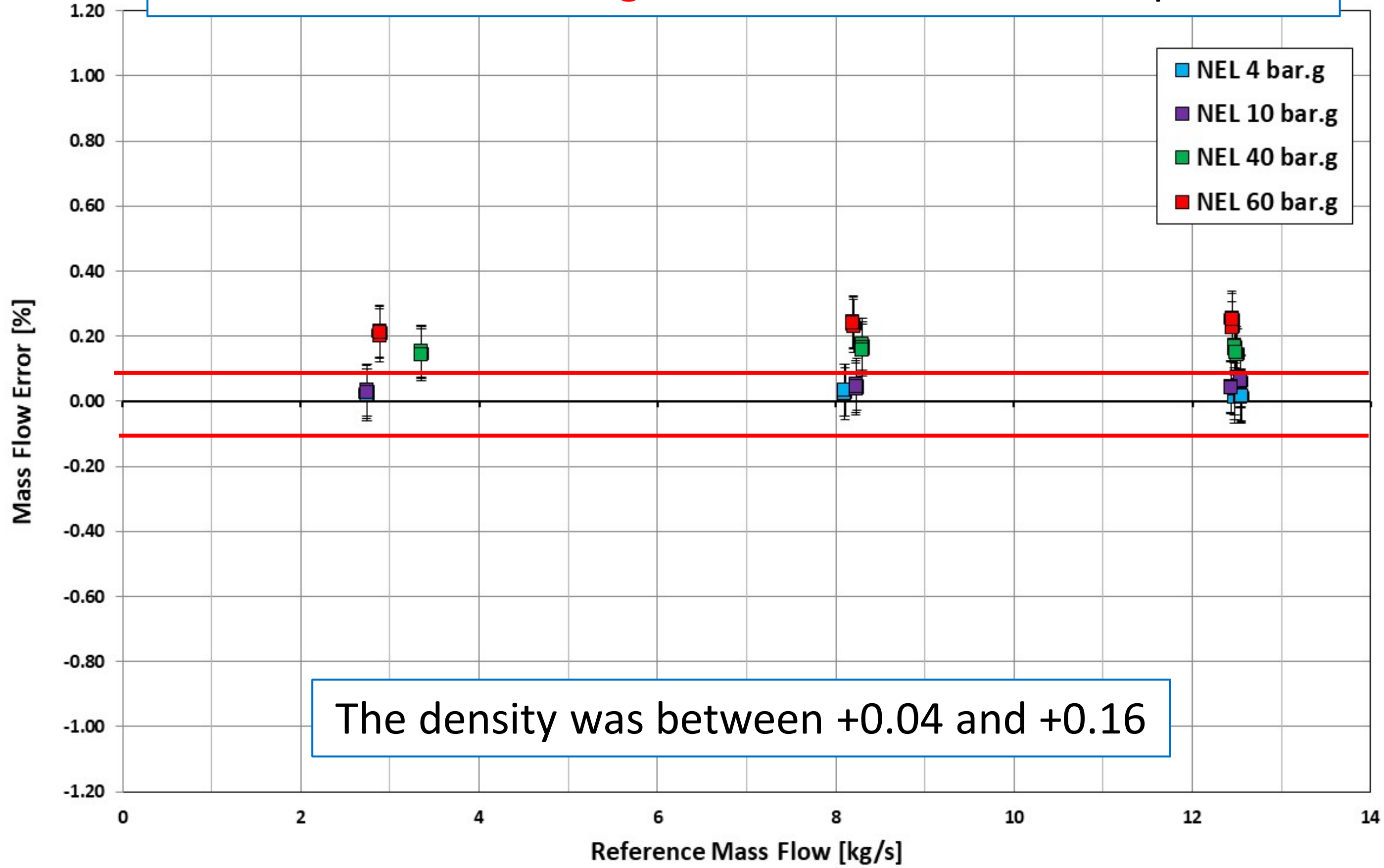
CORIOLIS#3: PRESSURE EFFECT vs. MASS FLOWRATE



No Pressure Compensation Activated

CORIOLIS#3: PRESSURE EFFECT vs. MASS FLOWRATE

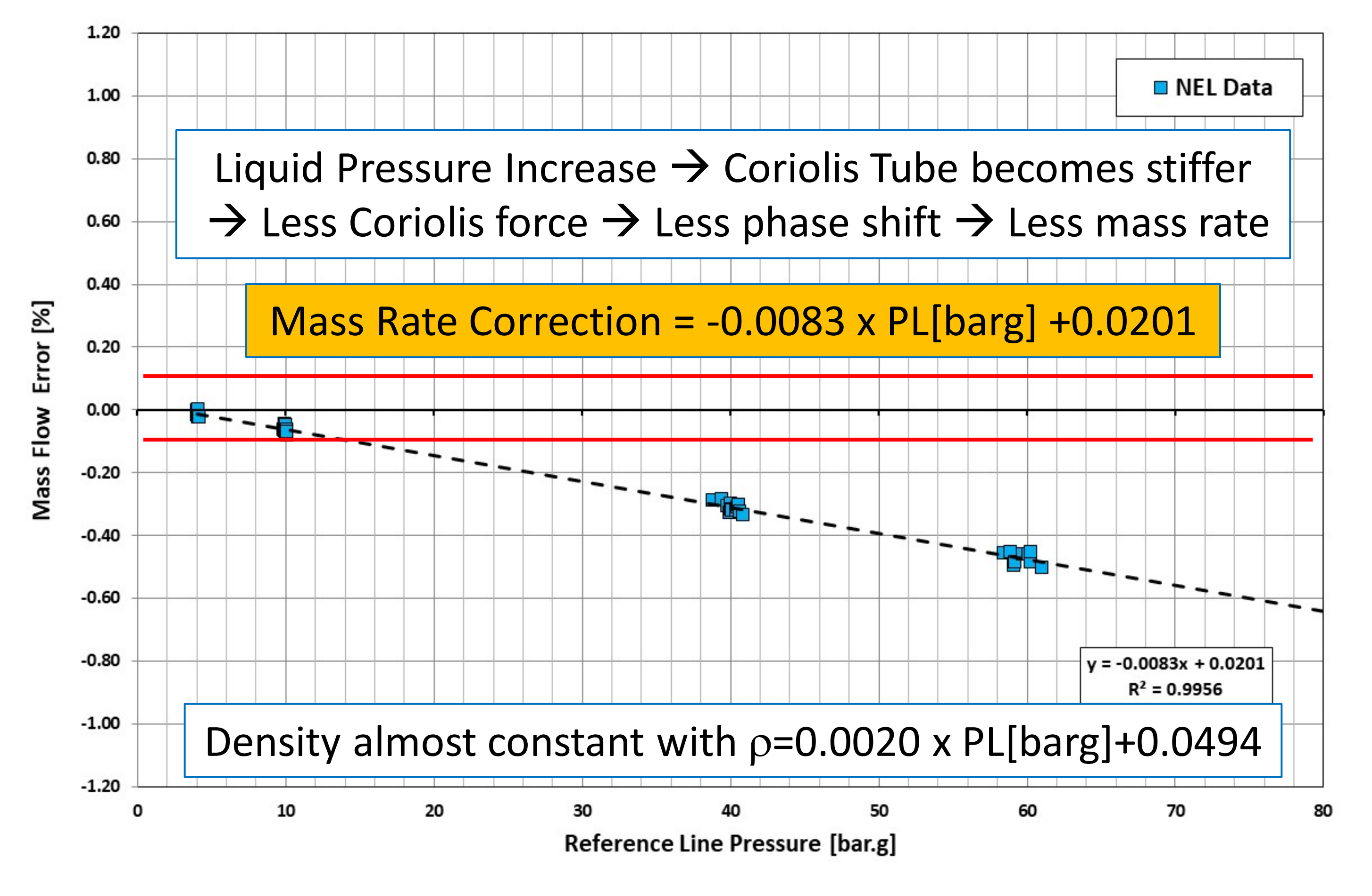
There is an over-reading and not mass flow rate dependent



The density was between +0.04 and +0.16

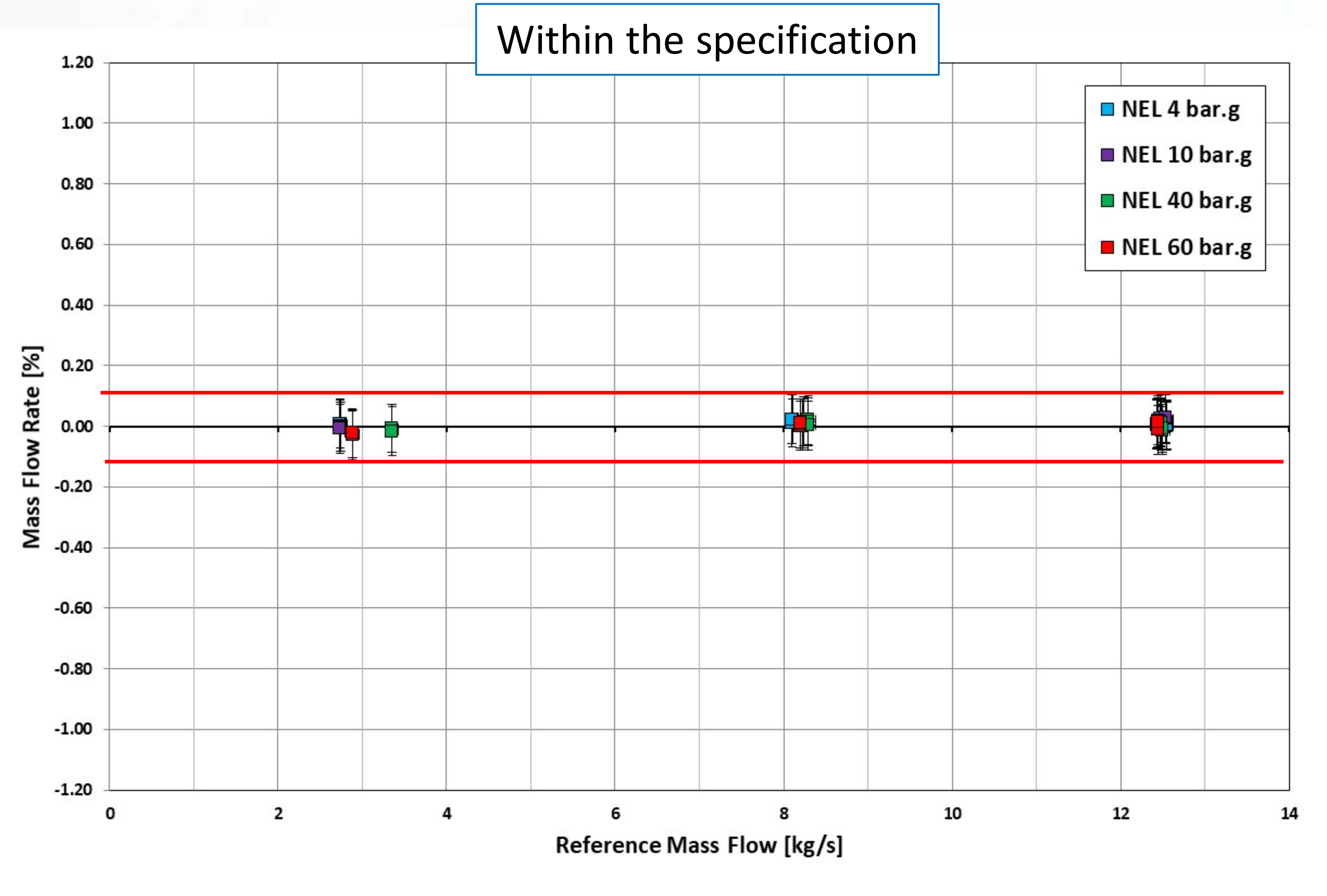
MANUFACTURER Pressure Compensation Activated

Review by TUV-NEL of the Pressure Compensation



We should expect a Coriolis sizing effect

CORIOLIS#3: PRESSURE EFFECT vs. MASS FLOWRATE



Test Calibration Pressure Compensation Activated

Temperature Effect

- Unfortunately the JIP data are confidential at this date but there is an effect and in the order of magnitude less
- NEL have commercial data that can't be published at present.
- Meanwhile, NEL are completing research program that will be published at later date.
- The main outcome is that Coriolis flowmeters published corrections which are not fully traceable at present.
- The Platinum Resistance Temperature inside Coriolis flowmeters are measuring tube temperature as opposed to fluid temperature (response lag) and it should be expected deviation in the flow transition

CONCLUSION

Conclusions (#1)

- The pressure analysis was compared with another facility which highlighted exactly the same phenomena from 10 to 40 barg.
- As pressure increase then the under reading of the mass flow rate increase and the density does not change, leading to an under reading of the volumetric flow rate.
- The under reading is not mass flow rate dependent for density the effect is less and overall the volumetric flow rates is very similar the behavior of the mass flow rate (trend and uncertainty)
- The correlation proposed by the manufacturer was limited, not traceable, and not bringing back the Coriolis within the expected performance (±0.1%) versus pressure, temperature, and Viscosity.

Conclusions (#2)

- Water calibration at standard conditions cannot replicate service conditions and still attain 0.1% meter specification
- They are different type of CORIOLIS and the end-user should know the type of application and conditions he is expecting → For a same oil company probably different providers (i.e. be careful with procurement)
- More important the industry is now aware that flowmeters cannot simply be calibrated at ambient conditions and then deployed to elevated service conditions.
- CORIOLIS like USM devices should be calibrated close to service conditions.
- CORIOLIS have a Pressure Lost higher than a Venturi and then crude oil needs to be well stabilized to avoid gas coming out of solution → 2 phases.

Conclusions (#3)

- The work will lead to revisit the ISO 10790:2015 “Guidance to the selection, installation and use of Coriolis flowmeters”
- To operate in UK according to OGA, only 3 ways are possible:
  - Calibration lab (EPAT) correction applied to mass factor.
  - Calibration lab (EPAT) traceable correction applied via a fixed value. (i.e 0.01% per 1 bar.g)
  - Calibration lab (EPAT) traceable correction applied via an input from a pressure transmitter.
- In any cases, the tests should be done also at 10 bar (above and below) the expected conditions at the given line temperature.

Thanks for Attention

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