Global Flow Measurement Workshop
22 - 24 October 2024

Technical Paper

Using an Adjustable DP Cone Meter to Measure Wet Gas

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1 INTRODUCTION

This paper presents the results and evaluations obtained from further testing of an adjustable cone flow meter with wet gas.

Laboratory calibration and field-test data were compared and wet gas algorithms were developed and/or improved. The predicted results that the new and improved algorithms generate, will be evaluated against data obtained from laboratory flow tests, planned for late 2024.

When the gas flow rate of a well significantly changes, the flow rate can fall below that of the operating range of a traditional fixed size Venturi meter, necessitating the replacement of the original meter with one of a smaller size.

With an adjustable cone meter the internal reconfiguration feature allows it to automatically switch from high operating flow range to low operating flow range, there is no requirement to disassemble the meter from the flow line for meter reconfiguration.

The adjustable cone meter has an internal sliding sleeve, moved by an external gearbox which is attached to the meter body. An actuator drives the gearbox, the actuator is controlled by a flow computer.

In high flow range (0.75 Beta), the sleeve is positioned such that it does not cover the cone. In the low flow range (0.5 Beta), the sleeve is positioned such that it covers the cone.

This paper presents developments in the technology and summarises recent laboratory flow testing and internal moving sleeve seal testing results.

2 TECHNICAL IMPROVEMENTS

In previous tests carried out by the authors [1], a singe flow meter was tested at the wet-gas flow loop at National Engineering Laboratory (NEL) in East Kilbride, Scotland. Improvements to the design as well as two meters in series, were tested, in the Advanced Multi-Phase facility at NEL, allowing the following comparisons to be made:

- Increased maximum pressure from 62 bar to 105 Barg
- Inclusion of a Watercut Meter, to determine the oil and water ratio at the meter location
- Direct comparison of two identical meters in series
- Comparison between “1D” and “1.5D” cone stem lengths
- Evaluation of position of the secondary differential pressure port

After calibrating two identical meters in series, with dry nitrogen gas, the meters were tested with increasing amounts of liquid being injected into the flowline, upstream of the meter. The liquid caused the differential pressure measurements on the meters to over-read. Based on the differential pressure measurements under varying flow conditions, algorithms were developed to measure the dry gas, liquid flow rate and watercut readings.

2.1 Increased Pressure and Watercut Measurements

Testing was carried out at three different pressures (62, 82.5 and 105 Barg) and with five different watercuts (0, 25, 50, 75 and 100% Watercut) using a comprehensive test plan, which allowed relative comparison of the tests with equal Watercut, Lockhart-Martinelli and Gas Froude values. Previous testing was conducted at 10, 35 and 62 Barg and using only oil as the wetting liquid. No attempt was made to compare any variations between water and oil wetted gases in the previous testing. Watercut meter test results are not presented in this paper.

2.2 Identical Meters in Series

Using two identical meters in series, direct comparison could be made between two meters manufactured at the same time, in the same machine shop, with the same CNC programme and by the same operator, ensuring that the two meters were geometrically identical. Any differences between the two meters' performance could be directly compared and would determine the reproducibility of results. This data could be used later to reduce calibration costs, allowing one meter per manufactured batch to be flow calibrated and a reasonable assumption made for the expected variation in Cd values.

As well as being manufactured identically, the meters were installed using identical pipework, so that any installation effect was minimised and would be as similar as possible in both meter locations. An additional DP transmitter was also located on meter 1, across the cone primary port and a pressure port located 500 mm downstream from the secondary DP port. It should be noted that the pipework was designed to closely follow the same setup as tested in previous field tests. These two DP meters would measure the meter recovery DP and the overall recovery DP after the meter.

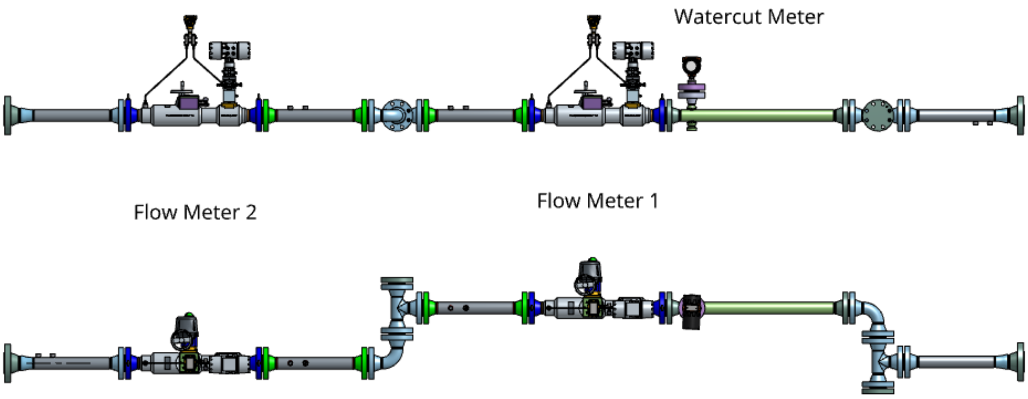


Fig1. Installation of two flow meters in series (Downstream DP meter not shown on meter 1).

2.3 1.0D and 1.5 D Cone Stem Lengths

Conclusions from previous testing led to a belief that the unique geometry of an adjustable cone meter, may lead to differences in performance between the meter in low range and in high range. It was theorised that fluid entering the meter, while in the low range, was subject to differing forces as it travelled through the meter bore.

When the meter is flowing in its high rage, upstream of the cone support, fluid first passes through a relatively long section of pipe with an ID equal to the pipe ID. It then passes by what is essentially a "traditionally" mounted cone, followed by another shorter section of pipe, again with an ID equal to the pipe ID. It then passes through the sliding sleeve, downstream of the cone.

Whilst the meter is flowing in its low flow range, the flow first passes through the same relatively long section of pipe with an ID equal to the pipe ID. After the cone mount stem, the flow path shape changes, with the introduction of the sleeve which changes the beta ratio.

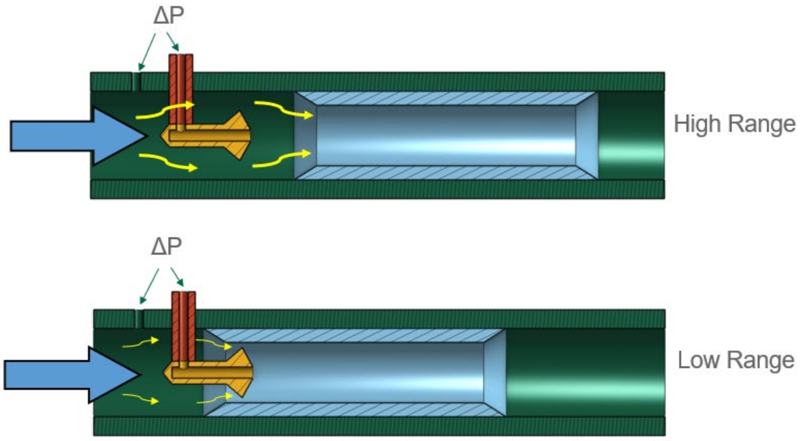


Fig 2. Adjustable cone meter high and low range positions.

It was thought that the assymetry of the components at this location, may induce pressure variations which may not be detectable with traditional Differential Pressure transmitters. In order to try to mitigate any effect of the cone interacting with the sloping sleeve entrance a longer cone mount, 1.5D in length, compared to a traditional 1.0D length cone, was tested. By placing the cone deeper within the sleeve, any inlet effects could be minimised and a more representative cone differential pressure could be measured, which was less affected by inlet flow forces.

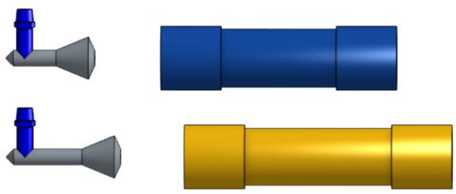


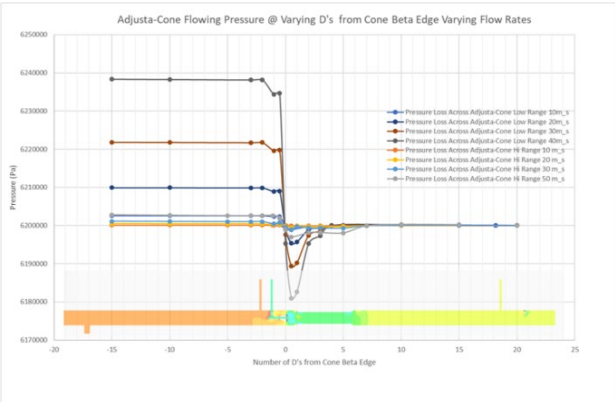
Fig 3. Comparison of 1.0 and 1.5D Cone Stem Lengths

2.4 Secondary Pressure Port Position

Since the primary method of calculating the liquid content for this device used the Pressure Loss Ratio method, it was essential that both primary and secondary differential pressure readings were correct. Great care was taken to ensure that the DP instruments were located relatively high and that there was no possibility of introducing liquid traps in the impulse lines. Care was also taken to ensure that any potential for liquid to build up in the meters was minimised using a liquid trap, downstream of the meter.

Fig 4. Optimum installation of impulse lines

Fig 5. Downstream liquid trap



Additionally, it was observed, using Computational Fluid Dynamics, that the physical location of the downstream tap would be ideally placed 7D downstream of the cone location. The studies showed that full pressure recovery took place at this location, at different flow rates, and this was used to locate a pressure port within the limits of the meter body, to simplify installation.

Fig 6. CFD analysis of secondary pressure port positioning.

3.0 SLIDING SLEEVE SEALS TESTING

As noted previously, the adjustable differential pressure cone meter utilises an internal reciprocating sliding sleeve to change the beta ratio and provide two flow ranges within the same flow meter body. The sliding sleeve is fitted with advanced seals of rugged design, to maintain and assure pressure integrity over the meter's lifespan. The author has observed many instances of leaking orifice plate flow meters being remedially worked on by well testing operators. It was essential to ensure that the sleeve seals would have a reliable long life, protecting operators from natural gas and especially from H_2S leaks.

A comprehensive seal testing programme was designed to test the effectiveness of the seals under raised pressure and temperature conditions, as well as linearly moving the sleeve to test the seal integrity and longevity.

A test meter was capped and filled with circa 300 Deg C flash point oil. The meter was wrapped with pipeline heating cable, wired to a temperature controller and wrapped in very high efficiency insulation material, to retain heat. Pressure was applied and controlled, via an N_2 bottle and hand regular.

A flow computer with integral multi-variable transmitter was attached to the meter remotely via stainless steel tubing and an RTD, in order to 1) continuously reciprocate the sliding sleeve between high and low positions and 2) record pressure and temperature data.

An additional pressure transmitter was fitted to the gearbox used to reciprocate the sleeve in order to verify that the internal sleeve pressure was not leaking past the sleeve seals and pressurising the gearbox, indicating sleeve seal failure.

The entire assembly was then mounted into a purpose built steel box and locked into a secure container. The tests were observed remotely and data observed and gathered via web link to the flow computer, which controlled the movement of the internal sleeve. The flow computer was connected to the meter from outside the test box, continuous 24 hour testing was undertaken.

Testing was undertaken with multiple seal sets over several months, under varying pressures and temperatures, up to the maximum expected pressures and temperatures in the field of 125 Barg (1,812 PSIG) and 125 Deg C (257 Deg F). Each test was planned to be carried out continuously until a specific cumulative number of sleeve cycles were reached (one sleeve cycle equals one sleeve out-stroke plus one sleeve return-stroke).

Fig 7 & 8. Test meter wrapped in heating cable and thermal insulation.

4.0 WET GAS CORRECTION THEORY

Previous testing showed that the pressure loss ratio was fairly successful in determining the liquid loading of a wet gas. Results showed that at lower pressures, over-read and pressure loss ratio were fairly closely correlated, but thought to be less reliable at higher pressures.

Utilising TR/ISO 12748 2015 [2], it is possible to predict the over-reading (Ø), (At limited conditions Fig 9) using equation 1. On the first iteration, we assumed that C and Ø are equal to (1).

$$q_{m.gas} = \frac{C}{\sqrt{1-\beta^4}} \varepsilon \frac{\pi}{4} d^2 \frac{\sqrt{2\Delta p \rho_{1.gas}}}{\phi} \qquad (1)$$

Parameter	Range
Pressure	1 360 kPa to 7 750 kPa
Gas to liquid density ratio	0,012 < DR < 0,090
Fr_g range	0,53 < Fr_g < 8,80
X_{LM}	< 0,305
Inside full bore diameter	0,096 9 m < D < 0,147 0 m
Beta	0,75 only
WLR	0 ≤ WLR ≤ 1
Gas phase	Nitrogen or Natural Gas
Liquid phase	Light Hydrocarbon Liquid and Water

Fig.9 Ranges of TR/ISO 12748- 2015

Measuring differential pressure and pressure, a mass flow rate of gas was obtained, followed by calculating a first iteration of the Gas Froude Number using equation (2).

$$Fr_{gas} = \frac{4q_{m.gas}}{\rho_{1.gas}\pi D^2\sqrt{gD}}\sqrt{\frac{\rho_{1.gas}}{\rho_{liquid}-\rho_{1.gas}}} \qquad (2)$$

Next, a Chisholm correction factor is obtained, using equation (3) and (4)

$$C_{Ch} = \left(\frac{\rho_{liquid}}{\rho_{1.gas}}\right)^n + \left(\frac{\rho_{1.gas}}{\rho_{liquid}}\right)^n \qquad (3)$$

$$\phi = \sqrt{1 + C_{Ch}X + X^2} \qquad (4)$$

Where, the value for n is obtained from from equation (5) or (6)

$$For\ Fr_{gas} \leq 0.5,\ n = 0.143 \qquad (5) \qquad For\ Fr_{gas} > 0.5,\ n = 0.5\left(1 - \left(\frac{0.83}{e^{0.3Fr_{gas}}}\right)\right) \qquad (6)$$

New values for C and Ø are calculated, using a calculated Reynolds number to arrive at a recalculated C and the recalculated Ø from equation (1) to arrive at a second estimate of the wet gas flow rate. This procedure is repeated until no changes occur and the wet gas flow rate is obtained.

Having arrived at a wet gas flow rate, the dry gas rate is simply the Wet gas rate divided by the over-read Ø.

Liquid flow rate is then calculated and the watercut meter reading used to split the oil and water flow rates.

5.0 TEST RESULTS

This approach worked well for the high range meter (0.75 beta) and Figure 9 shows general agreement within a few percent, between physical test results and ISO/TR 12748:2015(E) correlations.

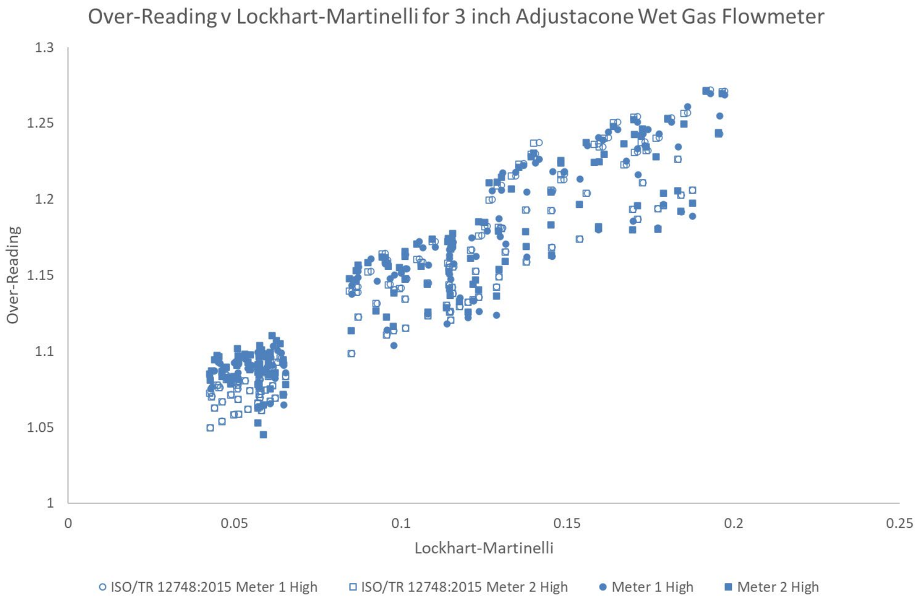


Fig 10. High Range Over-Read versus Lockhart Martinelli results and computed ISO/TR 12748:2015(E) correlations.

In low range (0.5 Beta) a distinct shift was observed, between test results and calculated results. However, since ISO/TR 12748:2015(E) is limited to 0.75 beta, this was expected. Further analysis is required to determine the best approach and curve fit, in order to produce predictable results.

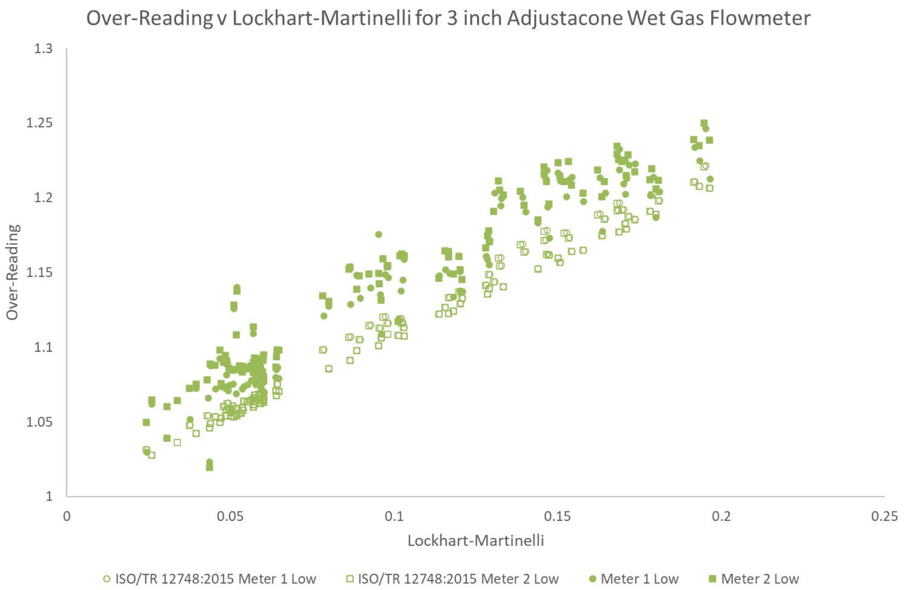


Fig 11. Low Range Over-Read versus Lockhart Martinelli results and computed ISO/TR 12748:2015(E) correlations.

One method which shows promise is the use of the secondary DP reading, located between the cone upstream pressure port and the pressure port located 500 mm downstream of the meter body.

Pressure Loss Ratio 1 (PLR1) is defined as the differential pressure across the whole flow meter, divided by the cone differential pressure. Pressure Loss Ratio 2 (PLR2) is further defined as the differential pressure across the whole flow meter plus the 500 mm pipe section, divided by the cone differential pressure. Taking a ratio of these two pressure loss ratios, and plotting it against the Gas Froude Number (Fig 11), produces a usable, curved plot, which can be utilised to predict the Gas Froude Number for values less than 1.5.

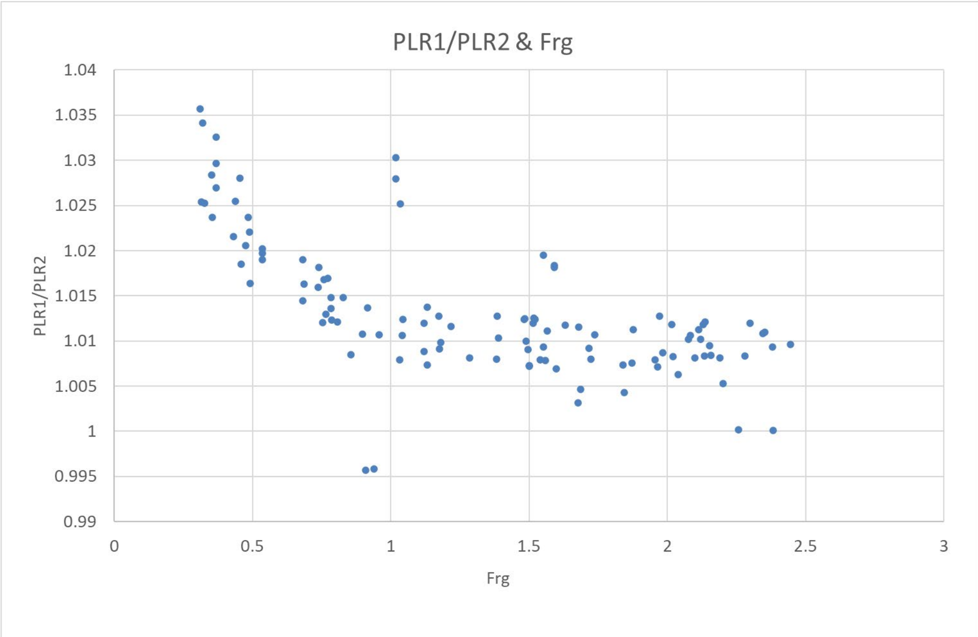


Fig 12. Ratio of PLR1 divided by PLR2, plotted against Frg.

5.1 SLEEVE SEAL TEST RESULTS

At pressures up to 125 Barg (1812 PSIG) and 125 Deg C (257 Deg F) the sliding sleeve was continuously reciprocated until a predetermined number of cycles was achieved. During this time, if any of the seals had leaked, the pressure within the gearbox, which drives the sleeve movements, would have increased to the same pressure as the meter pressure. The gearbox seals are designed to hold full line pressure, allowing safe and accurate metering operations to continue until maintenance can be undertaken.

Since no significant gearbox pressure build-up was observed, other than through heating of the gearbox oil, it was confirmed that no sleeve seal leaks occurred, and all the tests were terminated when the desired number of sleeve cycles was reached.

The desired number of strokes related to an example case where a flow meter was installed in a well and was cycled from high to low and back to high again, once per day*. Automated sleeve cycling is planned to be undertaken in some well applications for two separate reasons: 1) to record two measurements at the same flowing conditions, in both high and low flow ranges, in order to reduce overall meter uncertainty 2) as part of planned preventative maintenance, in wells which are prone to scale build-up over time.

	Seal Set 1	Seal Set 2	Seal Set 3	Seal Set 4
Average Pressure	127 Barg	105 Barg	108 Barg	108 Bar
Average Temperature	123 Deg C	101 Deg C	100 Deg C	103 Deg C
No of Complete Sleeve Cycles	2,552	3,757	3,833	3750
Nominal Equivalent Lifespan*	7 Years	10.3 Years	10.5 Years	10.3 Year
Evidence of Seal Leaks	None	None	None	None
Post-Test Seal Condition	No Wear or Damage Observed	No Wear or Damage Observed	No Wear or Damage Observed	No Wear or Damage Observed

Table 1 – Sleeve Seal Test Results

6.0 CONCLUSIONS & FUTURE WORK

At the time of writing, data analysis continues. As expected, it is confirmed that ISO/TR 12748:2015(E) wet gas Technical Report, does apply for the adjustable cone meter in high flow range (0.75 Beta), where the sleeve does not cover the cone.

Reference to the same standard will require to be modified slightly for it to be applicable in the low flow range (0.5 Beta). The authors are investigating the potential to create new “n” values, when using equations (eq 5 and 6), for the Chisholm over-read correction formula (eq 3 and 4) from the test data. Additional data set(s) will be required in order to make this fully applicable.

Additional flow testing is planned to be conducted in late 2024 or early 2025 at an alternative flow test facility, to cross-check the test data accumulated previously.

Additional watercut meter measurements will be made during the additional testing.

Upgraded algorithms will be developed and tested during the additional testing.

It is concluded that the sliding sleeve seals are well capable of operating successfully over prolonged time periods at upto 125 Barg (1812 PSIG) and 125 Deg C (257 Deg F). Operations at combined 125 Barg and 125 Deg C are well within the design operating envelopes of the sliding sleeve seals.

7 NOTATION

β	Beta ratio of the cone meter
C	Coefficent of Discharge of the cone meter
ε	Compressibility (sometimes called expansibility)
D	Meter ID or Sleeve ID
d	Cone OD
Δp	Cone Differential Pressure
ρ_{1gas}	Gas Density
ρ_{liquid}	Liquid Density
Ø	Wet gas over-read
$q_{m.gas}$	Gas Mass Flow Rate
F_{rg}	Gas Froude Number
X_{LM}	Lockhart Martinelli Parameter
WLR	Water to Liquid Ratio
g	Accleration due to gravity = 9.81 m/sec^2
C_{Ch}	Chisholm Coefficient
n	Factor used in the Chisholm Coefficent Calcluation

4 REFERENCES

[1] G. MUNRO & S. MAHALINGAM. Using an Adjustable DP Cone Meter to Measure Wet Gas, North Sea Flow Measurement Workshop 2021.

[2] Technical Report. Natural Gas – Wet gas flow measurements in natural gas operations ISO/TR 12748:2015(E) First Edition