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Technical Paper

Evaluation of the SONAR Meter in Wet Gas Flow for an Offshore Field Development

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1 INTRODUCTION

The ABC project is a high pressure gas condensate development currently in the implementation stage. Platform top-side surveillance is considered critical for better reservoir management, production optimization and flowline integrity management. After investigating different options, the SONAR clamp-on meter was identified as the solution to provide individual, real time production surveillance for ten flow lines (12-inch pipe) upstream of the production manifolds and the high-pressure (HP) separator.

In order to determine the wet gas flow uncertainty over the anticipated gas and liquid flow range, testing was performed at the NEL, Wet Gas Facility in Scotland. The results and conclusions from the testing are detailed in this paper.

The main requirement of the test program was to evaluate the SONAR meter for provision of real time gas rates and inferred oil and water rates across a range of flow conditions anticipated across the life of high pressure gas condensate development. This testing was limited to lab capabilities of;

- Measure max pressure of 63 Barg at 2 flow rates of 780 ACMH and 1040 ACMH
- 0 – 10% WLR
- Volumeteric Gas rate accuracy – 5-10%
- Volumetric Liquid Rate Accuracy 10-15%.
- Mass Bulk flow accuracy dependent on density measurement

2 SONAR Technology

SONAR technology involves observing the naturally-occurring coherent vortical structures within the flow (generated due to turbulence) by monitoring interactions of externally-generated acoustic pulses (pulse arrays) with those coherent structures. The subsequent processing algorithms involve analysis of the spatial wavelength (distance) and temporal frequency (time) of the sensor signals over a range of values.

Multiple spatial and temporal wavelengths are plotted to generate a k-omega plot which is essentially a high energy region called the vortical ridge. The slope of this ridge determines the flow velocity. The volumetric flow rate at standard conditions can then be calculated using the pipe cross-sectional area, pressure and temperature.

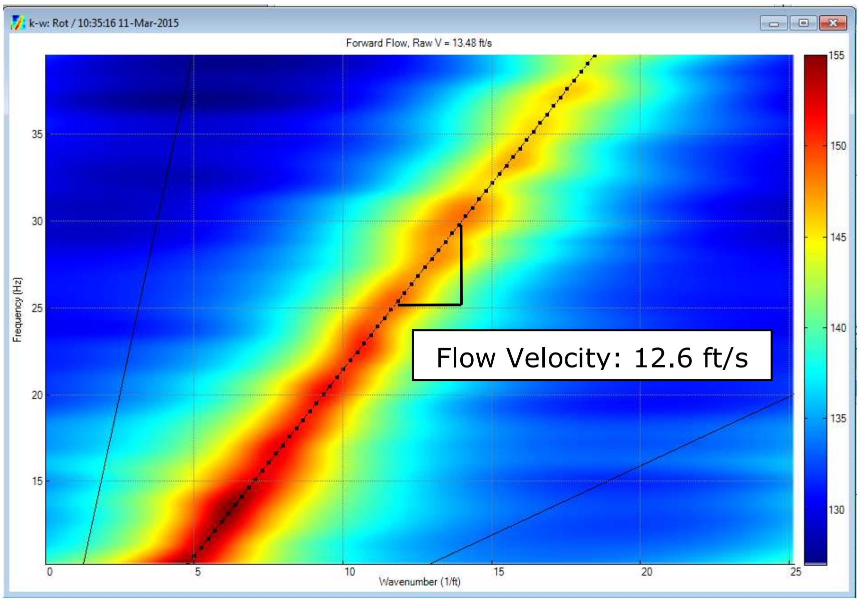

Fig.1 - SONAR Diagnostics: k-ω ridge

3 SONAR OVERREADING CORRELATION - BACKGROUND

In wet gas flow measurement, the flow meter generally over reads the gas flow rate due to wetness addition. The over-reading is defined as

$$OR = \frac{Q_g}{Q_g^{ref}} \tag{1}$$

where Q_g is the gas volumetric flow rate measured by the flow meter and Q_g^{ref} the actual gas volumetric flow rate given by the reference system in line condition.

Based on empirical data collected in flow loop testing conducted on 4-in Sch 40 and Sch 80 pipes, the over-reading of the 4-in ActiveSONAR™ flow meter can be characterized by the the following correlation:

$$OR = 1 + \beta\left(\frac{\sqrt{LVF}}{1+Fr^m}\right) + \varphi\left(\frac{\sqrt{LVF}}{1+Fr^m}\right)^2 \tag{2}$$

where $\beta = 2.5249$, $\varphi = -3.9043$ and

$$m = \begin{cases} F_r - 0.5, & 0.5 < F_r < 1.5 \\ 1, & F_r \geq 1.5 \end{cases} \tag{3}$$

The F_r number is defined as

$$F_r = \frac{V_{sg}}{\sqrt{gL}}\sqrt{\frac{\rho_g}{\rho_L - \rho_g}} \tag{4}$$

where V_{sg} is the superficial velocity of the gas flow, g the gravitational acceleration, L the characteristic length of the pipe (ID of the pipe here), ρ_g the gas density in line conditions and ρ_L the liquid density in line conditions.

The Liquid Volume Fraction (LVF) is defined as

$$LVF = \frac{Q_L}{Q_L + Q_g} \tag{5}$$

where Q_L is the liquid volumetric flow rate in line conditions. For low liquid loading, $Q_L << Q_g$, Eq. (5) is simplified as the ratio of the liquid volumetric rate to the gas volumetric rate

$$LVF \approx \frac{Q_L}{Q_g} \tag{6}$$

The over-reading correction shown in Eq. (2) enables the 4-in ActiveSONAR™ meter to report gas rates to within ±3% for 0<*LVF*<0.106 and 0.5< F_r <5.78.

There is another important dimensionless parameter for liquid fraction broadly used in wetness flow metering is Lockhart-Martinelli number, which is defined as

$$X_{LM} = \frac{Q_L}{Q_g}\sqrt{\frac{\rho_L}{\rho_g}} \tag{7}$$

For low liquid loading, we have

$$X_{LM} \approx LVF\sqrt{\frac{\rho_L}{\rho_g}} \tag{8}$$

4 TEST SETUP

Testing was performed in the NEl high pressure wet gas facility in 2 phases, Oct-2014 and Mar-2015. The flow meter was clamped onto a 12" sch 160 pipe spool with class 600 raised face flanges. The meter was mounted approximately 14.5 D (4.3m) downstream from the 12-in straight pipe upstream flange face. This setup was used in order to replicate the expected installation setup at the platform conditions.

The test section pressure tapping was located 1.5 m from the downstream flange and the temperature probe was located 643 mm from the downstream flange. The flow computer was installed on a vertical grating adjacent to the meter location. An identical test setup was used for both phases of testing.

Phase 1 testing used Nitrogen gas via 6"ultrasonic meters and kerosene via ½", 1" and 3" turbine meters. Testing followed a defined test matrix and maintained a ~63 bar(g) pressure, 15 °C and gas volumetric flow rates of 780 – 1040 m^3 /hr.

During the 6 month time from Phase 1 - Phase 2 testing, the NEL lab had been updated to a multiphase flow lab and incorporated the use of a 3" and 1 1/2" Coriolis meter as the liquid kerosene reference meters. The 6" USM remained the gas reference meter and maintain a ~63 bar(g) pressure, 15 °C and gas volumetric flow rates of ~500 – 1600 m^3 /hr.

The flow was wet gas, 100% nitrogen mixed with kerosene oil. After the geometric parameters of the pipe were obtained, the flow meter was configured. The driving frequency of the transducers and demodulation delay were obtained by using the built-in oprimizer. The configuration of the flow meter was fixed during the whole test period and identical configurations were used for both rounds of testing. The line pressure and temperature for both phases of testing ranged from 60-62 barg and 15-20^{0}C respectively.

The flow rate, pressure and temperature were stabilized before a 30-second pre-test point was logged. The CGR (condensate-gas ratio) for each test point was then provided to Expro for input into the flow computer. The actual test point was then logged for a period 240 seconds (4 minutes).

Meter performance criteria was defined as 5% to 10% for the gas flow rate measurement and 10% to 15% for liquid flow rate measurement.

5 TEST RESULTS

5.1 1st Testing Phase

Testing was conducted for 65 data points in total with 5 dry gas points and 60 wet gas points. For the dry gas test points, 2 points were tested before the wet gas test points and 3 points were tested after the wet gas test points. The testing was conducted at gas flow rates of 620 and 800 m3/h (at actual conditions). The Froude Numbers (Fr) range for the test points ranged from 0.69 to 0.89 and the Liquid Volumetric Fraction (LVF) ranged from 0 – 10.7%.

After NEL reference data was obtained, a comparative analysis was done between Expro and NEL gas and liquid rates for all the test points. For dry gas test points, the difference in Qgas at actual conditions was less than $\pm$1% which is within the SONAR meter specifications as shown in Figure 2.

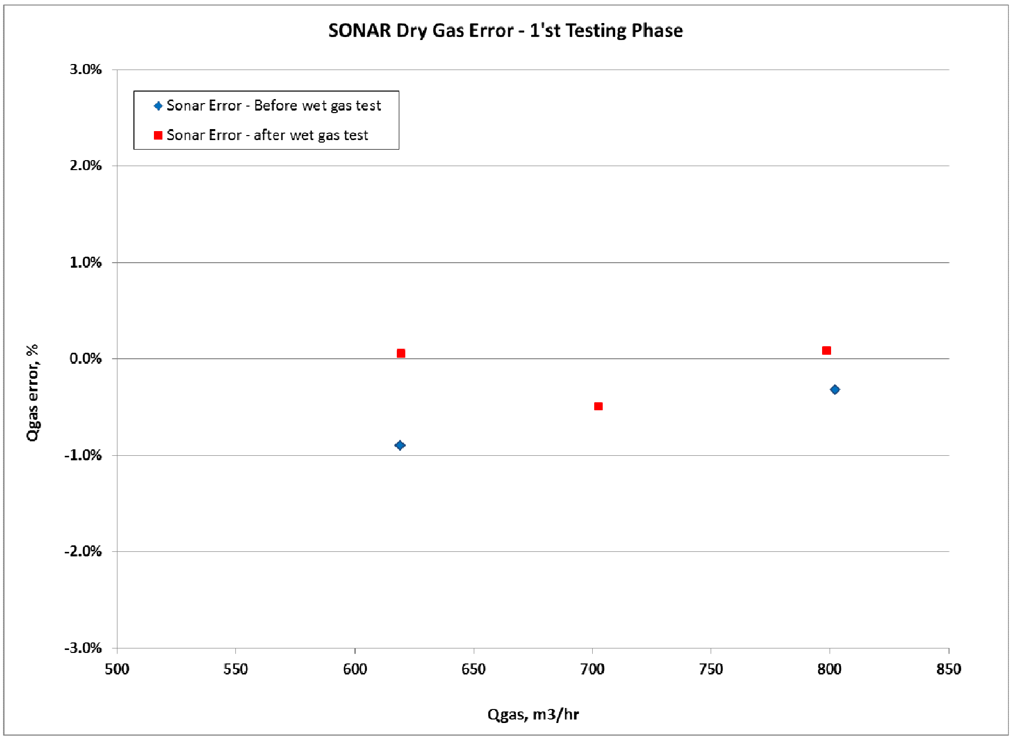

Fig. 2 - Dry Gas Error (SONAR vs. NEL) 1’st Testing Phase

For the wet gas test points, the average difference between Expro Qgas (at Actual conditions) and NEL Reference Qgas (Actual) was approximately -15% (Figure 3). Upon further investigation this error was attributed primarily due to the over-reading correlation. A secondary source of error was a mismatch in CGR (condensate gas ratio) for some of the test points and the actual CGR at flowing conditions. A modified over-reading correlation was developed and this has been detailed in section 5.2

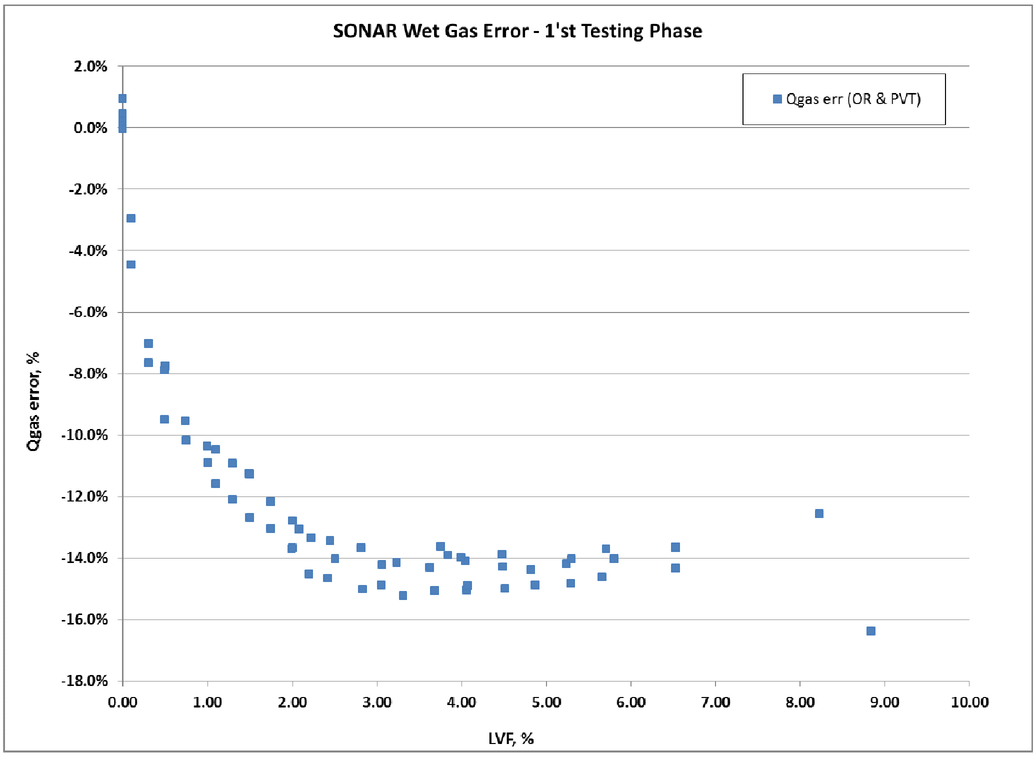

Fig. 3 - Wet Gas Error (SONAR vs. NEL) 1’st Testing Phase

5.2 Modified Overreading Correlation

For the first phase of testing, the over-reading correlation for 4-in wet gas flow shown in Eq. (2) and Eq. (3) (incorporated in the flow computer) was applied to the 12-in wet gas test points. Fig. **4 - 1** compares the actual over-reading for the NEL test points (OR NEL) and the reported over-reading using the existing 4” correlation (OR SONAR). The error in gas rate has been plotted on the Y-axis. It is evident that the actual over-reading is considerably lower than the 4” over-reading correlation and follows a linear trend. This indicates that the over-reading correction is pipe size dependent. Since the original correlation was developed for a 4” pipe and the NEL testing was conducted on a 12” pipe, the meter over-reading seems to decrease as the pipe size is increased.

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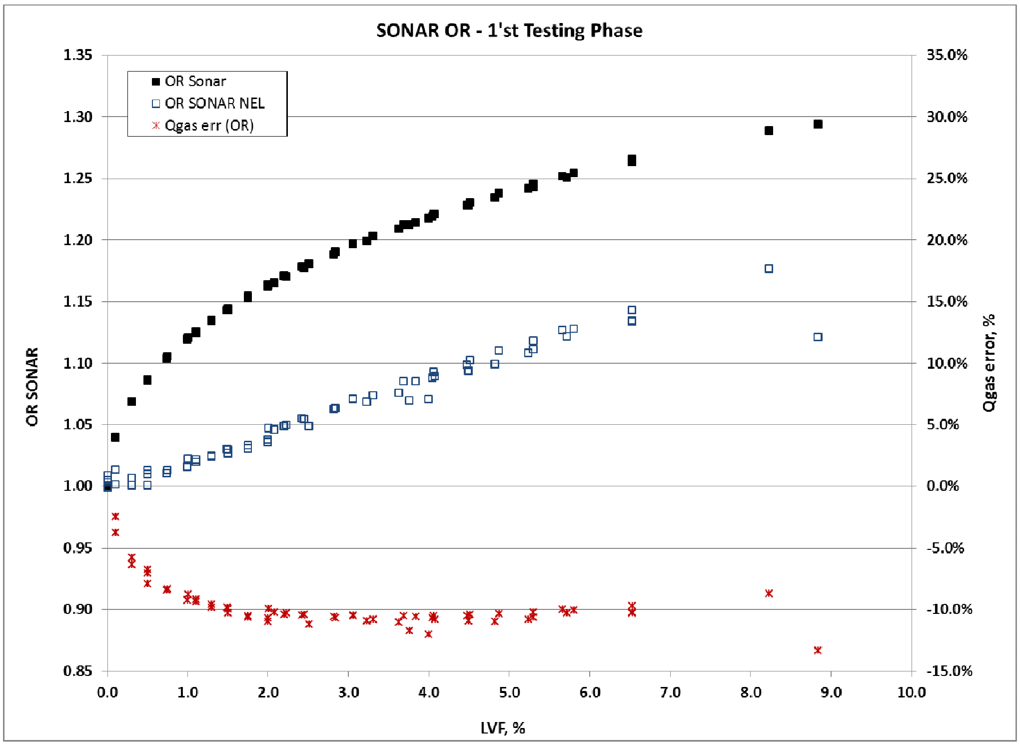

Fig. 4 - 1SONAR over reading versus LVF (1st Testing Phase)

Upon further analysis of the data, it was determined that the over-reading for the 12-in wet gas flow can be characterized by modifying the coefficients of Eq. (2). After a curve-fitting exercise, the following correlation was obtained for the 12-in wet gas flow:

$$OR = 1 + \beta\left(\frac{\sqrt{LVF}}{1+Fr^{m}}\right) + \varphi\left(\frac{\sqrt{LVF}}{1+Fr^{m}}\right)^{2} \qquad (12)$$

where $\beta = 0.037467$, $\varphi = 6.168157$ and

$$m = \{F_r - 0.5, \qquad 0.5 < F_r < 1.1 \qquad (13)$$

The above correlation has been developed only up to Fr = 1.1 and LVF $\leq$ 8%. Additional reference data was needed to validate the correlation at higher Froude numbers. The modified over-reading correlation was then applied to all the test points. Fig. **2** shows the curving fitting of the test points.

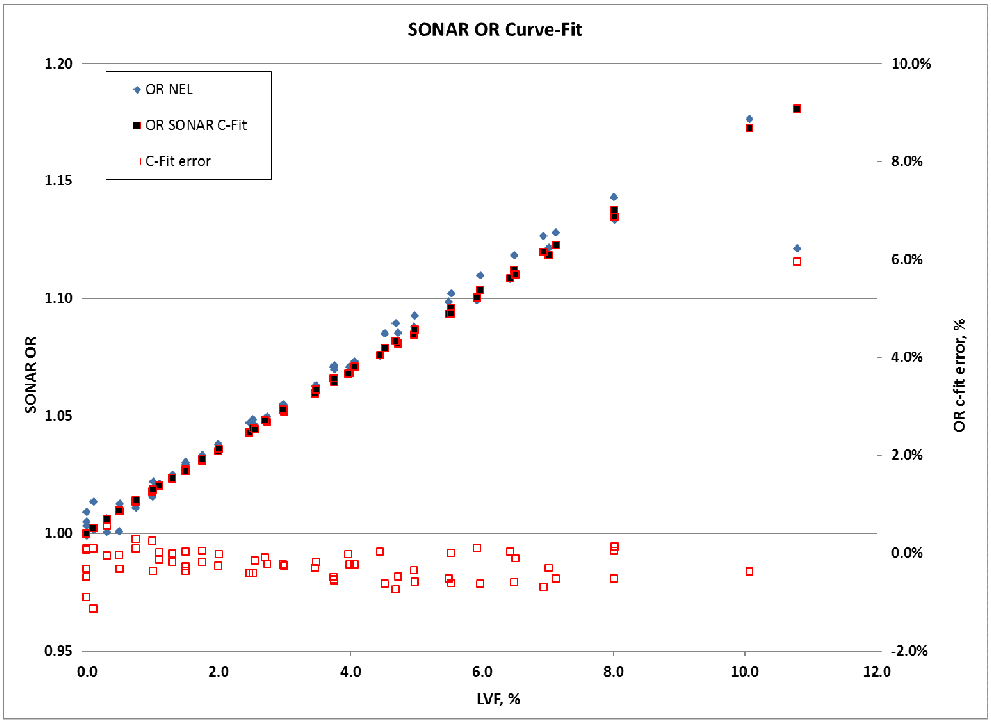

Fig. 2 - Over-reading curve-fitting for 12-in meter in wet gas flow

Error! Reference source not found. shows the Qgas error (SONAR vs. NEL) after applying the modified over-reading correlation to the test data. As evident from the graph, the difference between the SONAR gas rates and NEL gas rates was within ±2% for most test points.

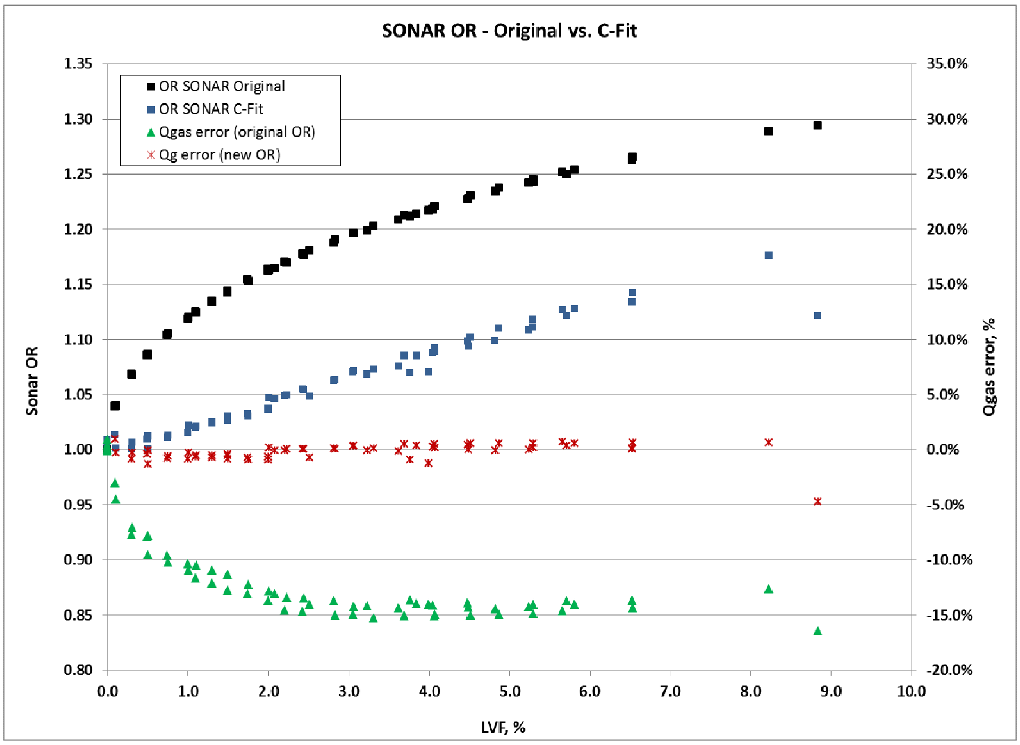

Fig. 6 - SONAR OR and Qgas Error versus LVF – C-Fit vs. Original OR

5.3 2nd Testing Phase

The 2nd round of testing at NEL was conducted in March 2015. The primary purpose of the test was to validate the over-reading correlation developed for the 12" meter based on the data analysis after the 1st round of testing. The new over-reading correlation was implemented in the flow computer prior to the commencement of the test.

As stated earlier, the meter and flow computer setup was identical to the previous setup in order to maintain repeatability of operating conditions. The test matrix was however condensed to 43 test points, 6 dry gas points and 37 wet gas test points. The Qgas (actual) range for the test points was 500 - 1000m3/hr. The Froude Numbers (Fr) range for the test points ranged from 0.69 to 1.1 and the Liquid Volumetric Fraction (LVF) ranged from 0 – 10.2%.

Figure 7 shows the comparison between the actual over-reading for the test points and the reported over-reading using the modified correlation using curve-fitting. It is evident from the chart that the modified over-reading correlation follows the same trend as the actual over-reading with increasing LVF.

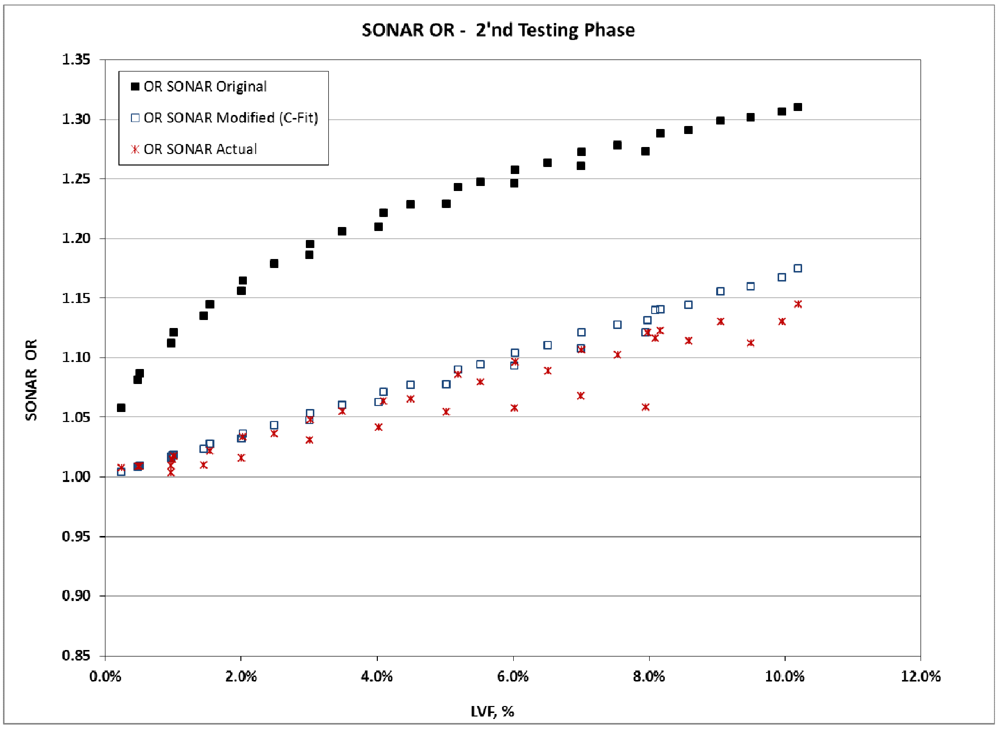

Fig. 7 - SONAR over reading versus LVF (2nd Testing Phase)

Figure 8 shows the comparison between SONAR Qgas actual and NEL reference Qgas actual versus LVF. As can be seen in the chart, 93% of the SONAR reported gas rates were within ± 5% of the reference rates. The remaining points were within 10% of the reference rates. The liquid rates are directly inferred from the gas rates using the CGR and hence are within the same error bands (Figure 9).

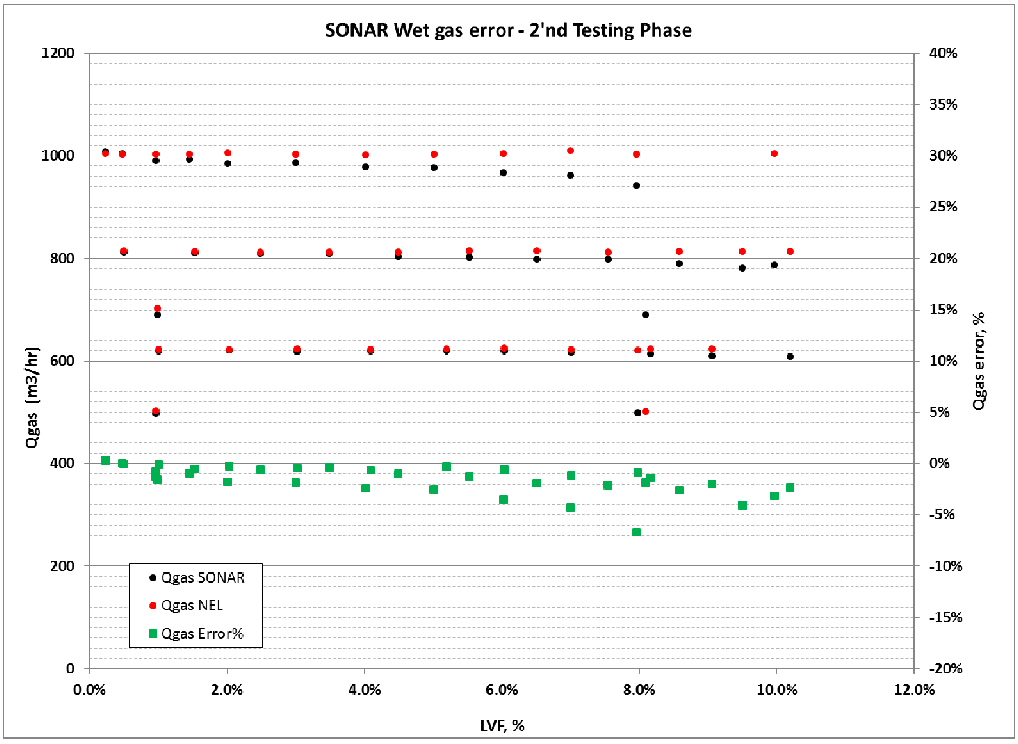

Fig. 8 - Qgas error versus LVF (2nd Testing Phase)

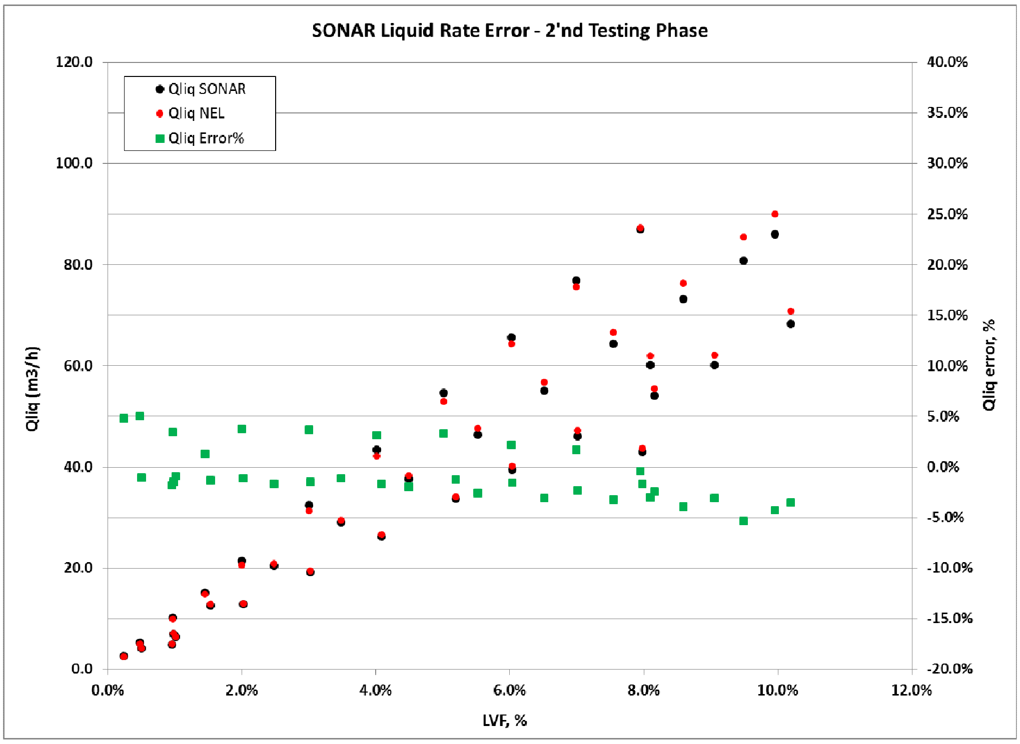

Fig. 9 - Qliq error versus LVF (2nd Testing Phase)

6 CONCLUSIONS

The meter qualification testing performed in the 1st phase (Oct-2014) led to the development of a modified over-reading correlation for the 12-inSONAR meter in wet-gas flow. This correlation was also validated in the NEL test loop by additional testing in the 2nd Phase (March-2015). It is evident from the testing at NEL (and previous flow loop testing) that the SONAR meter over-reading characteristic for wet gas flows is pipe size dependent. The over—reading also seems to decrease with increasing pipe size. It is recommended to perform testing at intermediate pipe sizes (6″ and 8″) and at higher Froude numbers to characterize the meter over-reading and subsequently implement it for future field applications.

7 NOTATIONS

β	Beta (Calibration Coefficient)
φ	Phi (Calibration Coefficient)
LVF	Liquid Volumetric Fraction
OR	Overreading
C-Fit	Curve-Fit
CGR	Condensate-Gas Ratio
Fr	Froude Number

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