Water Volume Fraction Measurement Challenges and Solutions of Roxar Wet Gas Meters in the Ormen Lange Field

G. Groote, H. Xu, K. Lillehammer A/S Norske Shell,
P. Bajpayee, Emerson
H. de Leeuw, DLFC/Flowways

1 ABSTRACT

The Ormen Lange field has Roxar subsea wet gas meters (SWGM) installed on each well for production monitoring. One of the functions is to monitor the water volume fraction (WVF) to identify the onset of formation water breakthrough. Once the WVF has reached the alarm limit action needs to be undertaken (e.g. choke back the well, shut-in the well or increase the MEG dose rate). Over time the WVF measurement has been slowly increasing. At the same time, other qualitative measurements implemented like downhole tracers, water content in rich MEG and surface ion analysis did not show formation water. A detailed study of the Ormen Lange meters was performed in collaboration between the asset, Shell metering SME's and Emerson in 2024 to better understand the metering behaviour, sensitivities and uncertainties. It was found that the observed increase in measured WVF is actually an effect due to the low production rates of the wells. The measured WVF increases as function of lower differential pressure over the meter. The effect of the low differential pressure on the WVF measurement can be corrected for and this enables more accurate monitoring of the actual WVF. The remaining sensitivity of the measurement was tested using known MEG injection upstream of the meter.

This work significantly increased the understanding of the flow meter behaviour. As a result the control system will be updated to correct for the apparent increasing WVF which is an effect of low differential pressure across the meter. The alarm value will be updated to help the asset to identify when a well starts producing formation water. Additionally, for some wells a manual adjustment to the WVF values is done to correct for some differences in the meters.

2 BACKGROUND

Ormen Lange is a subsea-to-shore gas/condensate development located on the Norwegian Continental Shelf, see figure 1. The water depth ranges between 850 and 1000 meters at the well head with an ambient sea water temperature below 0°C, making ice formation a real risk. During operation, gas is continuously dosed with MonoEthylene Glycol (MEG) to prevent hydrate formation and is then transported to shore via two 30-inch 120 km pipelines. To this day, no hydrate blockage has been recorded in any flowing section of the field.

Currently, one well has started producing formation water. The formation water rate was measured by the subsea wet gas meter and the water was dosed with the required amount of MEG to prevent hydrates. It is important to accurately measure the water rate so the correct amount of MEG can be dosed. Dosing too much MEG will increase the liquid holdup and decrease the gas production. Dosing insufficient MEG can result in hydrate formation, and this can form a pipeline blockage which can result in significant production deferment.

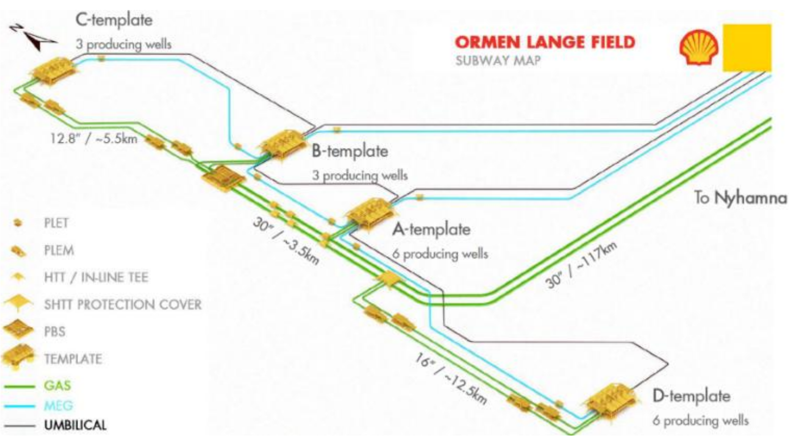

Figure 1 – Subsea map of Ormen Lange.

2 INCREASING WATER VOLUME FRACTION AT LOW FLOWRATES

2.1 Wet gas mode versus dry gas mode

The meter can operate either in wet gas mode or dry gas mode. For a gas volume fraction (GVF) above 99.5% it is recommended to operate in the dry gas mode. Below a GVF of 99.5% it is recommended to operate the meter in wet gas mode. The meters were switched from wet gas to dry gas mode in January 2021. Table 1 shows the uncertainty in the Water Volume Fraction (WVF) measurement versus the gas volume fraction (GVF) for dry gas mode according to the specifications. A higher gas volume fraction results in a lower WVF uncertainty in dry gas mode. The current GVF at the meters is around 99.92% and operating in dry gas mode results in ±0.02% abs. WVF uncertainty.

Table 1 – Dry gas mode versus wet gas mode specification.

Conditions	Dry gas mode	Wet gas mode
GVF > 99.95%:	±0.01% abs. WVF uncertainty	±0.1% abs. WVF uncertainty
GVF > 99.6%:	±0.02% abs. WVF uncertainty	±0.1% abs. WVF uncertainty
GVF > 99.4%:	±0.04% abs. WVF uncertainty	±0.1% abs. WVF uncertainty
GVF > 99 %:	±0.1% abs. WVF uncertainty	±0.1% abs. WVF uncertainty
PVT independence WVF measurement	Yes	No
In-line zero adjustment of WVF required	No	Yes

2.2 Water Volume Fraction (WVF) field data and correction

Figure 2 and 3 show the WVF versus differential pressure across the meter in 2024 and 2023, respectively. All the wells have almost the same water-gas-ratio (WGR) so these graphs clearly show that the meter shows a higher reading (i.e. higher WVF) at lower differential pressure (dp) across the meter. This effect is due to the meter set-up. The blue dots inside the red circle in figure 3 show the WVF for a well which is producing formation water. These blue dots clearly show that the WVF for this well is much higher than the other wells. This data also shows that the measurements below ~50 mbar have a large uncertainty (see for example the brown dots around 15 mbar which fluctuate between a WVF of 0.06% and 0.012%). This uncertainty is due to the fact that the fluid velocity drops below the minimum velocity across the V-cone.

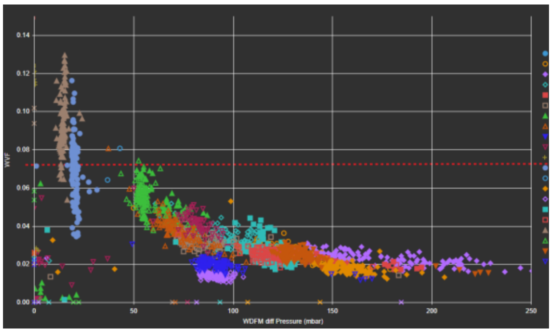

Figure 2 – WVF fraction versus differential pressure across the meter for all wells between December 2023 and December 2024. Every colour represents the data from a well.

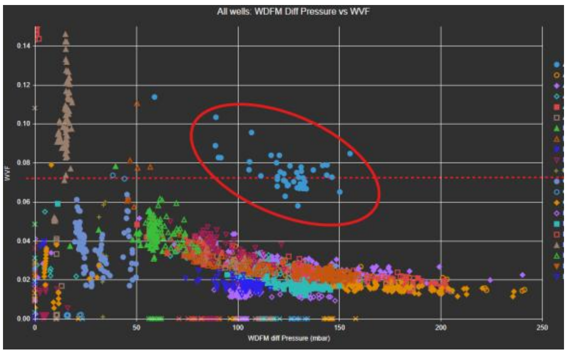

Figure 3 – WVF fraction versus differential pressure across the meter for all wells between December 2022 and December 2023. The blue dots inside the red circle show the well which is producing formation water.

Figure 4 shows the WVF versus mbar (similar as shown in figure 2) with averaging the data for several days. A curve is fitted through the data, see the red line. This curve is made using the following formula:

$$WVF = a * \exp(b*x) + offset \qquad (1)$$

The following are constants: a, b and offset. The differential pressure across the meter (in mbar) is denoted by x.

Figure 5 shows the "corrected WVF" using the following formula:

$$\text{"corrected WVF"} = \text{Meter WVF } (a * \exp(b * x)). \qquad (2)$$

The following are constants: a and b. The differential pressure across the meter (in mbar) is denoted by x. This correction is done to correct for the increased WVF reading at lower differential pressure across the meter. The graph shows that the corrected WVF is about 0.02 for all wells. This is close to the expected WVF of condensed water at wellhead conditions. Again, the meter shows a lot of noise at low differential pressures, see the brown and the light blue dots (i.e. below 50 mbar), see figure 5.

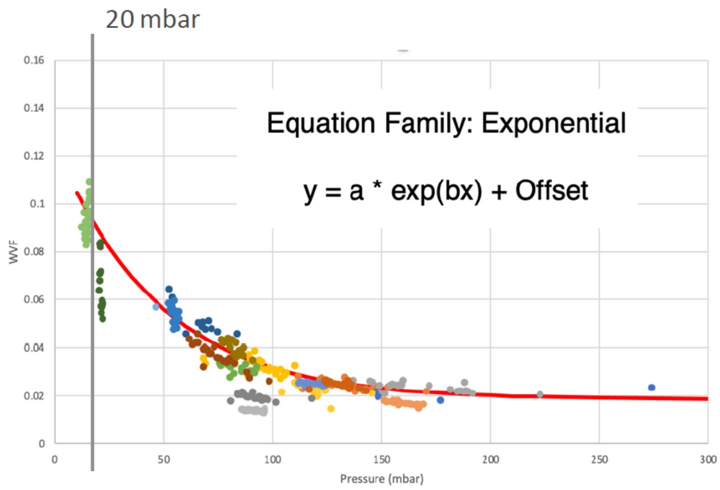

Figure 4 – WVF which is averaged for several days with a curve fitted through it.

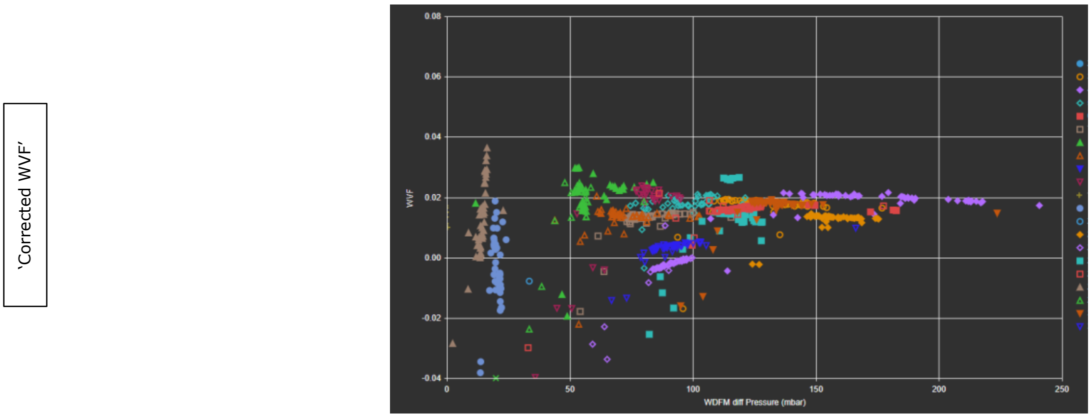

Figure 5 – "Corrected WVF" versus differential pressure for all wells between December 2023 and December 2024.

2.3 Individual well corrections

In Figure 5 it is observed that two wells (purple dots and blue triangle between 80 and 100 mbar) show a reading with a lower WVF compared to the other wells. However, the WGR is about the same for all wells so it is expected that this lower reading is caused by slight differences between the meters and this is not due to a low water flow from the well. To correct for this low reading a constant value is added to the reading so it will match the average WVF (of about 0.02). It is not known if this correction will also work at other pressure conditions (e.g. after the installation of the subsea compressor the wellhead pressure will decrease) so this needs to be reviewed when the pressure conditions at the wellhead change. Figure 6 shows the "corrected WVF" including the manual correction for two wells. Note that the corrections are within the uncertainty of the meter in dry gas mode (for this condition the uncertainty is 0.02% see table 1).

One well shows a WVF which is slightly higher compared to the other wells, see light the blue points (highlighted by red circle) around 110 mbar at a WVF of about 0.028.

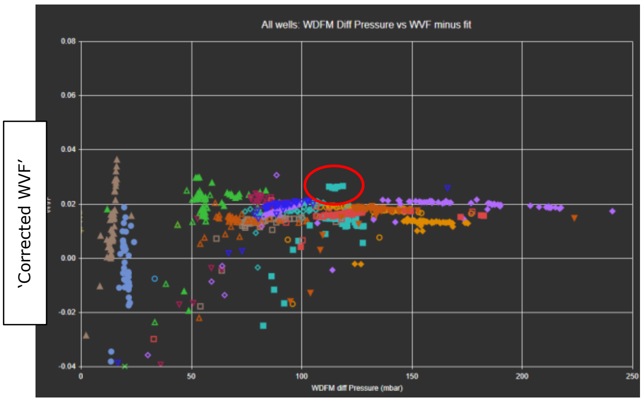

Figure 6 – "Corrected WVF" for all wells between December 2023 and December 2024 including manual corrections for 2 wells.

3 Sensitivity with flowing MEG through the meter

With the 'corrected WVF' it becomes easier to monitor for a real increase in water production. The question which remains is how sensitive the measurement is in case of formation water production.

To better understand the WVF sensitivity a test was performed by injecting MEG upstream the meter. Flowing extra water through the meter would have given even more realistic results, but this was unfortunately not possible. Tests were done with flowing MEG at various flow rates through the meter on the 2nd and 9th of December 2024. During the first injection test on the 2nd of December the measurement time per test point was around 5 minutes. This was considered to be relatively short therefore the test was repeated with longer measurement durations on the 9th of December. However, the results closely overlap.

The WVF sampling frequency in PIVISION is low therefore the measurement data from the SAS system is used. Figure 7 and Figure 8 show the WVF and MEG flowrate versus time. This data clearly shows that the WVF increases for an increasing MEG flow rate. The figures also show that the WVF is slightly decreased when the MEG is injected at a low rate (when the test starts), so this indicates that MEG behaves differently than water.

Figure 9 shows the injected WVF on the horizontal axis (assuming MEG is fully measured as water) and the measured WVF on the vertical axis from the meter for the two tests. The results for the two tests are similar because they are on the same line, note that the slope is linear. The slope of the points is below the expected slope of 1. This is likely because MEG behaves differently than water (due to lower surface tension, lower permittivity). The results for the 2 tests overlap (grey and blue points) despite the short measurement times of the first test on the 2nd of December. This indicates that the meter reacts quickly, and the measurement stabilizes quickly.

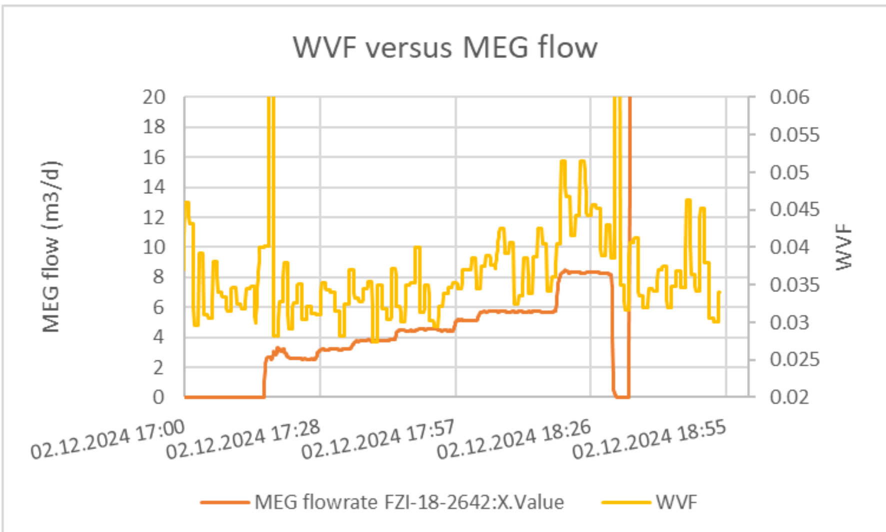

Figure 7 – Test WVF sensitivity: flowing MEG at various rates through the meter on the 2nd of December 2024.

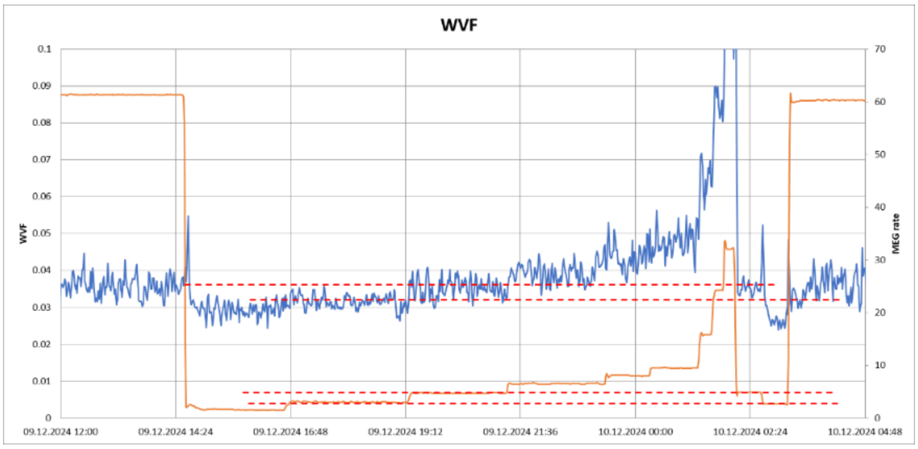

Figure 8 – Test WVF sensitivity: flowing MEG at various rates through the meter on 9-10 December 2024.

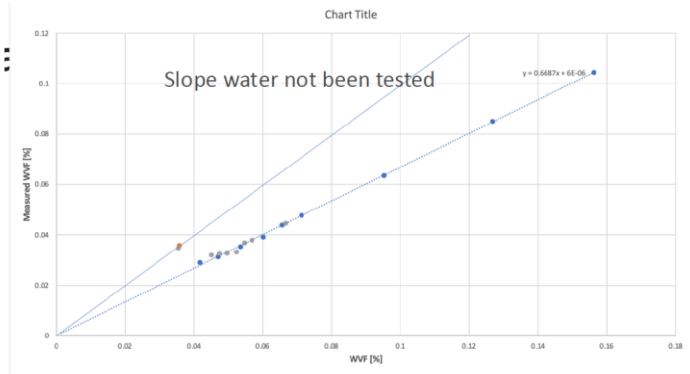

Figure 9 – Measured WVF versus injected WVF. Note that the slope is below 1. It is assumed that the lower slope is due to the fact that the test was with MEG instead of water.

An additional observation is that when a high flowrate of MEG is flowing through the meter the WVF shows a negative reading, see figure 10. This is typically observed during a well integrity test (WIT).

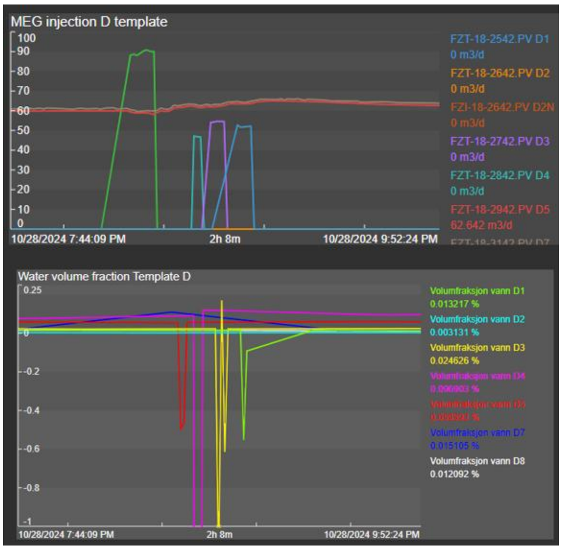

Figure 10 – Figure 5 12 Example of the WVF reading when a high flowrate of MEG is flowing through the meter during a WIT.

4 ALARM SETTING WVF

The water measurement in the meter is based on measuring the aqueous phase (condensed water). The saturated water in the gas phase is not measured. However, to calculate the total amount of water both condensed water and water in the vapour phase need to be considered. The split between condensed water and water in the vapour phase depends on the pressure. At lower pressure the vapour phase can contain more water. Therefore, the measured condensed water rate will decrease, see the orange line in figure 11. The yellow line shows the total WVF (sum of the WVF in gas and liquid phase).

The MEG dosing is based on the total water flow rate (condensed water and water in the vapour phase). Extra MEG is injected to account for uncertainties in the measurements (i.e. MEG flow rate meters, water detection, Saturated water volume, lean MEG concentration). The alarm limit for the total amount of water is set at the total calculated water rate plus 30% margin. Once the WVF has reached the alarm limit action needs to be undertaken (e.g. choke back a well, shut-in the well or increase the MEG dose rate).

Figure 12 shows the WVF in the liquid phase (orange line) predicted by PVTSIM at the meter conditions. The blue line shows the WVF alarm value in the control system. This blue line consists of the WVF in liquid phase plus 30% of the total WVF (the total WVF is represented by the yellow line in figure 11). The graph clearly shows that the alarm value is a function of the wellhead pressure.

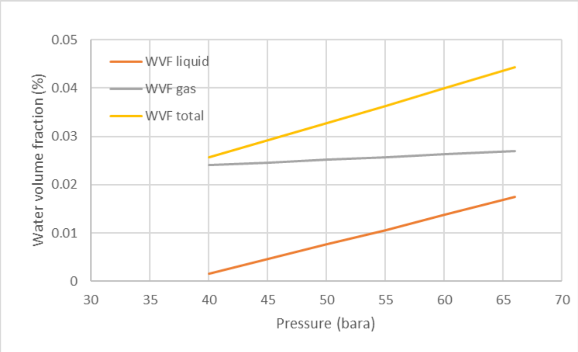

Figure 11 – WVF in the liquid, gas and total fluid versus pressure at the meter. The WVF is calculated at 72 degC and for the Ormen Lange fluid using PVTSIM.

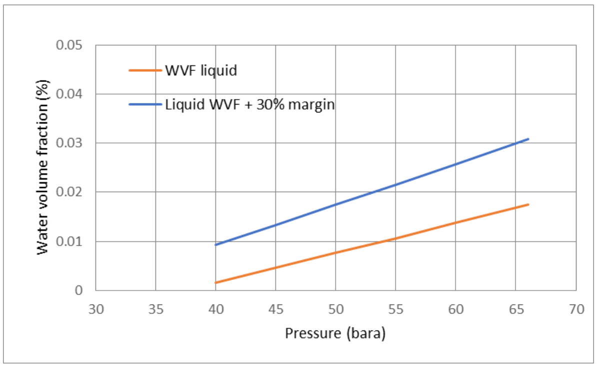

Figure 12 – Expected WVF without and with 30% margin versus pressure at the meter. The WVF is calculated at 72 degC and for the fluid composition shown in appendix 2.

5 CONCLUSIONS

- The WVF measured by the meters on Ormen Lange is a function of the differential pressure (i.e. gas flow rate).
    - Lower differential pressures across the meter result in higher Water Volume Fraction (WVF) measurements. This is due to the meter set-up. A fit is done through the data and a formula is used to correct for this effect. The re-calculated WVF is called the 'corrected WVF'.
- At low differential pressures across the meter (i.e. low flow rates) the noise in the measured WVF increases (and the uncertainty increases), especially below 50 mbar. This is due to the low velocity across the v-cone.
    - It will help to average the data to reduce the noise in the measurements, for example for 1 day. Note that formation water breakthrough is a slow process taking weeks or months.
    - Decreasing the pressure at the meter will increase the fluid velocity and this will increase the differential pressure across the meter. Therefore, this will reduce the uncertainty in the WVF measurement.
- The meter uncertainty is about 0.02 vol% in dry gas mode (for the Ormen Lange wellhead conditions). The measured values are between 0.01% and 0.02% so within the uncertainty range.
- Three wells show a WVF reading below or above the expected condensed water volume. This is unlikely and it looks like the meter is reading too low or too high. Therefore, a manual correction is done to match the theoretical condensed water rate.
- The WVF alarm needs to be a function of the wellhead pressure. The meter is measuring only the condensed water but not the water in the vapour phase. Therefore, the alarm limit shall decrease when the wellhead pressure is reduced. (with more water in the vapour phase not measured by the meter).

- Testing the WVF sensitivity of the meter with flowing MEG through the meter shows that the meter reacts very fast and shows a slightly lower reading compared to flowing water. The test points are very linear.

5.1 Acknowledgements

This work was a team effort. Special acknowledgements should go to Stephen Woodman and Bob Stevens for supporting this work.

Thanks for the Ormen Lange partners (Norske Shell, Petoro, Equinor Energy, Orlen Upstream Norway, Vår Energi) for allowing us to publish this paper.