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How Shell is Tackling Hydrate/Scale Formation and Optimizing Well Allocation and Production on the Ormen Lange Subsea Field Development

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1 INTRODUCTION

One of the most significant subsea production challenges today is hydrate/scale formation, due to formation water, and the sourcing of accurate information so that one can carry out urgent remedial measures, such as monoethylene glycol (MEG) injection, while at the same time accurately measuring gas rates and condensate for effective well allocation and production optimization. This paper looks at how Shell, in partnership with Emerson, addressed these challenges on the Ormen Lange field, one of the biggest and most complex developments on the Norwegian Continental Shelf (NCS).

Tackling hydrate/scale formation and ensuring that wells operate at their peak gas rate potential was achieved through the deployment of 19 Roxar Subsea Wetgas Meters from Emerson that were integrated within Shell's Subsea Module on the Ormen Lange field.

The meters, based on microwave resonance, DP, pressure and temperature measurements, were installed on a well-by-well basis to provide accurate and immediate water, gas and condensate flow rate information. In this way, the meters could immediately identify potential water breakthrough and water-producing wells, ensure optimized MEG injection, and provide the operator with accurate gas rate information for optimal well allocation and production.

Today, the wet gas meters are playing a crucial role in the daily monitoring and prevention (through optimal MEG injection) of hydrate and scale formation, reducing MEG costs and ensuring an effective well allocation and production strategy for Shell. Deviation from the fiscal metering system is less than 2% on gas flow with the meters meeting Shell's specified uncertainty rates (+/- 5% for hydrocarbon mass flow). In addition to looking at the wet gas meters, the paper will also examine how the meters fitted within Shell's flow assurance system (FAS).

2 THE ORMEN LANGE FIELD – HISTORY AND DESIGN CHALLENGES

In 1997, the Ormen Lange field (see figure 1) was discovered – Norway's first deep water development at between 800 and 1100 meters. The field is located in the Norwegian Sea, approximately 100 km off the northwest coast of Norway.

Ormen Lange brought with it some of the most significant production challenges the North Sea oil & gas sector has ever faced and which Shell had to take into account when producing from the field. These included:

- Seabed and environmental conditions. The field was characterized by extreme weather conditions, with strong waves and winds and strong fluctuating currents, and sub-zero temperatures. The seabed in the development area was also highly irregular with an extremely uneven seabed for subsea pipeline design and installation.

- Long offset control. With no surface facilities, the control of the subsea production system took place from the onshore terminal at Nyhamna with a 120 km subsea tieback in place. With such distances, the time that passes between the occurrence of water in a well to detection could be days, causing significant potential pipeline damage in the meantime.

- High well flow rates. The average flow rate from each individual well was as high as 10 MSm3/day. A major challenge for the project was to ensure that all equipment was designed to accommodate these very high flow rates, including issues relating to vibration and erosion.

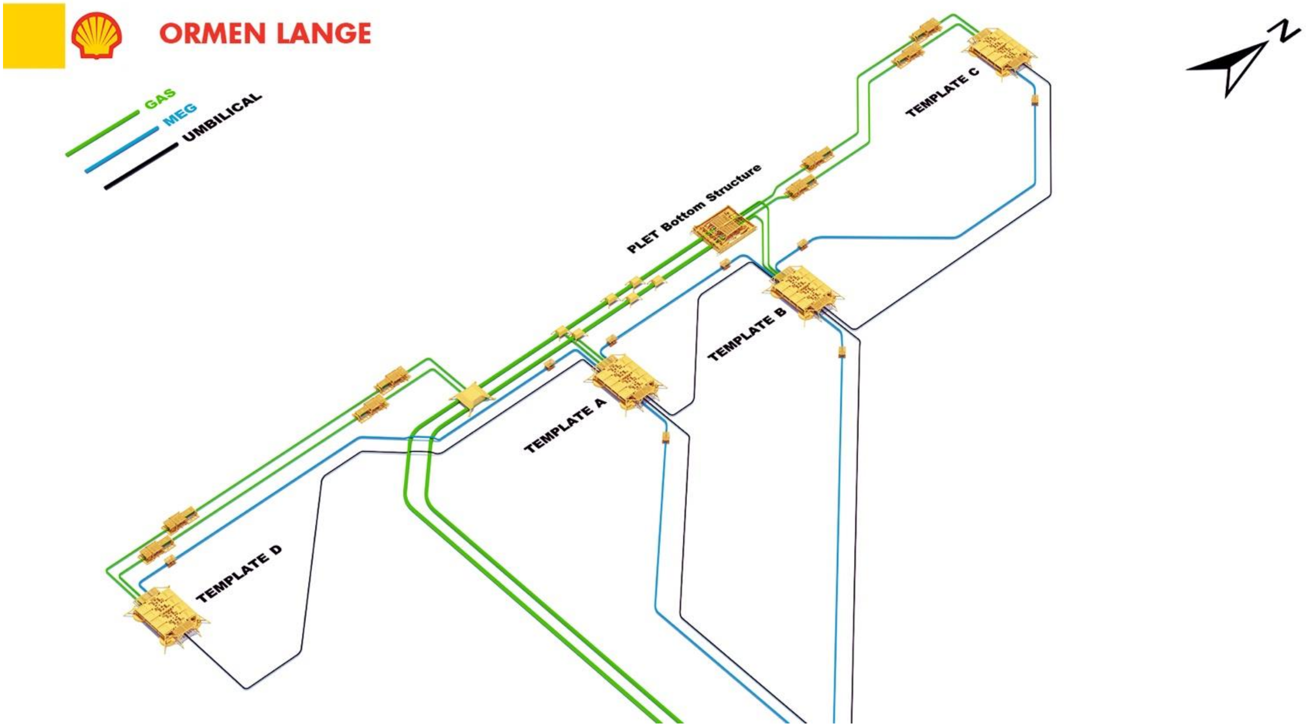

Figure 1: The Ormen Lange subsea development

- Water and Hydrate prevention. Finally there was the vital issue of water and hydrate prevention – one of the main technical challenges for the Ormen Lange subsea system.

Saline water often indicates formation water and greater volumes of water entering the production stream. These uninhibited volumes can have a potentially damaging effect on production, leading to scaling, corrosion and hydrates in the pipeline, blockages and in the worst scenario, the shutting down of wells.

Due to the low seabed temperature (-1ºC) on Ormen Lange, there was a danger that both hydrates and ice may form unless the well fluid is sufficiently inhibited. Furthermore, if a hydrate plug was formed in the pipeline, depressurization – although a viable remediation to hydrate a hydrate plug – would not be able to remove ice. This would leave the operator having to consider other costly remedial options or the pulling of the pipeline to the surface and removal of the clogged piping section. Such a course of action would lead to considerable production delays and increased costs.

The overall hydrate prevention strategy was therefore to minimize the risk of hydrates and ice through continuous MEG injection at the individual wellheads. For accurate injection control, each well is equipped with a MEG flowmeter and dosage valve. The MEG distribution system is designed with a capacity to inhibit the maximum expected condensed water plus a set amount of formation water production from individual wells up to the lowest detectable water concentration level.

Such a system, however, could only be truly effective if the onset of formation water was detected at an early stage, allowing the operator to mitigate the risk of hydrate and scale formation and manage water production effectively. This is why wet gas meters were so important to the production concept and flow assurance strategy.

In addition to the online detection of formation water onset, Resman tracer technology was installed in selected wellbores during well development to provide alternative means of offline sampling, analysis and detection of formation water breakthrough.

3 WET GAS METERING – TECHNNOLOGY, DESIGN AND OPERATING CONCEPT

Wet gas metering is the ability to measure water, gas and condensate rates with low uncertainty and was a central part of the flow assurance and MEG distribution strategy for the Ormen Lange field.

Wet gas meters provide real-time, accurate measurements of hydrocarbon flow rates and water production. The meters use advanced microwave-based dielectric measurements to generate accurate gas and condensate flow rates based on standard delta pressure devices. Their compact design and low power consumption ensures flexibility and easy integration into subsea systems, while providing dual redundancy. The wet gas meter's high sensitivity to changes in water fraction is also important to enable the early detection of water breakthrough.

3.1 The Wet Gas Meter Measurement Principle

In the case of the Roxar subsea Wetgas meter (figure 2) there are four main measurements: microwave resonance, differential pressure, pressure, and temperature.

- The microwave (µw) resonance is used for water fraction measurements, measuring the dielectric and real permittivity properties of the fluid with low uncertainty and very high sensitivity. With the microwave measurements, combined with pressure, volume and temperature (PVT) data, the fractions of hydrocarbon and water are calculated.

This measurement is performed at the top of the cone area, where the velocity is at its highest, creating a predictable and homogeneous environment and allowing for extreme sensitivity to changes in water and salinity levels. At resonance, the microwaves will propagate throughout the cross section of the pipe; hence, the meter is sensitive to changes in the flow, independent of type of flow.

Figure 2: The Roxar subsea Wetgas meter

Figure 3 shows a µw field set up between cone and pipe wall with total flow passing through the µw field and where resonance frequency depends on fluid dielectric properties (permittivity). A shift in the µw resonance curve to the left indicates increasing amount of water.

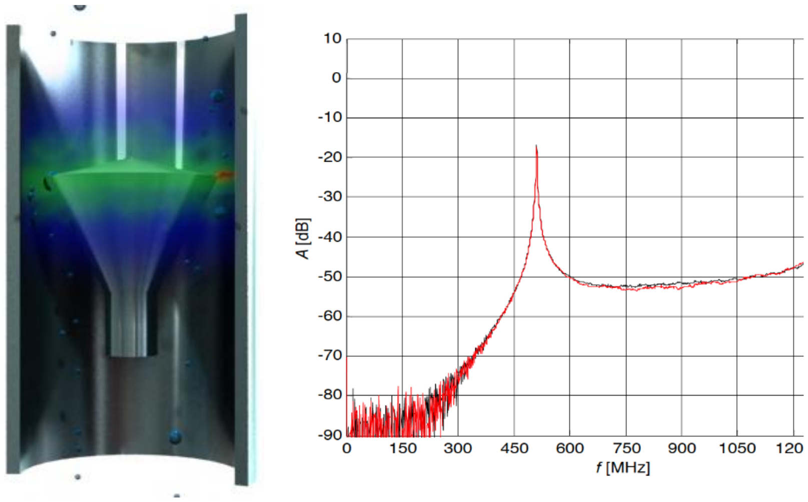

Figure 3: Left: resonance field between cone and pipe wall. Right: µw resonance curve

- The differential pressure is measured over a cone and used to obtain mass flow rates.

- The pressure and temperature are measured by dedicated, redundant transmitters with the information used to calculate the gas/condensate split of the hydrocarbons and to convert flow rates from actual to standard conditions.

Finally, gas and condensate rates are calculated using PVT software (PVTx) and hydrocarbon composition (input).

Due to using the cone as both a differential pressure and microwave measurement element, the mechanical design of the Roxar subsea Wetgas meter is both compact and flexible. enabling full integration within operators' Subsea Control Module. The meter is also designed to operate in the most extreme conditions, such as with Ormen Lange. It is constructed using Duplex stainless steel and can operate at more than 3,000 meters deep, and between -40°C and 150°C.

4 WET GAS METER DEPLOYMENT ON ORMEN LANGE

The Roxar subsea Wetgas meter was selected for the Ormen Lange field after an extensive and thorough testing and qualification program verified against set requirements. To date, 24 Roxar subsea Wetgas meters have been supplied to the Ormen Lange project.

4.1 Implementing and Working Alongside Shell's Production System

The technology development program that Shell underwent included, amongst others, the following items:

- Wet gas meter (WGM).
- Large Bore Tie-in System.
- MEG dosage valve (MDV).
- Subsea Step Down Transformer.
- Leak detector.
- 7" x 2" Completion/Workover Riser System.

Operational robustness was built into the field development at an early stage through deciding to install a fully redundant control system with two control cables and two MEG lines in a loop configuration between shore and the field (see figure 4).

There were also a number of key elements of the production system that needed to be taken into account when deploying and operating the Roxar wet gas meters:

- **Xmas Tree system.** The Xmas tree system comprised a 7" horizontal production tree equipped with annulus bore and was configured with a separately retrievable subsea control module (SCM) and choke module, the latter containing instrumentation, flow control and measurement equipment. The production flow loop, MEG, annulus test and control lines on the Xmas tree were connected to the choke module through a multibore horizontal hub.

- Choke module (CM). The main function of the CM was to serve as a flow loop with instrumentation and valves that can be easily retrieved and maintained. The CM included the following components: production choke valve, MEG dosing valve (MDV), instrumentation (including the Roxar wet gas meter), MEG injection point upstream PCV, and scale injection point (for future use).

- **The MEG distribution system**. With the threats of hydrate, ice formation and formation water, it is necessary to inhibit the fluid by injecting MEG continuously. Being able to calculate the required and sufficient amount of MEG is essential.

To this end, the MEG distribution system was designed to minimize the risk of hydrate formation. Each well is equipped with a distribution system ensuring that sufficient MEG is injected into each individual well with the Xmas tree system equipped with two MEG injection points.

For prevention of hydrate formation, all wells were continuously injected with MEG via two 6” pipelines from the onshore plant. One line is connected to template A, and the other to template B. A 6” crossover MEG line interconnects the two production templates for added flexibility. A computerized flow assurance system (FAS) is also used to monitor the integrity and performance of the subsea MEG distribution system.

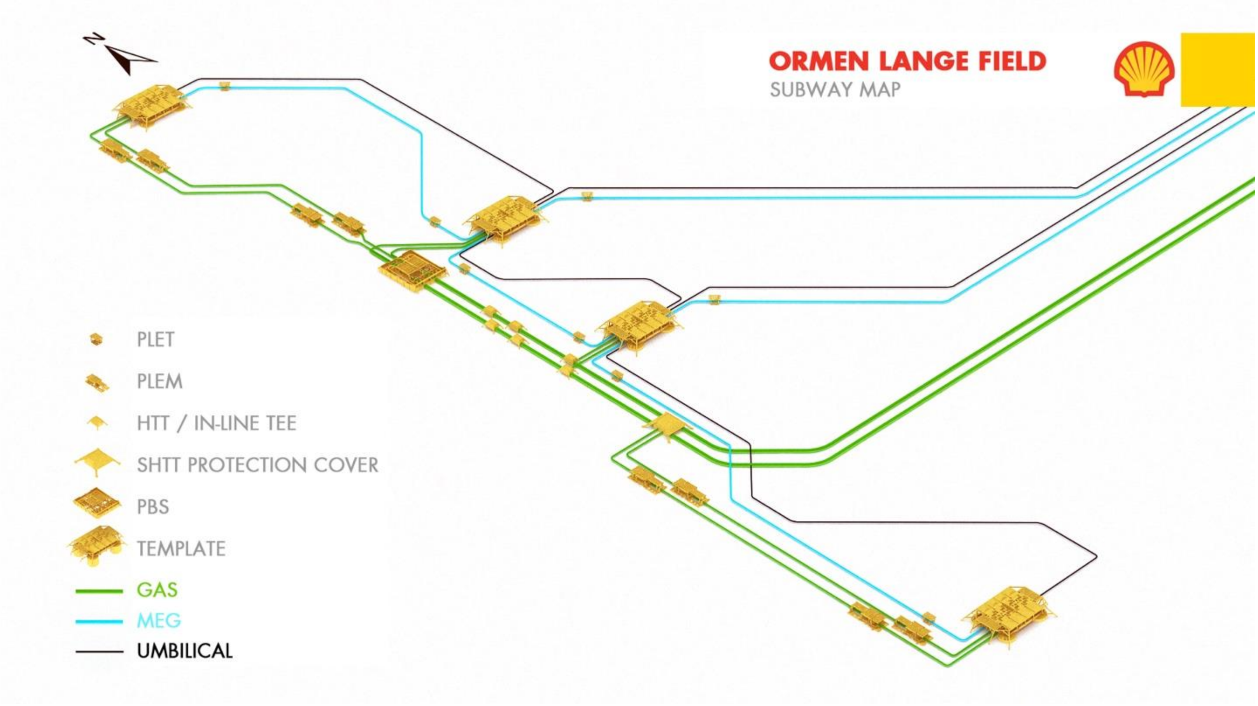

Figure 4: Ormen Lange field layout

- Flow Assurance System. Finally, a Flow Assurance System (FAS) was installed on Ormen Lange in order to give information about the multiphase flow through the entire subsea production and pipeline system. The FAS included a Virtual Flow Metering System (VFMS) module that calculated values of flow rates as backup to physical multiphase meters. The VFMS is used to calculate individual well production rates in parallel with the multiphase and wet gas meters.

The VFMS incorporates all measurements throughout the well flow path; hence does not depend on single sensors and it serves as a robust backup for the multiphase and wet gas meters. Furthermore, the Ormen Lange field does not allow testing of individual wells towards onshore facilities. Therefore, it was decided to calibrate the VFMS model towards gas rates measured by multiphase meters.

The VFMS is used to measure individual well production rates in parallel with the wet gas meters that installed at each wellhead and which this paper goes into detail on in section 4.2.

Pressure and temperature sensors in the well bore and at the wellhead, and pressure drop across the choke were also used. By comparing measured and calculated values the sensors are also kept under surveillance by VFMS. If any deviation is detected, an alarm is raised. The sensor surveillance may also discover and notify leakage or blockage at wellheads and templates.

In this way, the FAS reduces the risk of hydrate and ice formation with the transient simulator calculating pressure, temperature, water content and MEG concentration through the entire subsea system.

4.2 The Wet Gas Meter - Meeting Shell’s Requirements

For the control and monitoring of water in gas and as part of the FAS, Roxar subsea Wetgas meters were required for each well. A dedicated technology development program for this meter was initiated early in the project, the early start being necessary to generate confidence in the selected solutions. The Roxar subsea Wetgas meters were installed on each subsea well to measure the water content, condensate and gas flow rates. The meter is mounted on the choke module.

The following main production fluid properties are measured with the Wet Gas Meter Water: mass flow rate, Water volume fraction, Hydrocarbon mass flow rate (gas and condensate), and Formation water / salt detection.

In this way, Shell could use the relevant measurements to detect the breakthrough of formation water as early as possible in order to: i) provide information so that formation water can be included in the calculations of MEG injection; ii) to provide the best possible basis for concluding which wells that are the source, if onshore water balance or measurements of ionic characteristics indicate production of formation water; and iii) to provide useful information for optimum reservoir management.

Shell also had a number of requirements for the Roxar Wetgas meter. These included:

- Accuracy. Shell had demanding water detection requirements – 0.005 percent by volume. This translated into a required detection accuracy of nine gallons of water an hour in a 100 million cubic foot-a-day gas well.

Such accuracy was particularly crucial when it comes to MEG injection with the amount of MEG dependent on how much water is produced and the salinity of that water. Inaccurate water flow rate measurements would lead to an over injection of MEG. This would be not only costly but also mean that MEG would be occupying a substantial part of the volume of the pipe line, a volume that could have been used for the production of gas and thereby limiting gas production from the field.

- Size. The subsea production system concept also came with further restrictions for any subsea equipment in regard to length and operating envelope. Any meter needed to be compact and flexible in order to fit into the Subsea Control Module of the subsea X-tree. This was the case with the Roxar Subsea Wetgas meter.

4.3 Wet Gas Meter Performance

Prior to deployment, there was comprehensive onshore testing of the meters. This included site integration testing, pre-commissioning and functional tests before deployment subsea.

Performance results in the field also showed that the Roxar subsea Wetgas meters are operating well within the required accuracy range (see figure 5).

In figure 5, the unit along the x-axis is weeks and the test duration is one year with one test point for each week. There is no reference data for each well, so the meter readings are summarized and compared against the gas export meters (fiscal), the condensate storage tanks, and theoretical water gas ratios. It should be noted that all meters contribute in the same direction - for example, one meter does not cancel out the deviation of another.

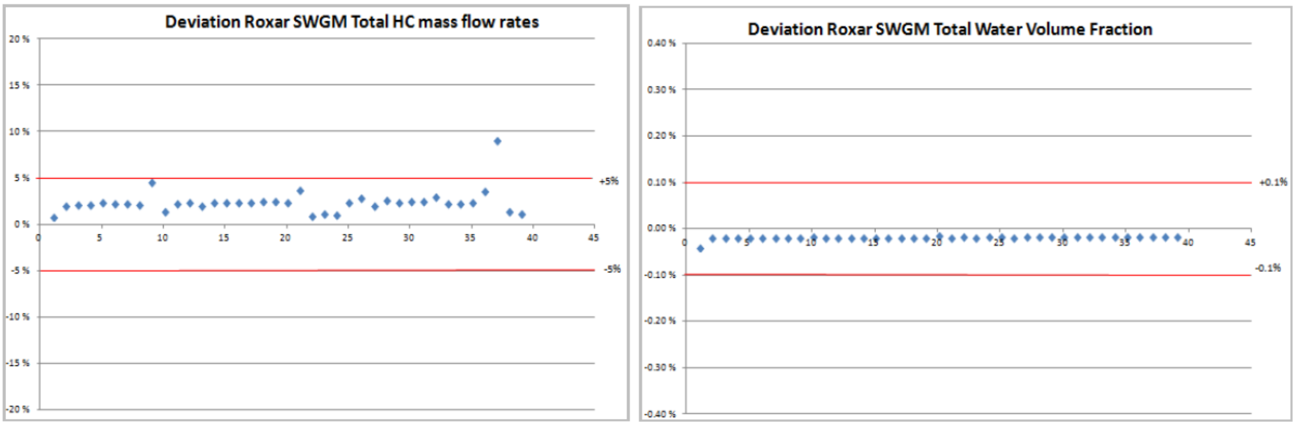

Figure 5 Left: Deviation on Total HC flow rates. Right: Deviation Water Volume Fraction measurement

As can be seen in the left-hand figure of figure 5, the total hydrocarbon mass flow is well within the specification from Shell and within Roxar specification (as show by the red lines). The Water Volume Fraction (WVF) deviation seen in the righthand illustration of figure 5 also shows that the meters are performing within the specified uncertainty

5 ONGOING PERFORMANCE MONITORING

Consistency and regular evaluation of the data that instruments deliver is often a challenge over the asset's lifecycle, especially during busy operational periods.

To this end, since the meters' deployment, Emerson has issued quarterly performance evaluation reports to Shell to verify the measurement results, the meters' health and identify any issues or concerns. The reports provide summaries of gas flow rates, condensate flow rates, water flow rates, water volume fractions, formation water detection, alarms and actions, and follows-up with specific recommendations.

The February 2019 report for the period Q3 2018, for example, found that the sum of the gas flow rates from the Roxar subsea Wetgas meters is stable against gas rates from fiscal export metering and shows an average relative deviation of about 1.98%. Figure 6 shows the cumulative gas production from the Roxar subsea Wetgas meters (in red) compared to the fiscal gas export metering system (in blue). The x-axis time scale is four months and the y-axis represent gas production rates (undisclosed).

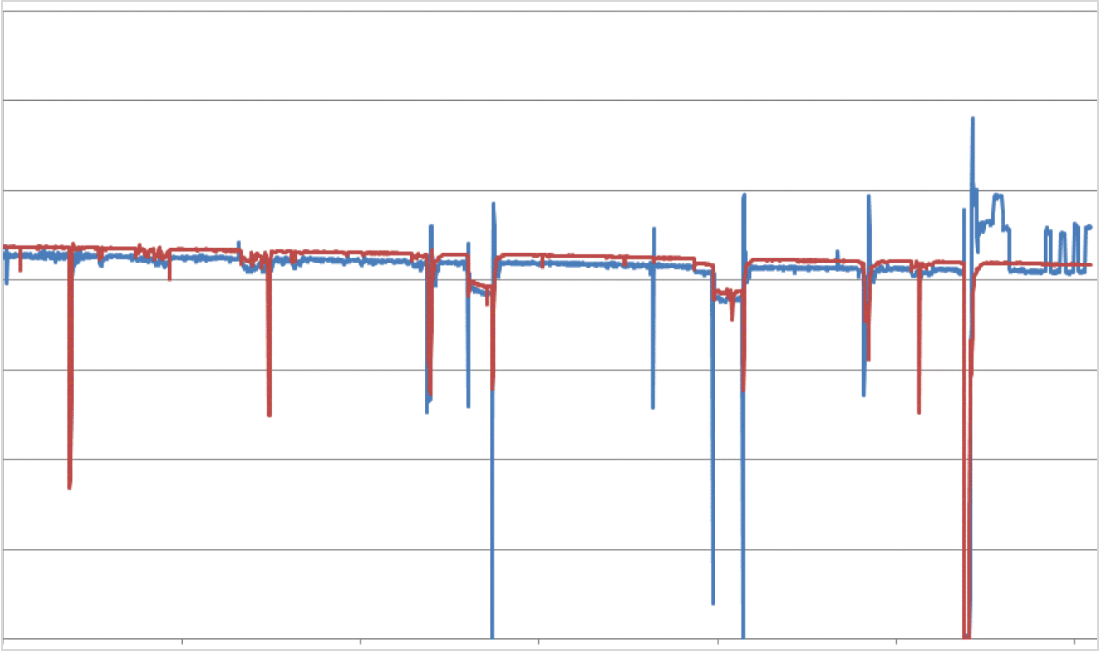

Figure 6: Gas production, sum all wells

Similarly, figure 7 shows the total condensate production from the Roxar subsea Wetgas meters (in red) compared to the onshore condensate storage metering system (in blue). Again, the x-axis time scale is four months and the y-axis is condensate volume flow rates (undisclosed).

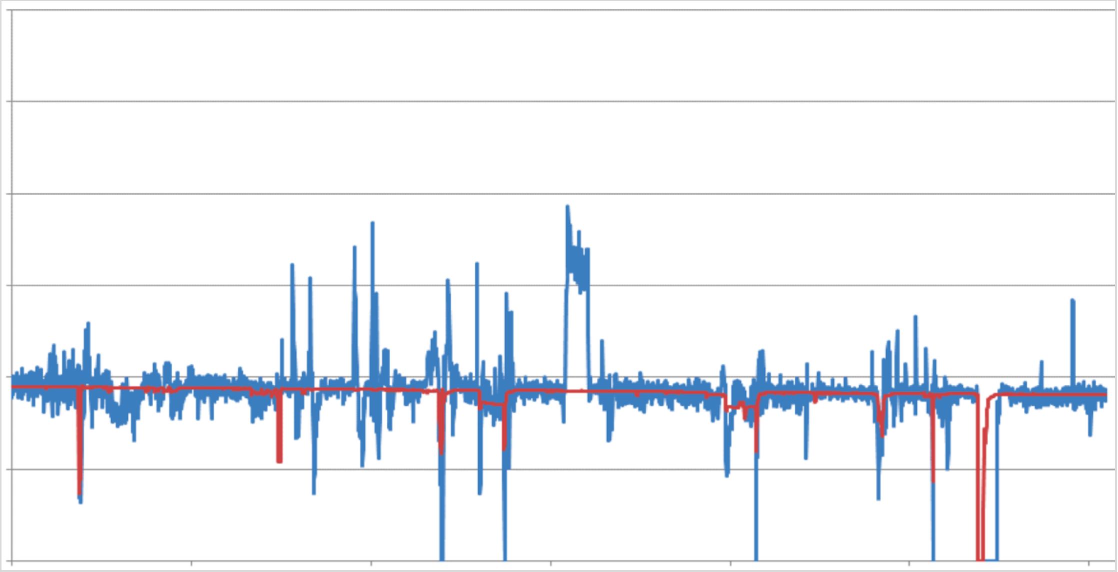

Figure 7: Condensate production, sum all wells

6 RESULTS FROM THE WET GAS METER DEPLOYMENT

So how successful has the deployment been?

All results are well within Shell's expectations and the Roxar subsea Wetgas meter readings are today used daily for monitoring the production and the onset of formation water on the Ormen Lange field. Deviation from the fiscal metering system is less than 2% on gas flow with the meters meeting Shell's specified uncertainty.

The Roxar subsea Wetgas meters are also key in the strategic management and optimization of MEG on the Ormen Lange field. The general MEG strategy is based on a continuous injection of MEG on the basis of a theoretical hydrate suppression plus a contingency accounting for uncertainties in (amongst others) water detection limits (blind zone), PVT (fluid dependent parameters), MEG rate metering and MEG quality.

The theoretical concentration of MEG is calculated on the basis of the prevailing pressure and temperature conditions of maximum Shut-In Tubing Head Pressure (SITHP) and the combined temperature effects of the ambient environment and Joule-Thompson from gas expansion (pressure drop). The aggregated contingency MEG volumes accounting for the various uncertainties yield a designed 50% overdosing. There is great value for a field like Ormen Lange and similar fields to optimize the overdosing part, which is predominantly achievable through increased accuracy in measurement and prediction, where wet gas meters play an instrumental role.

In terms of the wet gas meter and hydrate strategy the continuous MEG dosing is based on a **theoretical** minimum requirement based on max SITHP and -5*C temperature, plus a contingency based on the **uncertainty** ranges associated with amongst others water detection accuracy (WGM), MEG metering, PVT and MEG quality. For Ormen Lange, the present uncertainty understanding accounts for a 50% overdosing on top of the theorical requirement. There is therefore a big upside in accurate detection through a reducing of the uncertainty span.

The meters are performing well within their specifications and are an important tool for daily monitoring. The success of the wet gas meters is the result of Shell's and Emerson's joint dedication to maximizing the use and performance of the technology

Key benefits to Shell of the deployment include:

- The successful roll-out of the Ormen Lange subsea development concept.
- A flexible and compact meter that can fit seamlessly within subsea control modules.
- The early detection of the onset of formation water and the ability to take remedial action instantaneously.
- The efficient prevention of hydrate, ice and scale formation and MEG injection optimization. And
- Enhanced production and increased recovery rates, by optimizing MEG injection rates though field life along with improved system understanding on a risk based approach

A key reason for the success of the deployment was the level of detail and the quality of the conceptual engineering performed prior to the contract award that provided a very good basis for project execution in terms of planning cost estimates, specification of installation vessels etc. Similarly, the qualification and verification tests of all new components and the thorough testing onshore contributed to smooth and effective offshore operations.

7 CONCLUSION

From the remoteness of many offshore fields through to complex subsea production configurations, fast changing reservoir conditions and the grown in wet gas fields with the need to accurately measure water production profiles, operators today are being tested like never before!

Emerson and the Roxar Subsea Wetgas meter are rising to the challenge, as Shell and the Ormen Lange field testifies to. Today, the wet gas meters are playing a crucial role in the daily monitoring and prevention (through optimal MEG injection) of hydrate, ice and scale formation, reducing MEG costs and ensuring an effective well allocation and production strategy for Shell.

Another key conclusion from Shell's perspective was the time element in which the wet gas meters play a crucial role. Hydrates in gas systems form very fast and are hard to remove. Continuous water monitoring at high accuracy therefore allows for a fast response to any water breakthrough or other production upset which could put the system at risk. The Ormen Lange MEG system is not designed to allow for planned production of wells with formation water breakthrough, and without online monitoring, the contingency MEG rates in order to account for the risk of water onset would have reduced the gas production capacity significantly. The water breakthrough mechanism is also uncertain, whether the water comes in fast or slow, for which the former would deem an offline sampling/testing method inadequate.

In short, it is crucial for the optimal operation of the Ormen Lange gas field to have a highly accurate online measurement system which provides continuous monitoring of water production.

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