

# **The Implementation of Multiphase Meters in a High Sulphur Environment on TCO's Tengiz Field, Kazakhstan**

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## **1. Overview**

High hydrogen sulfide (H<sub>2</sub>S) levels within multiphase flow are a frequent point of discussion relating to multiphase meter performance. This paper will show how the Roxar Multiphase meter from Emerson Process Management is operating reliably and accurately in areas of high H<sub>2</sub>S concentrations on TCO's Tengiz field.

The paper will examine the technical challenges seen – in particular unstable mixed density measurements and extreme fluctuations of daytime to nighttime and winter to summer ambient temperatures.

It will examine how these challenges have been overcome and the long-term collaboration over the field's lifecycle between TCO and Emerson. The result - in the words of TCO – is a “*world-class multiphase metering environment.*”

## **2. The Operator & The Field**

Tengizchevroil LLP (TCO) was formed between the Republic of Kazakhstan and Chevron Corporation in 1993 to explore and develop the super-giant Tengiz Oil Field, discovered in 1979.

The Tengiz Field (see figure 1) is among the top 10 producing fields in the world. It covers 565 square kilometers. Today, the Tengiz Oil Field is one of the world's deepest developed oil fields, with the oil column measuring one mile thick. The field has recoverable reserves estimated at between six billion and nine billion barrels.

In the reservoir, Tengiz oil is mixed with ‘sour gas’ that is hydrocarbon gas with high concentrations of toxic hydrogen sulfide. Processing facilities separate the oil and sour gas, and stabilize and sweeten the oil. The sour gas is processed into sales gas, natural gas liquids, and elemental sulphur, and sold for fertilizer and other products.

2008 also marked the completion of a US\$7.2 billion expansion project that boosted production capacity from around 310,000 barrels per day to 540,000. The expansion - the Sour Gas Injection / Second Generation Plant - includes the largest crude oil and sour gas processing units in the world.

Current partners in the field are Chevron (50%), ExxonMobil (25%), KazMunayGaz (20%) and Lukoil (5%). Today TCO is the largest company in Kazakhstan and produces and markets crude oil, gas and sulphur.



*Figure 1 – The Tengiz oil field*

### **3. The Challenges of Sulphur**

As mentioned, the oil from Tengiz contains a high amount of sulphur (up to 18%). In 2014, TCO sold over 3.8 million metric tons of sulphur to customers in many countries, including Kazakhstan, Russia, Ukraine and China.

Such sour service conditions, however, bring with them significant challenges when it comes to multiphase measurement. These include fluctuating conditions in the field which typically produce  $H_2S$  of up to 18%, in addition to Gas Volume Fraction (GVF) of 65% to 80%, 0% to 5% Water Liquid Ratio (WLR), and pressures of 70 to 85 bars.

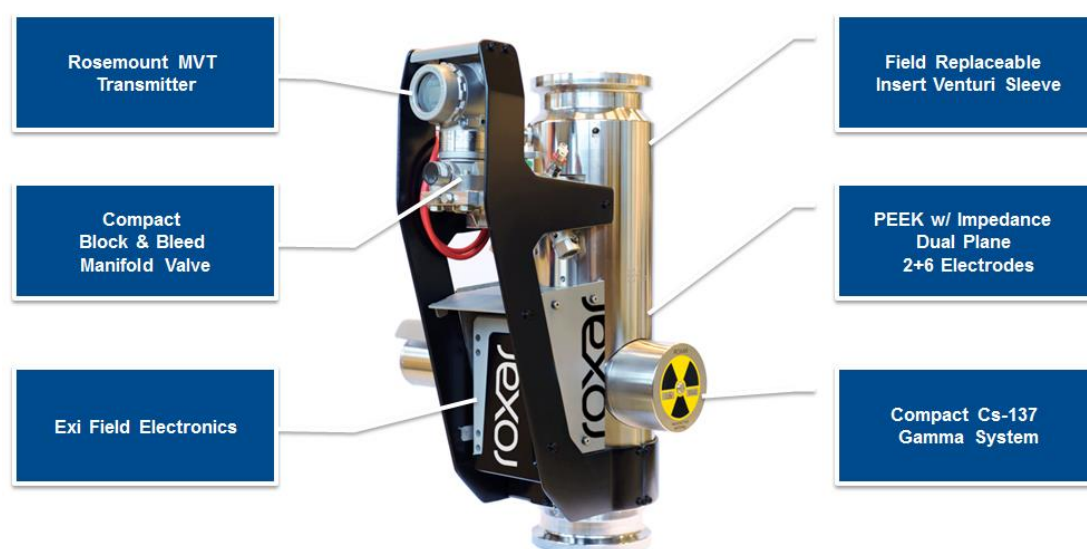
Due to high  $H_2S$  values and limited capacity of water treatment facilities, TCO remained highly focused on achieving water measurement with the lowest possible uncertainty and highest sensitivity and reliability.

#### 4. Multiphase Meters – Applications in H<sub>2</sub>S Field

Emerson Process Management delivered 16 second-generation Roxar Multiphase Meters (MPFM) 1900VI to TCO, with commissioning taking place from May 2007. The meters have been in use in the field ever since. Emerson replaced three of these meters with the third generation MPFM 2600, with the commissioning of these new meters taking place in May 2014.

The ability to measure flow rates reliably and accurately under the presence of high and fluctuating H<sub>2</sub>S is a central feature of the multiphase meters. To this end, the Roxar Multiphase Meters have a number of features to address this.

**The Measurement Principle:** The Roxar multiphase meter applies fractional measurements using electrical impedance measurements, in combination with either non-gamma software or a single high-energy gamma for density measurements (see figure 2)



*Figure 2: Roxar MPFM 2600 main components*

These measurement principles are highly robust against variations in H<sub>2</sub>S concentration. H<sub>2</sub>S that is present in the flow as a gas will be measured as gas by the Roxar Multiphase meter. There is no need for any precautions, special calibrations or compensations for high H<sub>2</sub>S operations.

The Roxar electrical impedance principle measures the mixed conductivity and permittivity to determine the phase fractions. It is not likely that the oil permittivity and water conductivity will change significantly in the presence of H<sub>2</sub>S gas and sulphur atoms. Roxar has never seen issues with the watercut determination or gas measurement due to high and fluctuating levels of H<sub>2</sub>S and sulphur.

**Low Maintenance Requirements:** When dealing with well streams containing hazardous sour gases such as  $H_2S$ , it is important to consider safety and environmental implications that cleaning and interruption of the well flow might have. The normal maintenance schedule of the meter will be a yearly empty pipe calibration of the gamma system and checkup of the meter's electronics and transmitters to see if there is no drift. It is important to mention that these maintenance activities do not require the meter to be opened up or that the process fluid is exposed to the atmosphere in any sense. All these maintenance actions can be performed remotely from the service console if the infrastructure required to this is planned for.

The advantage of annual rather than monthly maintenance is of high value for such operations, where any exposure to the gases involves a health hazard. Less maintenance means less people exposed to potentially dangerous areas.

**Material selection:** Process conditions are taken into account during the material selection for the meter. Stainless- or duplex like steels are normally suitable for process conditions with low  $H_2S$  concentrations. For applications with high  $H_2S$  concentrations, Inconel 625 material for wetted parts is often offered.

**Sampling requirements:** Atmospheric sampling of high  $H_2S$  fluids is generally unwanted, and should be minimized due to the HS&E aspects. Thanks to the inherently robustness of the measurement principles in the Roxar meter, there is no need to take samples from individual wells.

## 5. Addressing $H_2S$ Challenges on Tengiz

In order to put in place an effective and accurate multiphase metering strategy on Tengiz, a number of criteria had to be addressed – both at installation and as part of ongoing operations:

**Material Selection:** It is important to ensure that material selection is appropriate for the conditions in which the meter will be operating. Due to the high  $H_2S$  levels seen at Tengiz, Emerson delivered Roxar Multiphase meters in Inconel 625. All wetted parts were considered and evaluated to ensure appropriate material selections and that pipe integrity was maintained and assured.

**Accurate Measurement:** As mentioned, the Roxar Multiphase meter applies a combination of electrical impedance measurements and single high-energy gamma for determining phase fractions, combined with venturi and cross correlation for velocity measurements. There were subsequently no negative effects on the performance of the Roxar Multiphase meter due to the presence of  $H_2S$ .

**Providing PVT Input to the Meters:** Using fluid composition analysis, TCO created Pressure, Volume & Temperature (PVT) tables that were provided to Emerson for input into the Roxar multiphase meters. Due to high  $H_2S$  levels, TCO used a modified equation of state with updated properties table and binary interaction parameters (BIP), to ensure suitability to the  $H_2S$  levels experienced. These PVT tables provide

gas, oil and water densities for use within the algorithms to provide high quality outputs.

**Direct Measurements – Mixed Density:** The Roxar Multiphase meters use a number of direct measurements, adding to the robustness and redundancy of the meter. One of these direct measurements is mixed density measurement. As the Roxar Multiphase meter uses high-energy gamma, there is a negligible effect on the gas attenuation coefficient and this need not be considered with regards to measurement quality and the effects of H<sub>2</sub>S. As the values for mass attenuation are very similar, the Caesium-137 high-energy gamma system is insignificantly affected by variations in these substances.

It is worth noting that depending on the measurement techniques utilized by a multiphase meter, some may see much higher affects, degrading measurement quality due to the presence of H<sub>2</sub>S. In particular it is worth considering the gamma technology used, as the mass attenuation for sulphur (and other components) can be considerably higher than for typical hydrocarbons depending on the gamma system. It is therefore important for the operator to carefully consider the selection criteria in order to successfully implement multiphase meters in sour service conditions.

**Using Capacitance/Conductance Technology:** Roxar Multiphase meters also have direct measurements relating to the permittivity or dielectric constant of the flow, using capacitance / conductance technology and the Clausius-Mossotti relation. The permittivity of H<sub>2</sub>S and hydrocarbon gas are so close that H<sub>2</sub>S in gas form will be recognized and measured as part of the gas phase, without any negative effects on the measurement quality.

The permittivity of H<sub>2</sub>S in liquid form is in the range of 5 to 6, giving consideration to temperature fluctuations. This is higher than the permittivity of hydrocarbon liquid with a permittivity of 2 to 2.5. If H<sub>2</sub>S levels are high, then this can affect the measurement quality relating to hydrocarbon liquid. The Roxar meter counteracts this effect and maintains measurement quality by adding a compensation factor. In this way, the H<sub>2</sub>S in liquid form will not degrade the measurement quality, and will simply be reported as part of the hydrocarbon liquid, without negatively affecting any other measurement parameters.

## **6. Ongoing Challenges on Tengiz – Addressing Meter Damage**

Inevitably, some challenges have occurred over the years, with the Emerson service team and TCO working in close cooperation to address these. Such challenges include very high flow velocities resulting in damage to meters, unstable mixed density measurements, differential pressure impulse line clogging, and extreme fluctuation of daytime to nighttime and winter to summer ambient temperatures.

**Damage to Meters Due to High Velocities:** In 2011, three of the second-generation Roxar Multiphase meters (MPFM 1900VI), commissioned in 2007, experienced deviations in the capacitive sensor reading. During a visit by a Service Engineer, it was initially suspected that this could be due to contamination of the capacitance electrodes. Internal inspection was therefore arranged. When this was carried out, it

was found that each meter was missing an electrode. It is believed that this was due to a combination of high flow velocities, vibration and perhaps solids passing through.

The meter design back then secured each electrode with one bolt and there was a very small lip in the connection between the electrode and the insulating PEEK material in which the electrode was installed. This presented a degree of weakness to the conditions seen, allowed the flow to gain traction on the electrode and over time, causing the electrode to come loose.

**Addressing the Damage & Ensuring Continued Measurement:** Since this time, the design within the MPFM 1900VI was improved by splitting each electrode into smaller sections, with a bolt per section and the electrodes being entirely flush with the PEEK material. This is further improved within the design of the third generation Multiphase meter (MPFM 2600) where the electrodes are all smaller in size than the previous design.

As TCO operated three second-generation Multiphase meters with an absent electrode, this negatively affected the permittivity measurement and resulted in the absence of WLR measurements. It should be noted, however, that TCO operated with very low watercut rates and these are as such also relatively stable.

As a temporary solution, the meters were supplied with fixed WLR inputs. As the permittivity measurement is one of a number of direct measurements, by providing a fixed WLR input, all other measurements could continue to perform as usual. This provided TCO with continued valuable measurement from the three damaged meters.

Without the capacitance measurement and with a fixed WLR input, it is also still possible to identify changing WLR within the Roxar Multiphase meter.

Production of water results in higher mixed density measurement and higher temperature readings. If the WLR increases while using a fixed WLR input, the reported GOR will be lower than expected. If we assume stable Gas Oil Ratio (GOR), which in the case of TCO's production was a fair assumption, then it is possible to quantify the change in WLR by updating this in order to restore the expected GOR. The fixed WLR input can then be updated to reflect this change, maintaining measurement results that are representative of the production.

This highlights once again the value of a robust measurement technology where measurement is not lost if there are issues in just one area.

In addition, TCO also then began to look into options for the replacement of the three damaged meters. They decided to purchase three third generation (MPFM 2600) Roxar Multiphase meters.

This also provided the opportunity for TCO to install a larger meter size in these locations and to better accommodate the increased volume flow seen, due to the combination of high GVF and reducing pressure. These meters were commissioned in 2014, replacing the damaged meters and restoring full measurement capabilities and performance.

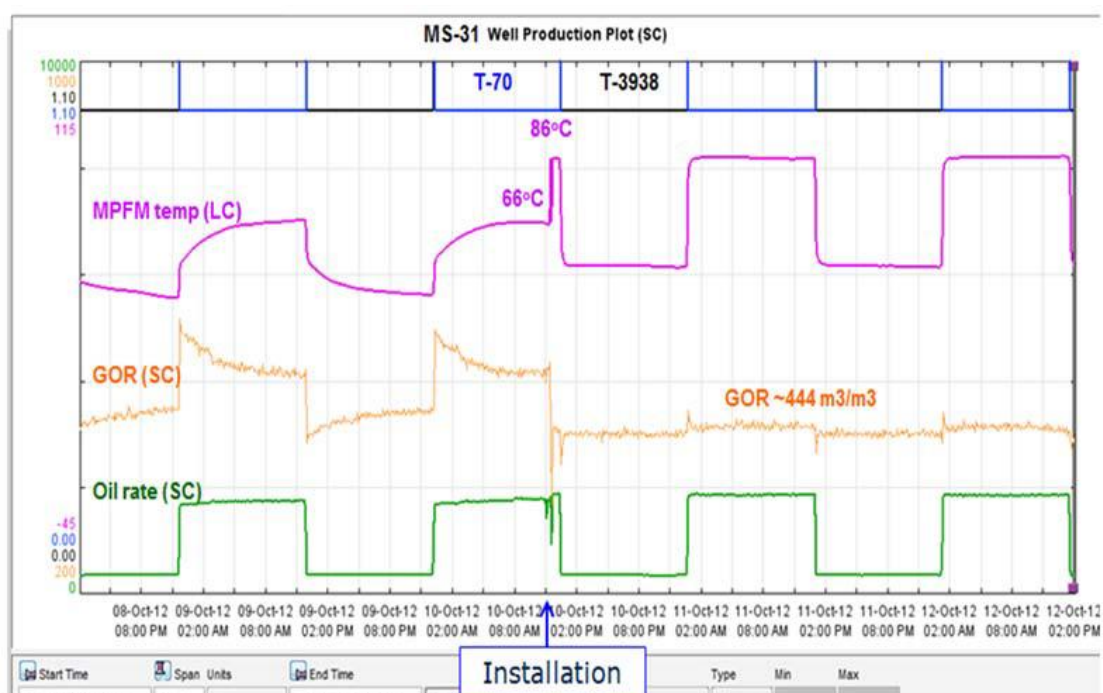
## 7. Ambient Temperature Fluctuations

The second generation Roxar multiphase meters were also found to be sensitive to the temperature fluctuations observed between winter and summer, day and night, and between wells with hot production and cooler production. Here, the body temperature of the meter influenced the meter's temperature sensor, which may not always be the same temperature as the fluid being measured.

Initially, the GOR was seen to fluctuate between winter and summer, night and day, and when different wells (with similar GOR, but different surface temperatures) were flowing through the meter. During a visit by a Roxar Service Engineer, the design of the temperature measurement within the second-generation Roxar multiphase meters was considered. The design has a thermowell in contact with one of the electrodes and is not directly in the flow. It was therefore concluded that given the extreme ambient temperature changes, combined with the positioning of the thermowell in the multiphase meters, this was not providing optimum temperature measurement.

The problem was solved by installing temperature probes in the actual flow stream at the inlet blind-T of the meter. The temperature probes measured the correct fluid temperature, and eliminated the temperature fluctuations caused by the meter body temperature not fully stabilizing, or due to ambient temperature variations.

Figure 3 shows the rapid temperature stabilization after the installation of the new temperature sensor and the resulting stability of the GOR measurement.



*Figure 3: Production information for one well, showing the change in results achieved. The point where the external temperature probes were taken into use is pinpointed. Prior to this one can see the temperature fluctuations as measured by the MPFM 1900VI, and the effect of this on the reported GOR. One can then see the stable GOR after installation of a temperature measurement directly into the flow and used as an input to the MPFM 1900VI.*

The design within the third generation MPFM 2600 multiphase meter is no longer the same regarding thermowell placement. The thermowell for the new meter has contact direct with the flow, improving the reliability of the measurements achieved and reducing any risk of ambient temperature affects.

Temperature measurements achieved on the MPFM 2600s in use on the Tengiz Oil Field have been meeting expectations and requirements to ensure quality meter performance.

In addition, the initial meters delivered and commissioned in 2007 were insulated and had low power heat tracing applied. It was found that the heat tracing was not sufficient for the conditions experienced and therefore in the period from 2010 to 2012, the heat tracing on these meters was replaced with higher power heat tracing. The meters were delivered from Emerson in 2014 with full higher power heat tracing and insulation. This arrangement further protects the meters from any ambient temperature effects.

## **8. Mixed Density Measurement**

In 2008, some issues were seen regarding the density measurement achieved by the gamma systems on a number of the Roxar Multiphase meters. The Roxar Service Engineer therefore suggested performing calibrations on the relevant gamma systems, which was completed. This was a two-point calibration with gas or air and portable water. However the calibration was not seen to resolve the issue.

The log files were seen to show some time-outs relating to the internal communication link between the flow computer and the gamma pulse interface unit. Other internal communication links were not showing any time-outs and it was therefore possible to identify the gamma pulse interface unit as the probable issue.

At the time of the TCO delivery, Emerson was in the process of updating the gamma pulse interface unit, however this was not yet complete. TCO therefore received a modified version, designed to work with previous software. The work was completed within Emerson to replace the gamma pulse interface unit and this was installed in other locations without issue.

The Gamma Pulse Interface Unit was therefore replaced on one of the meters, to evaluate if this resolved the issue. This replacement was carried out in conjunction with a zero calibration of the gamma system - a one point calibration with gas or air. This was found to resolve the challenges experienced and the update was therefore performed on the other meters, restoring full measurement performance.

## **9. An Ongoing Dialogue: Trust and Collaboration**

A key factor in the successful rectifying of challenges has been the open dialogue and communication between TCO and Emerson/Roxar. During an intensive period from 2007 to 2009, pre-commissioning and commissioning of the multiphase meters took place, and many service engineers were involved.



From 2011 onwards, Emerson changed this approach to appoint one Roxar Senior Service Engineer to maintain the contact, follow up and support. This has proven to be of great value to both TCO and Emerson. The Service Engineer was able to gain a deeper understanding of TCO's requirements, production, and installed base of Roxar Multiphase meters. This has allowed for a systematic approach to the challenges that have been seen through the years, ultimately ensuring strong service support and prompt resolution to any challenges seen. The Senior Service Engineer followed up and optimized the multiphase meters, including calibrations, performance, troubleshooting and any other support functions required.

This teamwork-based approach has been developed further. Between the summer of 2014 until January 2015, Emerson had a more frequent presence at TCO. This has been achieved through a rotation plan with the appointed Senior Service Engineer and two other identified Service Engineers rotating attendance.

This allowed the continuation of the knowledge sharing between TCO and the appointed Senior Service Engineer, whilst also building knowledge, trust and support with two additional Service Engineers. This not only provides TCO with more service support from Emerson, but builds resilience into the support available with respect to site knowledge and TCO's measurement requirements.

John Clark, TCO advises: *"The Roxar service team has provided TCO with many quality service reps from Europe, Asia, South America and the Middle East since we started commissioning the meters in 2007."*

*"Once TCO and Roxar established continuous support from a small group of reps, we were better able to collaborate and solve the issues we experienced at Tengiz. This relationship has worked well, allowing TCO to trust Emerson and Emerson to trust us."*

He concludes: *"It would be nice if MPFMs were a simple plug and play device, but we have learned that the meters require some attention to get the full benefit of the technology."*

## **10. Conclusion – Meter Performance**

And what of the meter's performance?

John Clarke, TCO has been pleased with the performance of both second and third generation meters.

He continues: *"Most of our wells produce with extremely low water cuts and have the same GOR. The Roxar meters report accurate GORs and water cuts with very little tuning. We provide our PVT data to Roxar, and the gamma detectors are calibrated at commissioning. The meters work very well, and help TCO easily identify any significant changes in the water cut or the GOR. These meters are meeting our testing needs and helping to identify problem wells."*

He concludes: *“Together, we have created a team that has solved the problems we encountered, and as a result we have world class MPFM measurement in Tengiz”*

This paper has demonstrated the applicability of Roxar multiphase meters in a high H<sub>2</sub>S environment. It also shows how challenges, such as unstable mixed density measurements and extreme temperature fluctuations were addressed and solved to deliver a sustainable and long-term multiphase metering strategy.