GLOBAL FLOW MEASUREMENT WORKSHOP
measuring for the energy transition

Innovations and Insights: Field Experience and Advanced Operations in Multiphase Metering

Zhou Zheng, TechnipFMC
Frank Svendsen, Aker Bp

---

1 INTRODUCTION

TechnipFMC's MPM™ meter is a high-performance, combined multiphase and wet gas meter designed to accurately measure the flow rates of oil, gas, and water in both topside and subsea applications. By combining gamma and 3D Broadband™ technologies, the meter enables continuous real-time monitoring of flow conditions, thereby enhancing operational safety.

This paper demonstrates how MPM™ multiphase meters achieve optimal performance in field operations. It will also provide insights into the periodic verification service model, which is used in the service phase as a robust tool to ensure optimal meter performance and reliability throughout the entire lifecycle. Details about how this model works and the benefits it brings to our operators are demonstrated.

Field experiences and case studies from Aker BP's operations are presented to illustrate the practical application and performance of the MPM™ meter.

2 INTRODUCTION TO MPM™ METER

The MPM™ meter is a precise and advanced instrument for multiphase flow metering that integrates measurements, algorithms, PVT model, and flow computer into one system. It covers the full gas volume fraction (GVF) range from 0% to 100% and the water-liquid ratio (WLR) range from 0% to 100%.

The meter is equipped with a microwave tomography measurement system (3D Broadband™) to measure fluid permittivity. It also measures GVF and WLR by combining high-energy gamma measurements. The 3D Broadband™ system is also used for formation water detection in wet gas fields.

A venturi is used at the inlet for total flow rate calculations.

The gamma densitometer measures fluid density and, in combination with the 3D Broadband™ system, measures GVF and WLR.

The salinity probe operates on the same electromagnetic measurement principles as the 3D Broadband™ system but with a significantly broader spectrum. It measures water salinity under water-continuous conditions and measures WLR in high-conductivity mode, with maximum conductivity of 900 mS/cm.

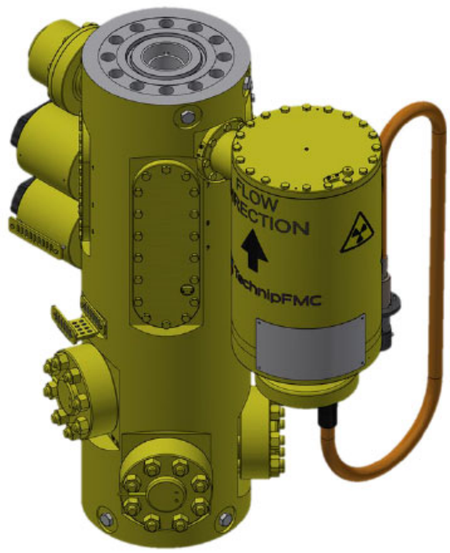

Fig. 1 - Subsea multiphase meter

The meter is also equipped with a flow computer that combines all the raw measurements data and by using advanced flow calculation algorithm, and Multiflash™ PVT (Pressure Volume Temperature) model, the individual flow rates for oil, gas and water are measured instantaneously.

3 FIELD PERFORMANCE: COMPARE AGAINST TEST SEPARATOR

To evaluate the long-term field performance of multiphase meters, 11 tests against a test separator (TS) were conducted over a period of more than three years. These tests were performed in an operational oil field located in the North Sea, using a test separator as the reference measurement system. Each test involved a systematic comparison of flow rate measurements obtained from the MPM™ and the test separator. To determine whether the meter remained within its specified performance limits over time, the results from each test were evaluated against the corresponding overall measurement uncertainties.

The topside multiphase meter operating in this oil field is a standard MPM™ meter type, equipped with embedded Multiflash™ PVT software. Dual mode is enabled on the meter to cover full GVF range.

A test separator was installed downstream of the topside multiphase meter to compare flow rates and determine correction factors. An ultrasonic flowmeter is used for both oil and gas metering in the test separator. Additionally, a smaller-sized coriolis meter is employed for oil metering when the flow rate is below a certain limit.

As shown in Fig.2, a third-party flow computer collects real-time flow rates from both the multiphase meter and the test separator, converting the flow rates from test separator conditions to MPM™ conditions. This flow computer is equipped with a PVT model that overrides the PVT model on multiphase meter. It calculates single-phase properties at the meter's operating pressure and temperature (Figs. 3 and 4), and inputs the fluid properties to the multiphase meter, which uses them in its flow calculations.

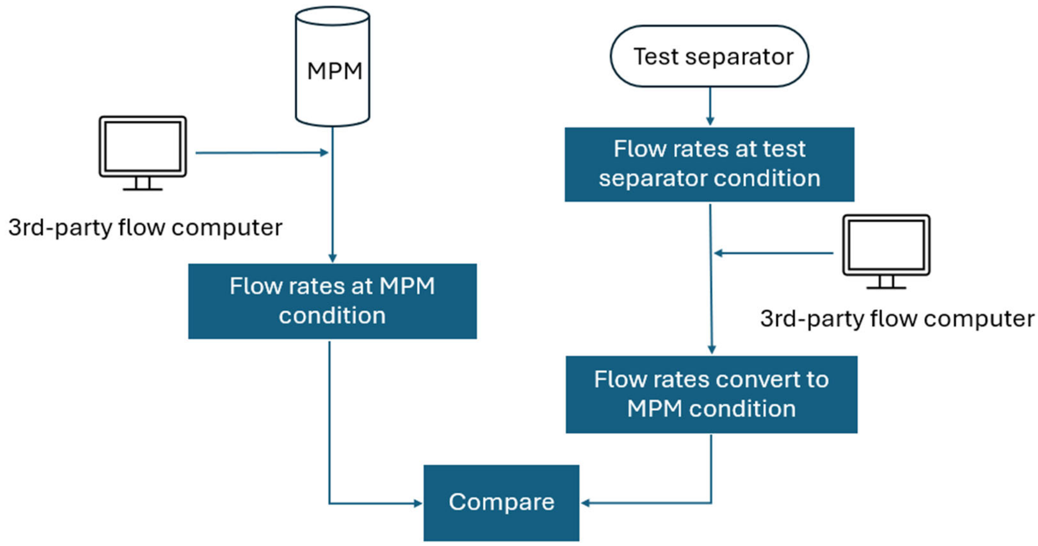

Fig. 2 - Data flowchart

An overview of the operating conditions for both the multiphase meter and the test separator during the 11 tests is presented in the figures below.

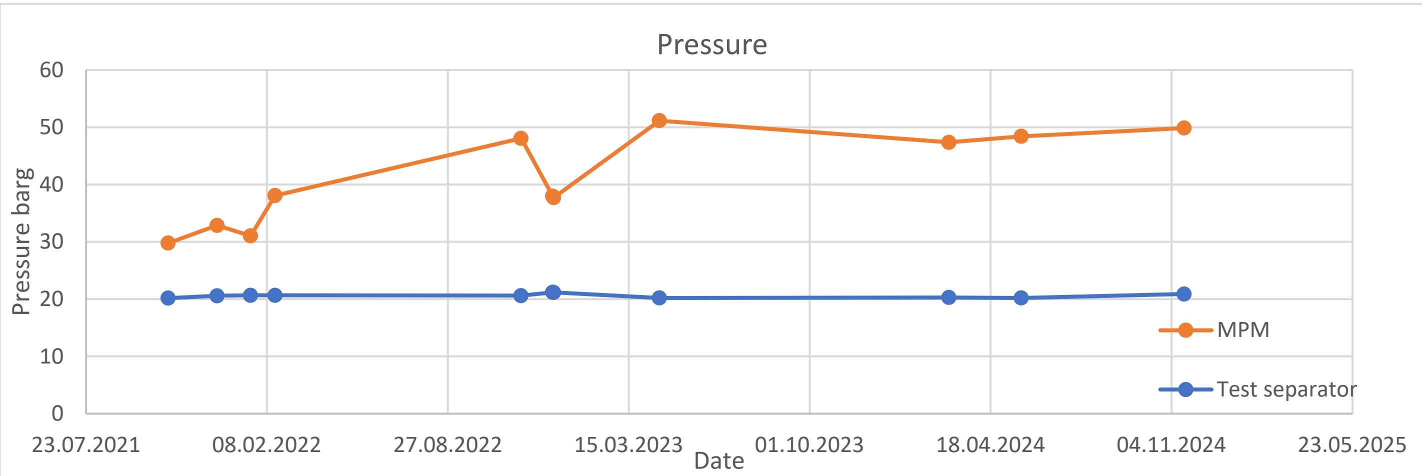

Fig. 3 - Average pressure values measured by the MPM™ and test separator for each test

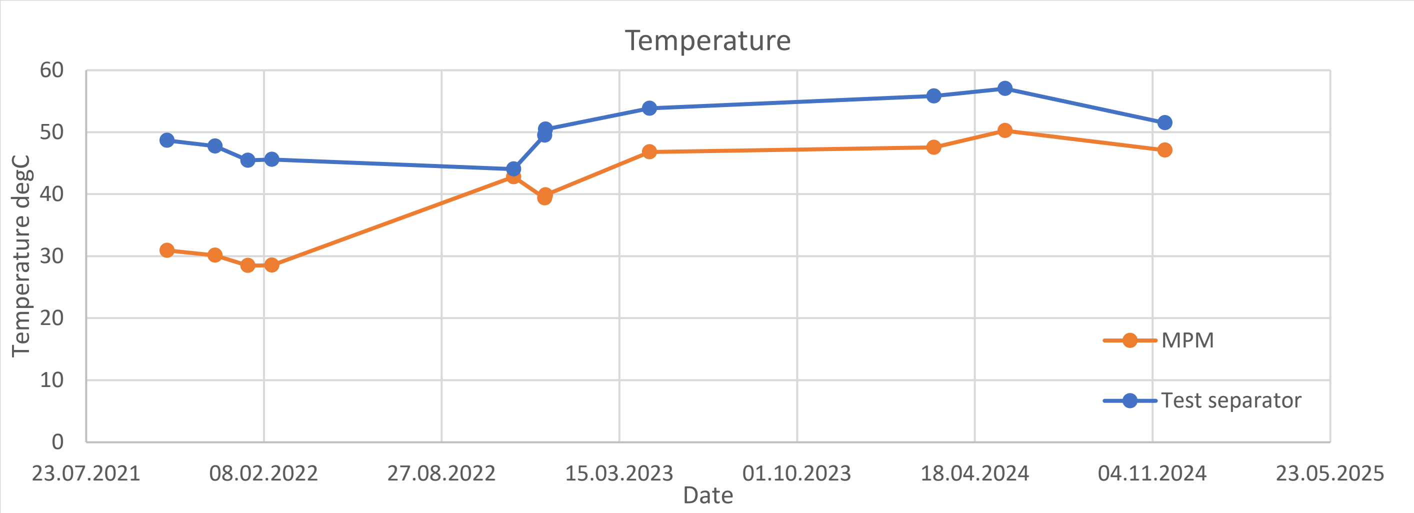

Fig. 4 - Average temperature values measured by the MPM™ and test separator for each test

Note that a heater is installed between the multiphase meter and the test separator.

3.1 Uncertainty Calculation

The overall measurement uncertainties were calculated and systematically compared across 11 tests to verify the long-term performance of the multiphase meters. There are various methods for uncertainty estimation. However, the approach applied in this study is simplified and intended solely as a reference for the comparison with each test. If a more rigorous uncertainty analysis is required, a detailed and comprehensive study should be conducted.

As illustrated in Figure 2, the overall measurement uncertainty primarily originates from three key inputs: the multiphase meter, PVT model, and test separator. The uncertainty calculation (Table 1) is performed in accordance with ISO 5168 [1], under the assumption that the input parameters are uncorrelated. Given that the water flow rate is negligible compared to oil and gas, its contribution to the overall uncertainty is excluded from the calculation. Individual uncertainties for the multiphase meter, PVT model, and test separator are calculated separately, and the overall uncertainty is derived by combining these three components.

Table 1 - Input Parameters And Uncertainty

Input parameters	Uncertainty
Test separator	Uncertainty Calculation Report, Test Separator Metering [proprietary report, 2020].
PVT model	Density uncertainty stated by 'CM Handling of Multiphase Flow Meters' [proprietary report, 2015], and recalculation of raw data from testing period.
Multiphase meter	Uncertainty calculated by meter uncertainty specification based on input from each test.

3.1.1 Uncertainty Calculation For The Topside Multiphase Meter

The mass flow rate uncertainty for oil and gas at meter condition is calculated based on meter uncertainty specification. Average data for the whole testing period has been used. The calculated uncertainties are listed Table 2:

Table 2 - Uncertainty For Multiphase Meter

Test Number	Test date	MPM™ gas mass uncertainty	MPM™ oil mass uncertainty	MPM™ HC mass uncertainty
1	22.10.2021	4.00%	5.92%	5.09%
2	15.12.2021	4.09%	5.71%	4.94%
3	21.1.2022	4.00%	6.84%	5.27%
4	17.2.2022	4.25%	5.50%	4.74%

5	16.11.2022	4.31%	5.42%	4.58%
6	21.12.2022	4.26%	5.49%	4.74%
7	22.12.2022	4.26%	5.49%	4.74%
8	18.04.2023	4.62%	5.01%	4.38%
9	03.03.2024	4.46%	5.27%	4.54%
10	22.05.2024	4.56%	5.12%	4.47%
11	18.11.2024	4.57%	5.13%	4.47%

3.1.2 Uncertainty Calculation For The Test Separator

The mass flow rate for oil and gas at test separator condition have been calculated in 'Uncertainty Calculation Report, Test Separator Metering'[proprietary report, 2020].

- Maximum oil mass flow rate uncertainty is 0.27%
- Maximum gas mass flow rate uncertainty is 0.98%

Hydrocarbon (HC) mass flow rate uncertainty is calculated as:

$$u(TS,HC) = \sqrt{u(TS,Oil)^2 + u(TS,Gas)^2} \quad (1)$$

Based on the above equation, the calculated uncertainty in the test separator HC mass flow rate is 1.03%.

3.1.3 Uncertainty Calculation For The PVT Model

The uncertainty associated with the PVT model affects both the MPM™ multiphase meter and the test separator. The multiphase meter utilizes the PVT model as an input for flow rate calculations, whereas the test separator applies it solely for converting flow rates to meter conditions. It is assumed that the uncertainty introduced during this conversion process is negligible compared to the impact on flow calculations within the meter. Therefore, the PVT model uncertainty associated with the test separator is excluded from the overall uncertainty analysis.

The uncertainty introduced by the PVT model to the meter's flow rate measurements is quantified based on the uncertainties in oil and gas density and through recalculation of raw data obtained during the testing period.

Based on 'CM Handling of Multiphase Flow Meters' [proprietary report, 2015], the uncertainties associated with oil and gas densities at meter conditions have been estimated under the assumption that a good hydrocarbon (HC) composition is available. The estimated uncertainties are as follows:

- PVT oil density uncertainty: 3%
- PVT gas density uncertainty: 3%

To calculate the PVT model uncertainty, raw data from the entire testing period has been downloaded and used for recalculations to obtain the uncertainty of the mass flow rate.

Because there are 11 tests and the meter remains stable in multiphase and oil-continuous mode for most of the time, the average GVF and WLR are used to evaluate the selection of raw data.

Table 3 - GVF And WLR During Tests

Test number	Test date	GVF	WLR
1	22.10.2021	80.6%	0.0%
2	15.12.2021	77.3%	0.1%
3	21.1.2022	87.0%	1.6%
4	17.2.2022	72.6%	0.1%
5	16.11.2022	70.6%	1.0%
6	**21.12.2022**	**72.1%**	**1.0%**
7	22.12.2022	72.2%	1.2%
8	18.04.2023	61.5%	2.0%
9	03.03.2024	66.3%	4.3%

10	22.05.2024	63.3%	3.8%
11	18.11.2024	62.9%	5.9%
Average		71.5%	1.9%

From table 3, the average GVF and WLR are close to test number 6. The raw data from test 6 was retrieved from the meter and utilized to calculate uncertainty using the MPM™ recalculation tool [proprietary data, 2024], with an assumed oil and gas uncertainty of 3%.

The recalculated results are in Table 4:

Table 4 - Uncertainty From PVT Model

Uncertainty	Oil mass flow rate uncertainty	Gas mass flow rate uncertainty	HC mass flow rate uncertainty
Oil density 3% uncertainty	0.4%	2.5%	0.4%
Gas density 3% uncertainty	0.7%	4%	0.3%

Based on table 4, maximum uncertainty has been selected for the calculation.

- Oil mass flow rate uncertainty derived by PVT is 0.7%
- Gas mass flow rate uncertainty derived by PVT is 4%.
- HC mass flow rate uncertainty derived by PVT is 0.4%.

3.1.4 Overall Uncertainty

The overall uncertainty (Table 5) is calculated based on following equations:

$$u(Oil) = \sqrt{u(TS, Oil)^2 + u(MPM, Oil)^2 + u(PVT, Oil)^2} \quad (2)$$

$$u(Gas) = \sqrt{u(TS, Gas)^2 + u(MPM, Gas)^2 + u(PVT, Gas)^2} \quad (3)$$

$$u(HC) = \sqrt{u(TS, HC)^2 + u(MPM, HC)^2 + u(PVT, HC)^2} \quad (4)$$

Table 5 - Overall Uncertainty

Test Number	Test date	Overall gas mass uncertainty	Overall oil mass uncertainty	Overall HC mass uncertainty
1	22.10.2021	5.74%	5.97%	5.20%
2	15.12.2021	5.80%	5.76%	5.05%
3	21.1.2022	5.74%	6.88%	5.38%
4	17.2.2022	5.92%	5.55%	4.86%
5	16.11.2022	5.80%	5.84%	5.01%
6	21.12.2022	5.96%	5.47%	4.71%
7	22.12.2022	5.93%	5.54%	4.86%
8	18.04.2023	5.93%	5.54%	4.86%
9	03.03.2024	6.19%	5.07%	4.51%
10	22.05.2024	6.07%	5.32%	4.66%
11	18.11.2024	6.14%	5.17%	4.60%

3.2 Comparison Of Field Data With Overall Uncertainty

During each test, the oil, gas, water, and hydrocarbon mass flow rates at meter conditions were used for comparison. Due to the consistently low water liquid ratio, the water flow rate was excluded from the analysis.
The relative deviations in oil, gas, and hydrocarbon mass flow rates between the MPM™ multiphase meter and the test separator were calculated using the following equations:

$$\sigma(Oil) = \frac{QmOil\_MPM - QmOil\_TS\_converted}{QmOil\_TS\_converted} \qquad (5)$$

$$\sigma(Gas) = \frac{QmGas\_MPM - QmGas\_TS\_converted}{QmGas\_TS\_converted} \qquad (6)$$

$$\sigma(HC) = \frac{QmHC\_MPM - QmHC\_TS\_converted}{QmHC\_TS\_converted} \qquad (7)$$

The relative deviations are further compared with the calculated overall uncertainty based on table 5. The results are as follows in Figs. 5, 6, and 7:

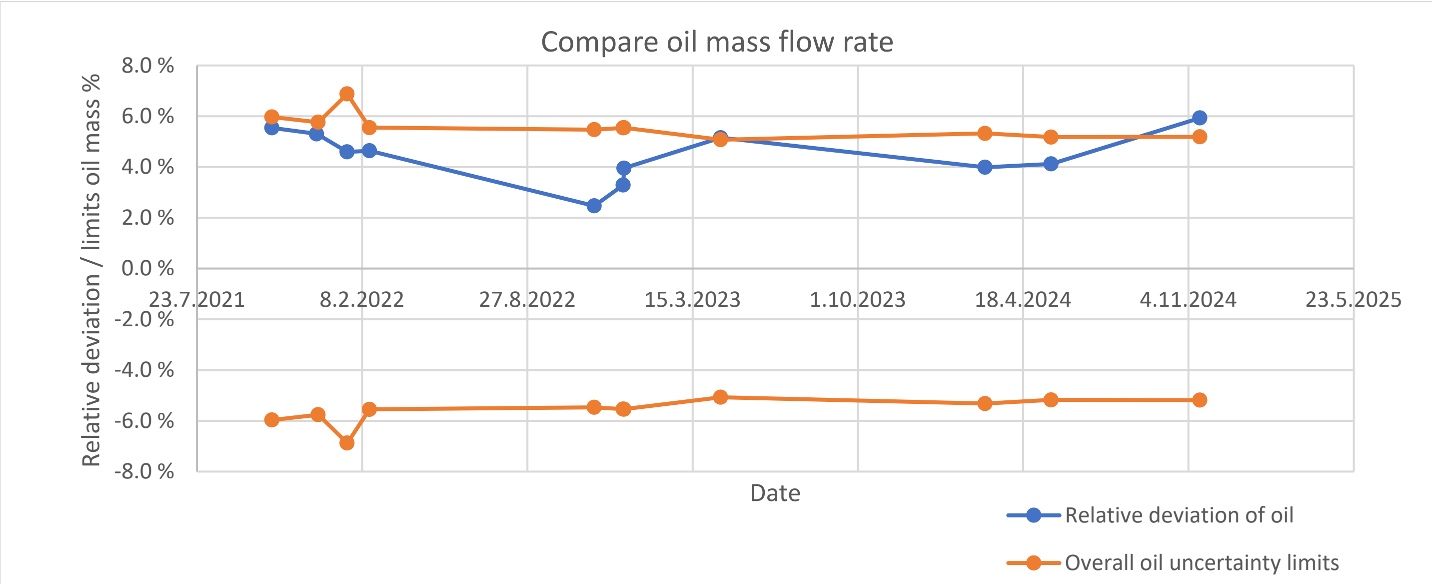

Fig. 5 - Oil mass flow rate relative deviation, including overall measurement uncertainty

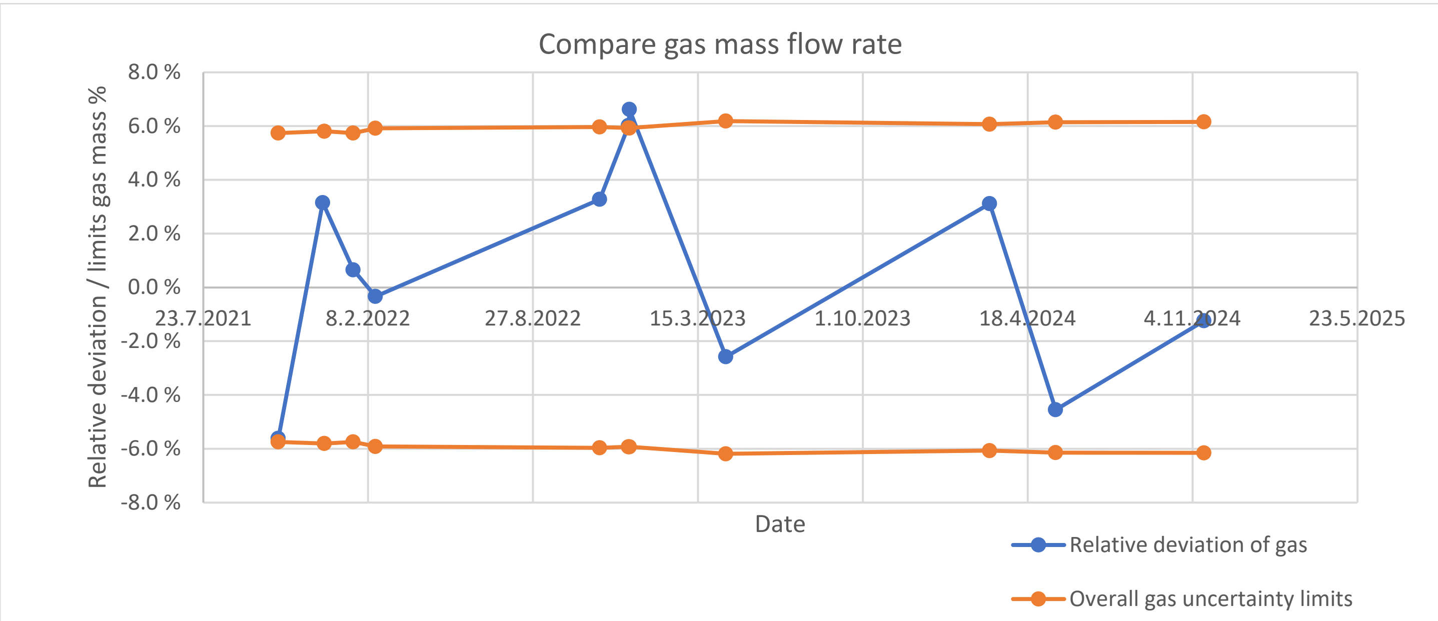

Fig. 6 - Gas mass flow rate relative deviation, including overall measurement uncertainty

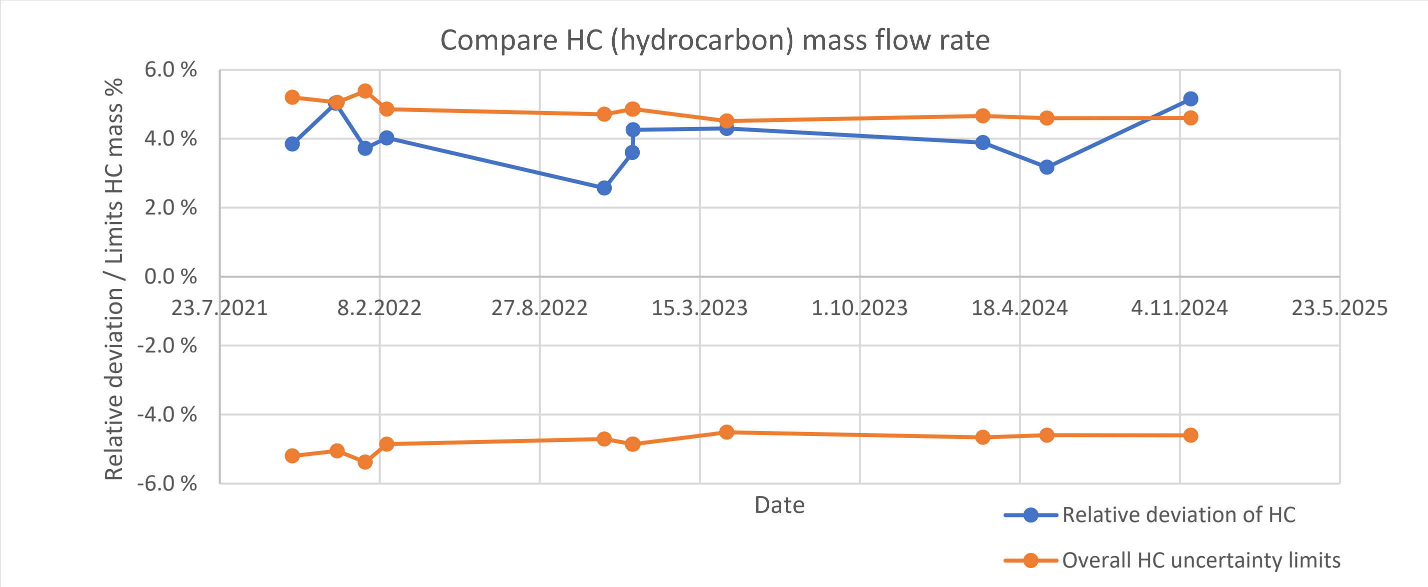

Fig. 7 - HC mass flow rate relative deviation, including overall measurement uncertainty

Based on the calculations and comparisons presented above, the performance of the MPM™ multiphase meter is demonstrated to be well within the calculated uncertainty boundaries. While one or two data points approach the boundary of the uncertainty envelope, this may be attributed to factors not accounted for in the simplified uncertainty model.

In summary, over more than three years of operation in the field, the MPM™ meter has demonstrated outstanding performance, showing good repeatability and reliability.

4 ENHANCED FUNCTIONALITY - GOR MATCHING AND DEPOSITS BUILD-UP

For meters operating in oil fields, the most common issues that heavily influence meter performance are build-up of deposits at low temperatures and additional gas from the gas cap, gas injection, or gas lift, with unpredictable or unstable amounts flowing through the meter along with the reservoir fluid. Some of these challenges might be addressed by implementing currently available functions, while others might be resolved using new functions that TechnipFMC is currently developing.

4.1 GOR Matching

It is common to have a gas cap in an oil reservoir. However, predicting the amount of gas produced from the gas cap can be challenging. This results in an unpredictable GOR (Gas Oil Ratio) at standard conditions, leading to high deviations observed in the oil and gas flow rates at standard conditions.

The GOR matching method has been introduced to compensate for the impact of the gas cap, provided it has a similar composition to the reservoir gas. By using the GOR matching method, deviations at standard conditions can be significantly reduced. This method is also applicable for gas lift when produced gas is reinjected into the flow line.

The process for GOR matching is automated and is outlined in the steps as follows (Fig.8):

- Upload embedded Multiflash™ PVT model based on reservoir composition to MPM™ multiphase meter.
- Perform flash calculation at the meter's actual condition.
- Use the MPM™ measured GOR to recombine gas and oil composition to obtain the new PVT model.
- Use new PVT model to convert meter condition to standard or reference conditions.

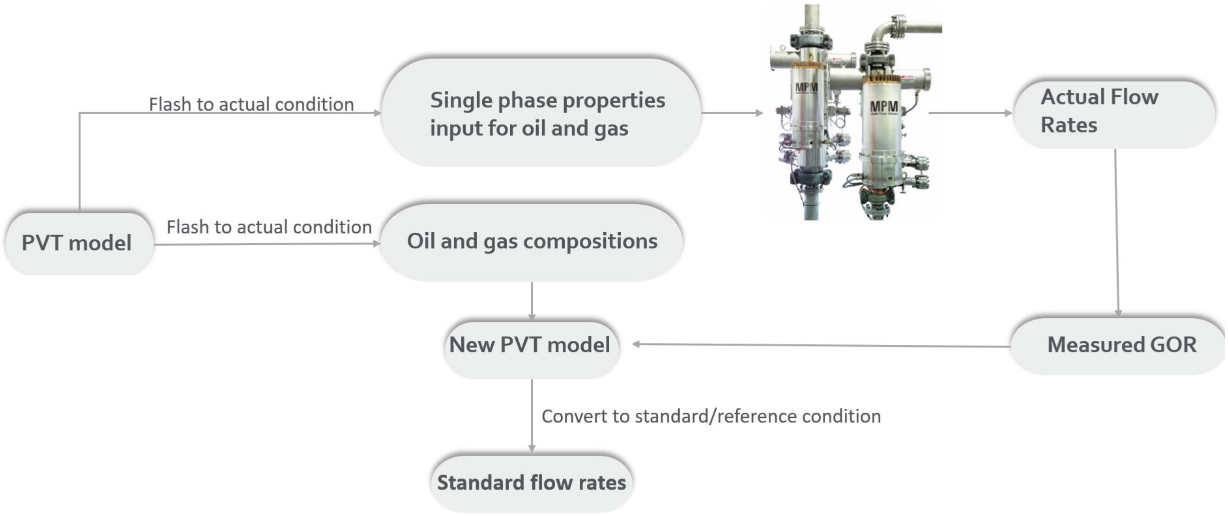

Fig. 8 - Plot to demonstrate GOR matching used by multiphase meter.

4.1.1 Field Experience With GOR Matching

One of the oil fields in the North Sea has a gas cap in the reservoir. It is not possible to predict the amount of produced gas from the gas cap, which results in high deviations in the recombined fluid compositions. The multiphase meter requires a PVT model (fluid composition) for flow calculation, and the high deviation in fluid composition results in high deviations in flow rates. However, because the gas cap has a similar composition to the reservoir gas, the deviation in fluid composition has no impact at meter actual conditions due to the GOR being directly measured. It only impacts the conversion from meter conditions to standard or reference conditions.

There are three subsea multiphase meters installed in this oil field, each using its own Multiflash™ PVT model based on the reservoir fluid composition, which differs for the three meters.

Due to the gas cap impact, the PVT model used on the subsea meters could not reflect the true fluid composition, resulting in high deviations, especially for gas at standard conditions.

The GOR matching method has been developed and implemented in the meter software since 2020. Significant improvements were observed immediately after the update. For the comparison presented in Fig. 9, 10 and 11, standard flow rates from the topside allocation system are used as the reference.

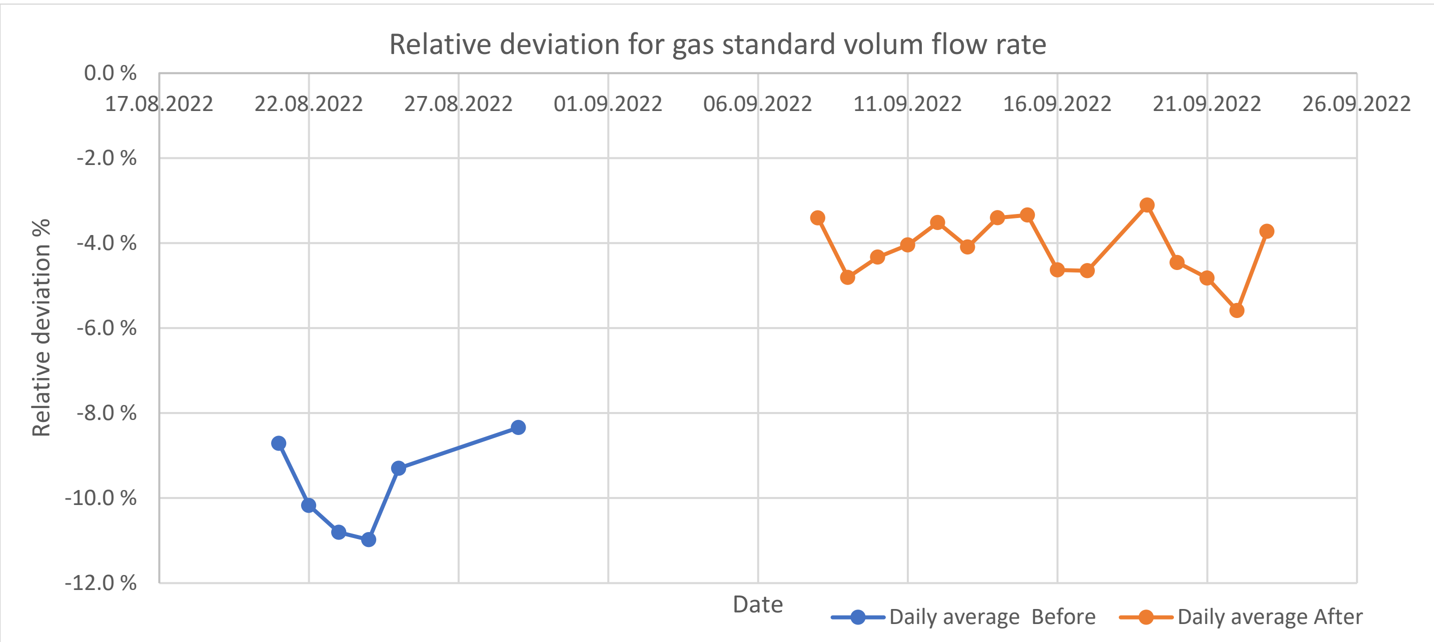

Fig. 9 - Relative deviation for gas standard volume flow rate before and after GOR matching enabled

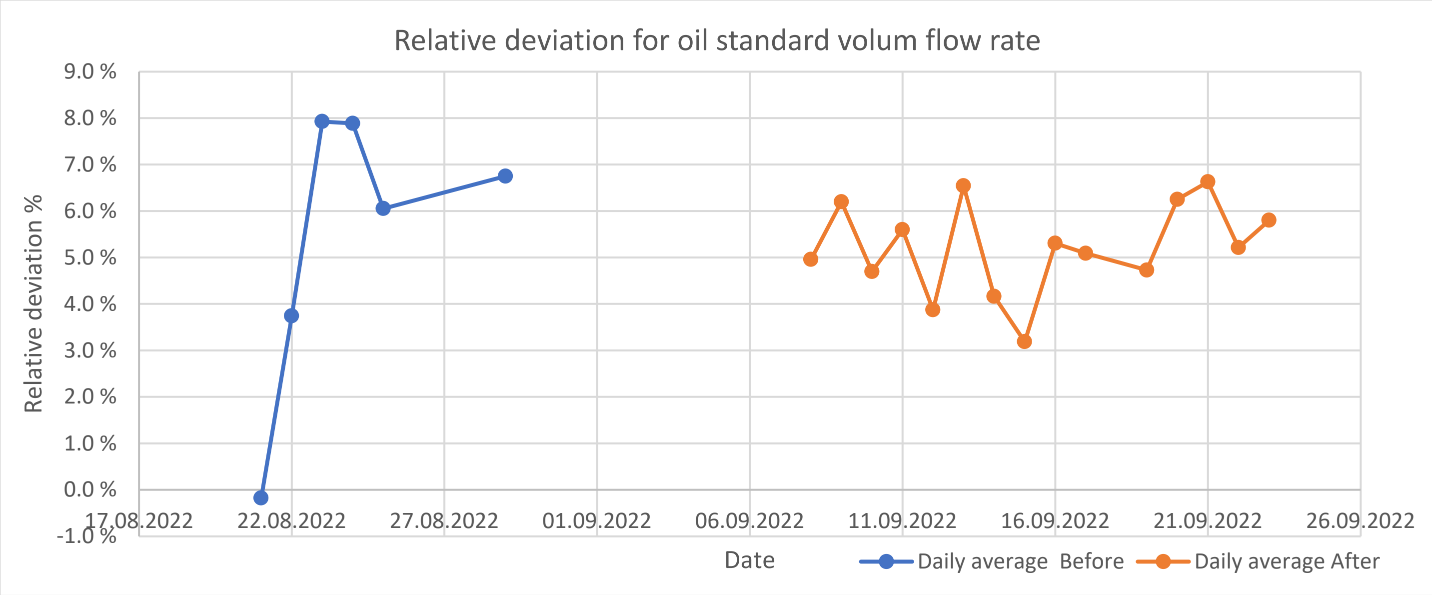

Fig. 10 - Relative deviation for oil standard volume flow rate before and after GOR matching enabled

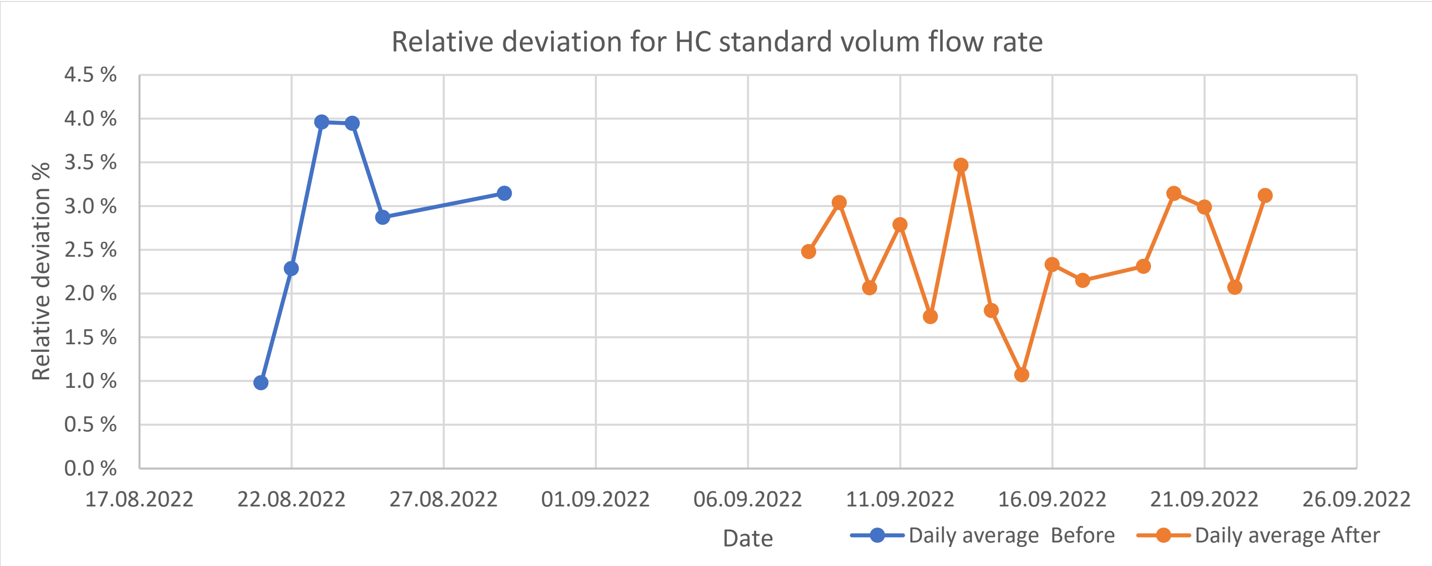

Fig. 11 - Relative deviation for HC standard volume flow rate before and after GOR matching enabled

From these three figures, it is clear that the deviation for the standard gas volume flow rate has been reduced from an average of about −10% to −4%. The deviation for the standard oil volume flow rate and the standard hydrocarbon volume flow rate is slightly less compared to before.

4.2 Deposits Build-Up

For meters installed subsea, the temperature can be high during operation. However, during shutdowns, temperatures may rapidly drop to approximately 4°C. At such low temperatures, deposit such as wax and scale could accumulate within the meter body if there is no or insufficient inhibitor injection. These deposits can heavily influence meter performance once operation resumes. Additionally, they can result in safety and flow assurance issues for the entire pipeline.

By utilizing MPM™'s high-energy gamma densitometer, it is possible to obtain indications of deposits build-up. If a single phase is trapped inside the meter, the measured density can be compared against the PVT density. The deviation between these two measurements can provide an indication of deposits build-up.

4.2.1 Field Experience Of Deposits Build-Up

A topside meter has been installed in the North Sea for well monitoring. Periodic verifications have been conducted remotely. During these verifications, it was observed that the difference between the gas density and the gamma density has been increasing over time.

In Fig.12, the PVT gas density, represented in blue, is the gas density calculated by the PVT model. The measured gas density, shown in red, is obtained when the meter contains only reservoir gas and is measured directly by the high-energy gamma from the multiphase meter.

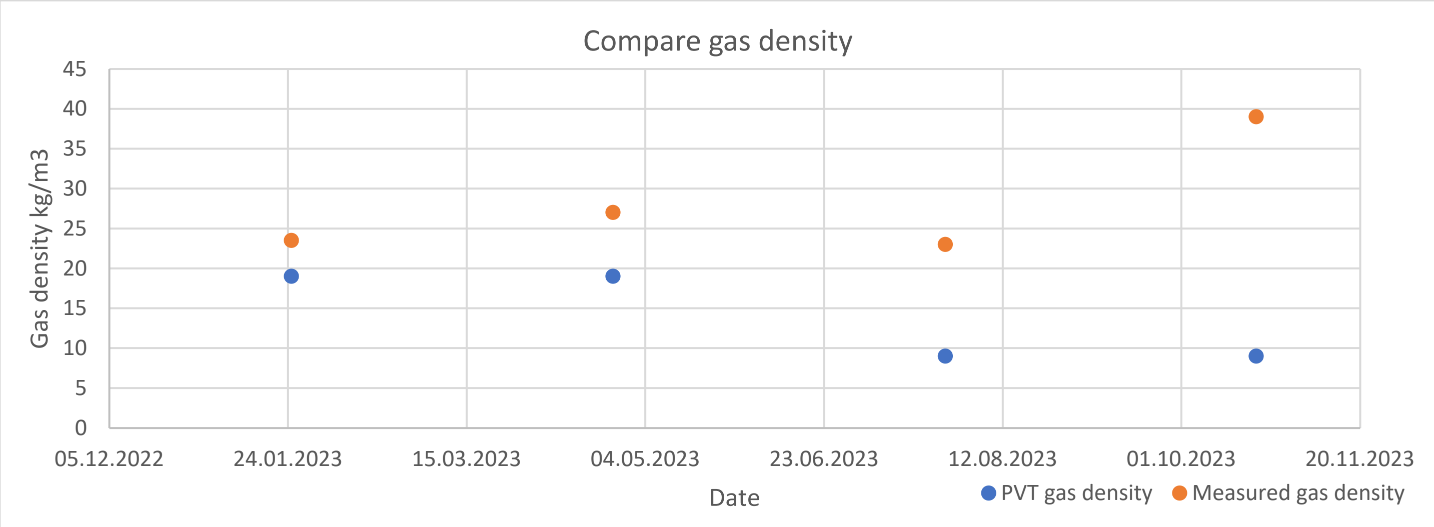

Fig. 12 - Compare PVT gas density with meter-measured gas density

It is evident that the difference between the measured density and the PVT density is increasing over time, indicating that deposits are building up inside the multiphase meter. Due to these heavier deposits, the meter measures a higher mixture density and subsequently a too high liquid content, leading to significant deviations in the oil, gas, and water flow rates under such circumstances.

Upon further examination by the operator, the deposits inside the meter were identified as wax and barium sulfate.

The meter has been cleaned and further inspected. Following this service, the measured gamma density aligns well with the PVT model, and the meter now measures flow rates satisfactorily.

5 PERIODIC VERIFICATION

Periodic verification is a service that TechnipFMC offers to operators to maintain high performance throughout the entire field life for both subsea and topside multiphase meters.

5.1 Introduction Of Periodic Verification

Producing oil and gas from a reservoir is never an easy task. Small operational changes can result in significant alterations to the production profile. For topside and subsea meters operating in the field, this can lead to unpredictable PVT and water properties, extreme slugging, deposits build-up, and operation outside of specifications, among other issues.

To ensure meters maintain high performance under all circumstances, it is highly recommended to perform periodic verification. This sustainable method involves a comprehensive examination of the meter and an evaluation of the potential to reduce uncertainty under challenging conditions.

The periodic verification process encompasses several key checkpoints, each with associated sub-checkpoints. These checkpoints are systematically evaluated, and where significant deviations are identified, uncertainty calculations may be performed to quantify their impact on overall meter accuracy. Additional studies may be initiated to further mitigate uncertainty. In the near future, this process may be automated to enhance efficiency.

Main verification checkpoints:

- Calibration or well testing
- Transmitters include differential pressure, pressure, temperature
- Gamma and 3D Broadband™
- Flowing conditions and stabilities
- Transmitter communication and internal sensors
- Critical alarms and events

5.2 Current Process Of Periodic Verification And Field Experience

Currently, periodic verification requires remote access to the meter's service/terminal computer. To obtain remote access approval, a work permit must be sent to the offshore instrument responsible person, detailing safety, risk, and the scope of work.

Once remote access is granted, the required data is downloaded and analyzed in accordance with established procedures, including the key checkpoints outlined in section 5.1. Following the completion of the verification process, a detailed report is delivered to the end user, containing recommendations and potential improvements.

Common issues that experienced during periodic verification are summarized in as follows:

- Work permit delays: Issuance of work permits was postponed due to the prioritization of other offshore activities.
- Data unavailability: Communication issues resulted in the absence of data required for verification.
- Deposits build-up: The accumulation of deposits within the meter caused significant deviations in flow measurements and adversely affected differential pressure readings.
- Water salinity uncertainty: High uncertainty in the input water salinity has caused notable deviations in WLR calculations. It is recommended that the salinity probe be activated to improve measurement accuracy.
- Downstream separator influence: Flow conditions in downstream separators have impacted the accuracy of standard flow rate calculations. Incorporating separator conditions into the flow calculation model is advised.
- Gas lift impact: The presence of gas lift may introduce high uncertainty in the measured flow rates.

6 SUMMARY

This paper presents field cases and operational experiences from both topside and subsea meters used in Aker Bp's fields. It is evident that the MPM™ multiphase meters exhibit high performance in field operations in comparison with against test separators over the long term.

These meters not only measure accurate flow rates under actual conditions but also have the capability to calculate standard flow rates accurately by considering downstream processes and using the GOR matching method.

By utilizing high-energy gamma and unique 3D Broadband™ technology, the multiphase meters are capable of directly measuring single-phase fluid properties and, under certain conditions, providing indications of deposit build-up within the meter.

Periodic verification is recommended to maintain the high performance of these meters. The most common issues that were experienced during the verification are summarized. The verification process has the potential to be automated in the near future.

7 NOTATIONS

GOR	Gas Oil Ratio
GVF	Gas Volume Fraction
HC	Hydrocarbon
MPM™	Multiphase Meter
PVT	Pressure Volume Temperature
TS	Test Separator
WLR	Water Liquid Ratio

$u(TS, HC)$	Test separator HC mass flow rate uncertainty
$u(TS, Oil)$	Test separator oil mass flow rate uncertainty
$u(TS, Gas)$	Test separator gas mass flow rate uncertainty
$u(Oil)$	Overall uncertainty of oil mass flow rate
$u(Gas)$	Overall uncertainty of gas mass flow rate
$u(HC)$	Overall uncertainty of HC mass flow rate
$u(MPM, Oil)$	MPM™ oil mass flow rate uncertainty
$u(MPM, Gas)$	MPM™ gas mass flow rate uncertainty
$u(MPM, HC)$	MPM™ HC mass flow rate uncertainty
$u(PVT, Oil)$	Oil mass flow rate uncertainty derived by PVT
$u(PVT, Gas)$	Gas mass flow rate uncertainty derived by PVT
$u(PVT, HC)$	HC mass flow rate uncertainty derived by PVT
$\sigma(Oil)$	Relative deviation of oil mass flow rate when compare MPM™ and test separator
$\sigma(Gas)$	Relative deviation of gas mass flow rate when compare MPM™ and test separator
$\sigma(HC)$	Relative deviation of HC mass flow rate when compare MPM™ and test separator
$QmGas\_MPM$	Gas mass flow rate at MPM™ condition
$QmOil\_MPM$	Oil mass flow rate at MPM™ condition
$QmHC\_MPM$	HC mass flow rate at MPM™ condition
$QmOil\_TS\_converted$	Oil mass flow rate of test separator converted at MPM™ condition
$QmGas\_TS\_converted$	Gas mass flow rate of test separator converted at MPM™ condition
$QmHC\_TS\_converted$	HC mass flow rate of test separator converted at MPM™ condition

8 REFERENCES

[1] ISO 5168:2005 Measurement of fluid flow — Procedures for the evaluation of uncertainties