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Technical Paper

Subsea Multiphase Fluid Analyzer (MuFA) – A new concept to provide accurate fluid parameter input to multiphase flow meters

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ABSTRACT

Multiphase flow meters (MPFMs) rely on accurate knowledge of fluid parameters such as densities and dielectric parameters in order to calculate flow rates with good accuracy. Uncertainties and variations over time in the composition can lead to large uncertainty in the estimated fluid parameters. Uncertainty in fluid parameters is a main contributor to the overall uncertainty of multiphase flow measurements. In this paper we present a new concept for a subsea multiphase fluid analyzer (MuFA), in which the fluid parameters are measured directly at operating conditions using an add-on module to the MPFM. Thus, accurate input parameters are provided that will increase the reliability and accuracy of MPFMs. The functionality of the MuFA concept is to sample the multiphase flow into a subsea chamber, let the fluids separate within the chamber, and measure the fluid parameters of the three phases directly at operating conditions. The fluids are released into the multiphase flow after characterization. The concept has been verified by multiphase flow loop experiments over a broad range of flow conditions applying electromagnetic sensors and a gamma densitometer. A control system for automated sampling and analysis of the three fluid phases has been implemented and tested.

1 INTRODUCTION

Multiphase flow meters (MPFMs) rely on knowledge of fluid parameters in order to calculate flow rates with good accuracy. Typical input data are densities and dielectric parameters for gas, oil and water at operating conditions. These fluid parameters are usually estimated from hydrocarbon and water composition using PVT simulation software.

In this paper we present a concept for a subsea multiphase fluid analyzer (MuFA) that measure these fluid parameters online, and thereby can increase the reliability and accuracy of MPFMs. The idea behind the MuFA concept is to sample the multiphase flow into a subsea chamber, let the fluids separate within the chamber, and measure the primary input parameters of the three phases directly at operating conditions. Note that the fluid samples do not have to be representative with regard to GOR and WLR as oil and gas are characterized at operating conditions. The fluids are released into the multiphase flow after characterization. The concept builds upon previous work by Christian Michelsen Research and the University of Bergen [1], but applies a novel sampling methodology where the fluids are analyzed sequentially [2].

Equinor has about 20 subsea tie-in fields to host platforms and some subsea-subsea tie-ins, where ownership allocation by using MPFMs is implemented. With commingled production of several wells into a common flowline, the fluid properties for each individual

well are difficult or even impossible to obtain, and thus over time the measured rates may drift off from the actual values. This is especially the case for oil producing fields where gas injection, gas lift and/or water injection is implemented. For such cases the change in fluid properties can be significant and result in considerable measurement errors. One way to minimize the measurement errors can be to reduce the error in well fluid parameters input to the MPFM using the MuFA-concept described in the current paper.

These issues have become more important the last years as MPFMs are increasingly being used fiscally for allocation purposes. MPFMs installed topside can be regularly verified towards test separators to achieve a sufficient accuracy, but this is difficult for meters applied in subsea tie-in installations. However, as the flow at topside installations often consists of commingled streams with large variation in fluid composition, it would also be beneficial to get more frequent fluid information than obtained through test separator verification campaigns.

The MuFA concept is most suitable for new field developments, but provided there is space, it may be applied also on existing fields in operation if the MPFM is retrieved and replaced.

2 MPFM INPUT PARAMETERS

The phase fractions provided by gamma/electromagnetic-type MPFMs are calculated from measured mixture permittivity/conductivity and mixture linear attenuation coefficients. The flow rates are then found by combining the fraction measurements with differential pressure measurements over a Venturi. The primary input fluid parameters for gamma/electromagnetic type MPFMs are water conductivity, linear attenuation constants and permittivity of oil and gas. For dual-energy type MPFMs, the main input parameters are the linear attenuation coefficients at the high and low energy levels and the water salinity. These input parameters are typically provided by first estimating fluid densities at operating conditions from the hydrocarbon composition using PVT calculations, followed by calculation of permittivity and attenuation coefficients using fluid models. In addition, water conductivity/salinity is found either from water samples or by measurements with dedicated conductivity sensors in the MPFMs. This process is illustrated in Figure 1~~Figure 1~~.

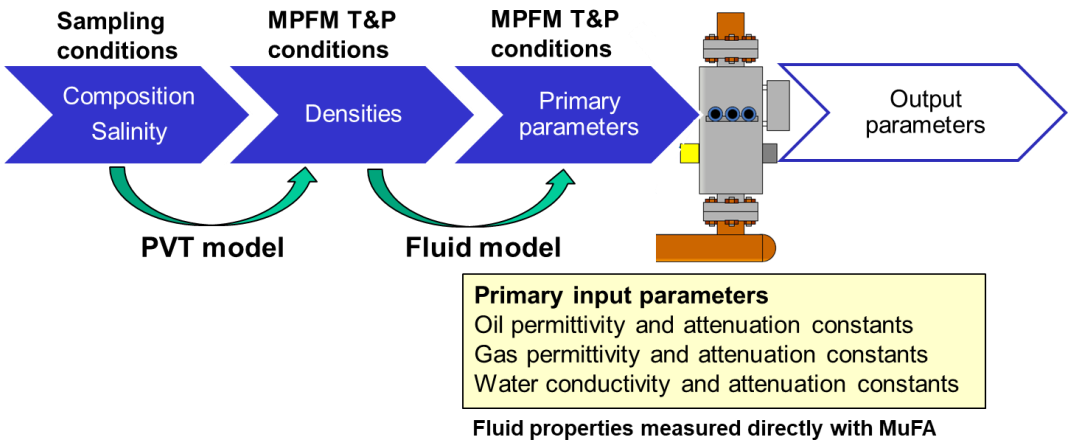

Figure 1 Derivation of MPFM primary input parameters from composition (for Gamma/electromagnetic type MPFM).

This traditional approach of estimating the primary input parameters leads to uncertainties due to the following:

- Uncertainty in the hydrocarbon composition and water salinity due to e.g. sampling and analysis: Representative samples of the multiphase flow are usually not available. Samples taken from test separator may be a combination of fluids from several wells with different properties.
- Well samples may also not be representative over time, as the fluid composition may change as different zones are produced and gas/water injection influence the composition.
- Model uncertainty in the PVT algorithms used to calculate densities from hydrocarbon composition
- Model uncertainty for estimating oil and gas permittivity from densities[1].

Figure 2~~Figure 2~~(a) shows an example of how errors in fluid parameters can result in systematic errors in the measured hydrocarbon mass flow rates. This is estimated over the lifetime of an example field that has GVF and WLR variations as shown in Figure 2~~Figure 2~~(b). The estimations are based on fundamental equations for a gamma/EM-type MPFM (see e.g. [3]) in combination with published fluid models [4], [5] and a typical hydrocarbon composition. Note that this estimation does not include proprietary adjustments or model improvements implemented by MPFM vendors. The estimations are shown for two cases: One case with high input errors that could be relevant for a subsea tie-in installation (10% density error and 5% salinity error) and one case for which input errors are reduced significantly by an appropriate method (1% density error and 1% salinity error). The error in measured hydrocarbon mass flow is significant for the case with high input error, while a much lower error is obtained if the density and salinity uncertainties can be reduced to 1%. It is also observed that the error in hydrocarbon mass depends strongly on the flow conditions (WLR and GVF). This example illustrates the need to know the fluid properties accurately in order to achieve accurate measurements from an MPFM.

The idea behind the MuFA concept is to provide accurate input fluid parameters to a MPFM by sampling the multiphase flow, let the fluids separate, and measure the primary input parameters of the three phases individually directly at the operating conditions. This is indicated by the yellow shaded box in Figure 1~~Figure 1~~. The main benefits of this approach are:

- Fluid samples of the actual multiphase flow are characterized. Thus, the analysis is done on representative fluids.
- All parameters are measured at actual operating conditions. Thus, there is no need for flashing.
- The primary input parameters are measured directly with similar instrumentation as is applied in the MPFM. Thus, uncertainty due to PVT estimation and correlations between densities and primary MPFM input parameters are avoided.

[1] The model uncertainty for estimating linear attenuation coefficients from densities (and composition) is low.

Compared to sampling methods where multiphase samples are taken with ROV followed by chemical analysis in a laboratory to determine hydrocarbon composition, the MuFA concept has a very short response time from sampling to completed analysis. The operational cost is also heavily reduced compared to the use of ROV. Note also that the method does not require phase representative sampling, i.e. capturing of a sample with true volumetric representation (WLR and GVF) of the flow.

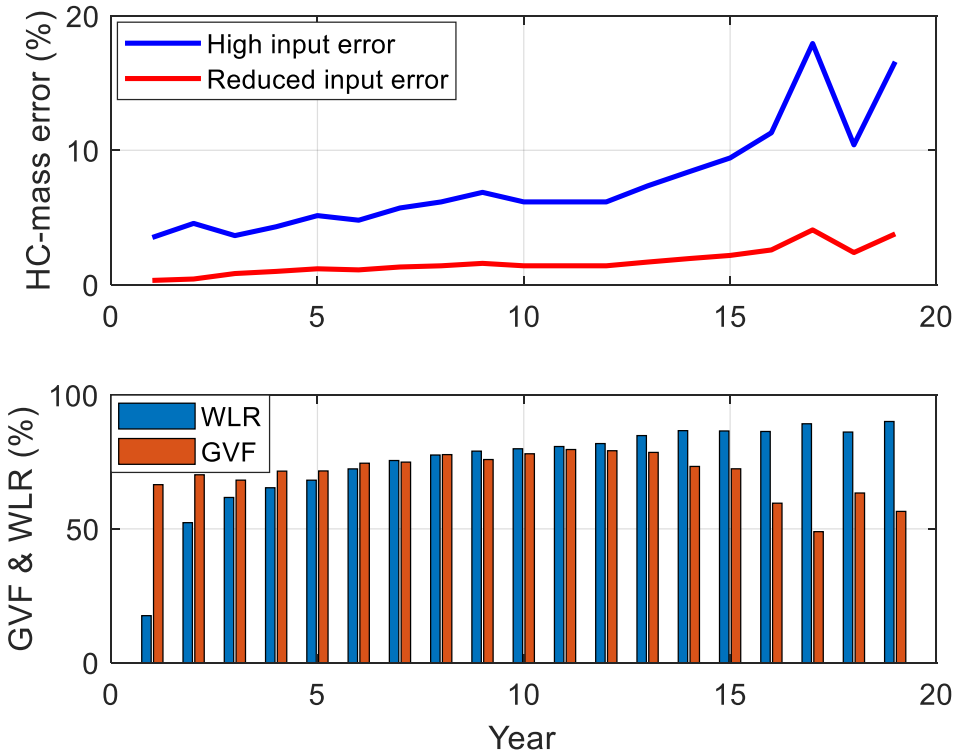

Figure 2 (a) Estimated systematic relative error (%) in measured hydrocarbon mass over the lifetime of an example field due to density and water salinity errors. High input error case: 10% density uncertainty, 5% salinity uncertainty. Reduced input error case: 1% density uncertainty, 1% salinity uncertainty. (b) GVF and WLR variations for the example field.

3 MuFA CONCEPT DESCRIPTION

Figure 3~~Figure 3~~ shows a sketch of the suggested MuFA concept. The main part in the concept is a *sampling and analysis module* that is placed vertically in parallel with the MPFM. This module consists of an *analysis chamber* that is connected through two *sampling units* to the main pipeline. Each sampling unit consists of a valve with electrical actuator and a T-junction. A sensor set is placed within the analysis chamber. This sensor set preferable consist of the same sensor technologies as applied in the MPFM. For instance, this can be a gamma densitometer, a permittivity sensor and a water salinity sensor. In addition, temperature and pressure sensors measure the T&P conditions in the module.

During normal operation both valves are closed, and all the flow is routed through the MPFM. When a new characterization of the fluids is needed, some of the flow is routed through the module and analyzed. Gas, oil and water are analyzed in separate steps as follows:

1. Gas sampling and analysis: Both valves are opened and some of the flow will go through the module ensuring that the module is filled with representative process fluids. This flushing will also ensure that the module is heated to the process temperature. The upper valve is closed, and gas will gradually accumulate in the module. When the module is filled with gas, the lower valve is closed, and gas is analyzed by the sensors.
2. Oil sampling and analysis: Both valves are opened to flush the module with the process mixture. The lower valve is closed, and liquid will accumulate and gradually fill the module. The upper valve is then closed, and liquid is allowed to separate into oil and water. Oil is characterized by the sensors, which are placed in the upper part of the analysis chamber. If the water level reaches the sensors, the lower valve is opened for a short time to let out water. The oil sampling and analysis part is then started over again until the sensors only sense oil
3. Water sampling and analysis: Both valves are opened to flush the module with the process mixture. The lower valve is then closed, and liquid will accumulate and gradually fill the module. Water will separate from oil while the valve is open, and the water level will increase and finally covers the sensors. The upper valve is then closed, and water is characterized when the separation has stabilized.

The concept described above is a modified version of our original concept described in [2]. In the original concept, an upper and a lower sensor set is applied in the analysis chamber. This allows simultaneously characterization of water and oil by adjusting the water-oil level to be between the upper and lower sensor set. The modified concept allows for a cost reduction by only requiring a single sensor set.

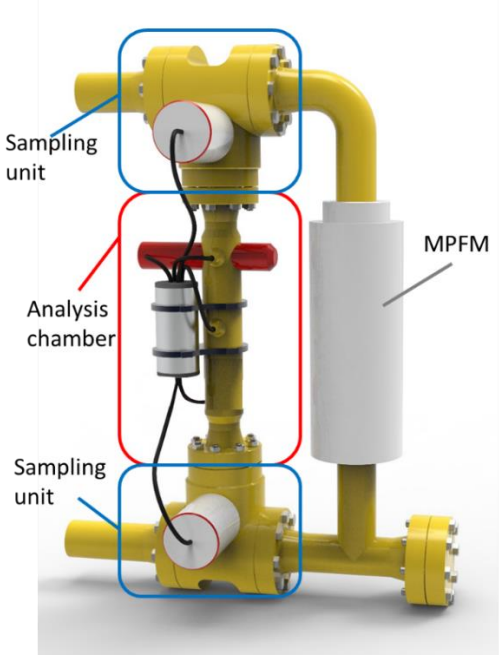

Figure 3 Illustration of sampling and analysis module for the multiphase fluid analyzer concept mounted in parallel with a MPFM.

4 FLOW LOOP DEMONSTRATOR

A simplified version of the concept was studied in NORCE's multiphase flow loop. Figure 4~~Figure 4~~ shows a sketch of the experimental set-up. Instead of dedicated sensors, a full MPFM with high energy gamma densitometer and electromagnetic sensors was applied in

the analysis chamber. Further on, a dummy Venturi section was mounted in the main pipeline to simulate the effect of a MPFM. A view glass was also mounted in the analysis chamber and video was recorded.

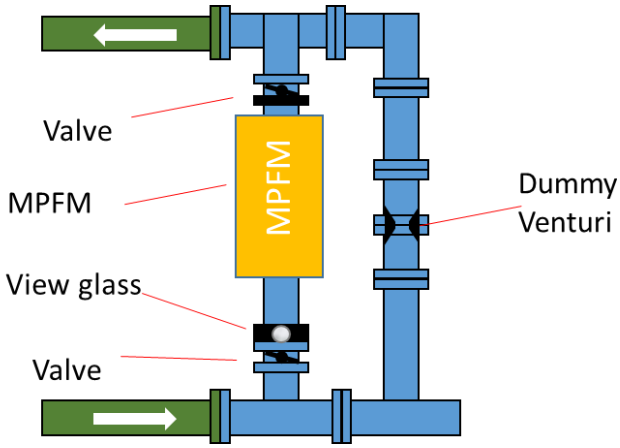

Figure 4 Experimental set-up.

Two measurement campaigns were carried out. Focus in the first campaign was to gather experience with the system and its response for a wide range of flow conditions (flow rates, WLR and GVF). In the second campaign, a more compact version of the system was investigated. The sampling and control algorithm was also updated based on findings from the first campaign.

Figure 5~~Figure 5~~ shows an example of gamma counts (upper part) and permittivity measurements (lower part) as a function of time during sampling and analysis of a test point. Valve operations are shown using green (open valve) and red (close valve) vertical lines in the upper/lower part of the figure for opening of the upper/lower valve, respectively. The analysis periods for gas, oil and water are shown using yellow, blue and red rectangles, respectively.

Gas is first sampled and analyzed when the fluid has stabilized (analysis period marked in light yellow in Figure 5~~Figure 5~~). When gas analysis is completed, the upper valve is opened and kept open until the analysis chamber is filled with liquid. The liquid is then allowed to separate and stabilize, and oil is characterized by the sensors (analysis period marked in light red in Figure 5~~Figure 5~~). When oil analysis is completed, the upper valve is opened again such that more liquid is sampled. As water is heavier than oil, water will separate out and finally fill the whole analysis chamber. The upper valve is then closed, and water allowed to stabilize before it is analyzed (analysis period marked by light blue in Figure 5~~Figure 5~~). In other test points with high or low WLR, some of the sampling steps must be repeated in order to ensure that the fluid that is analyzed fills the complete sensor measurement volume.

The sampling and analysis process is fully automated. A software algorithm reads data from the sensors and applies this data to control the opening and closing of the valves.

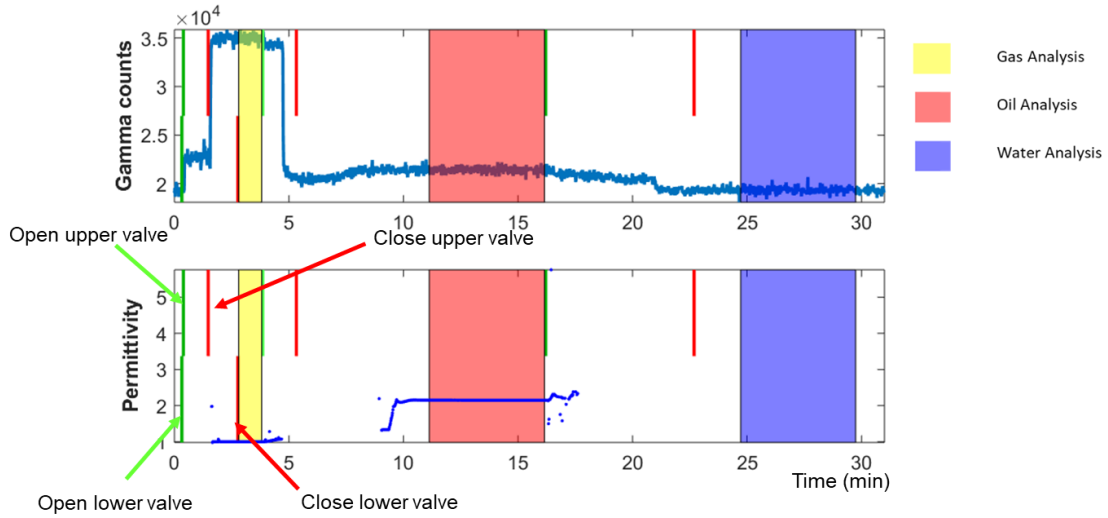

Figure 5 Example of measured data (gamma counts and permittivity) versus time during one test-point in test campaign 1. The time intervals for analyzing gas, oil and water are indicated by yellow, red and blue filled rectangles.

Figure 6~~Figure 6~~ and Figure 7~~Figure 7~~ summarize how some measured fluid parameters varied between the different test points. Figure 6~~Figure 6~~ shows how the gamma measurements for water and oil varied around the mean value for test campaign no. 1 and no. 2, whereas Figure 7~~Figure 7~~ shows the variation in permittivity for gas and oil. The fluid properties were the same for all test points apart from a slight difference in water conductivity. The temperature and pressure were within 8 °C and 2 bar during the tests. The variation between the different test points should therefore be close to zero in the ideal case. Thus, the variation in measurement data between the test points gives a measure of the functionality of the MuFA system.

The error bars show the measurement uncertainty for each point. The lower measurement uncertainty observed for the gamma measurements in test campaign no. 2 is due to a longer analysis time.

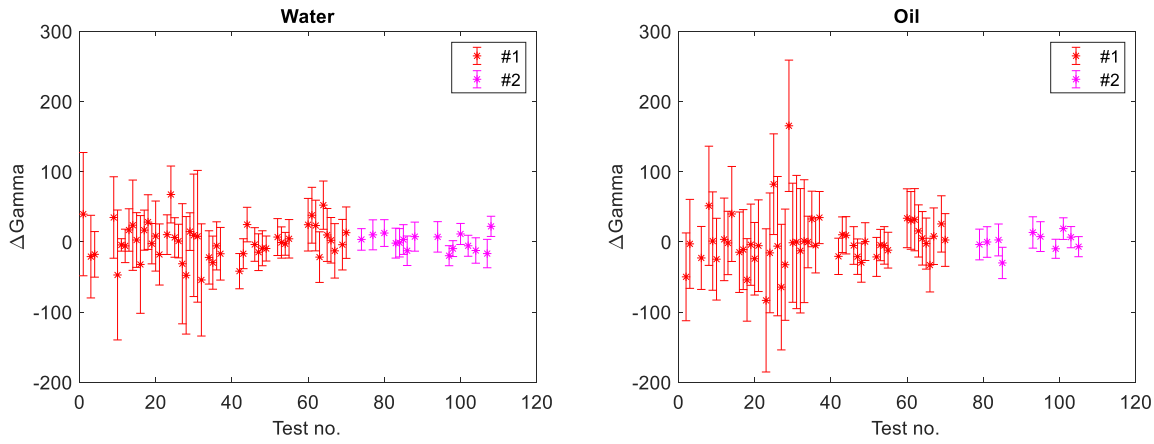

Figure 6 Measured gamma densitometer data of water and oil for the various test points. The data shown are the difference from the mean gamma counts for test campaign 1 and 2.

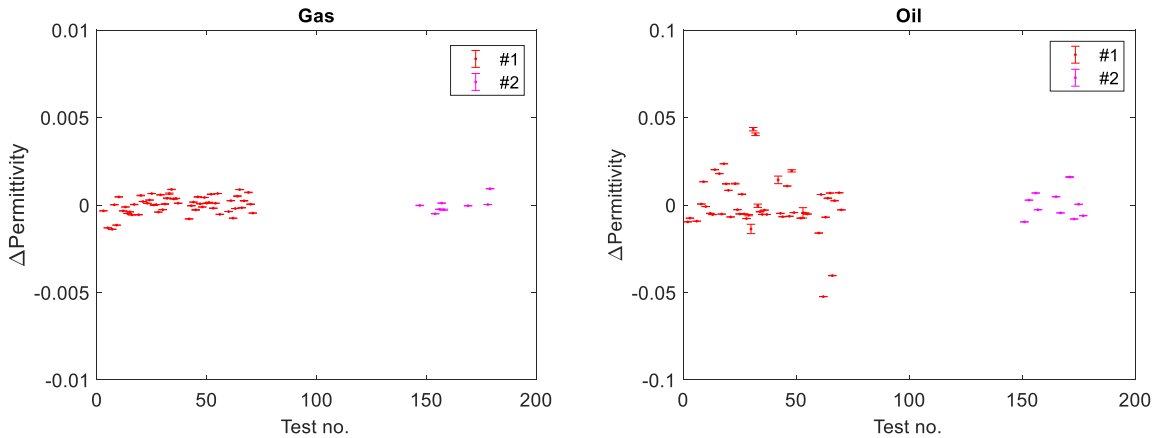

Figure 7 Measured gas and oil permittivity data for the various test points. The data shown are the difference from the mean permittivities for test campaign 1 and 2. Note the different scales on the figures.

The flow loop tests showed that the fluid parameters could be measured with high accuracy. The variation in oil permittivity was within 1% for test campaign 2, while the variation in gas permittivity and gamma counts were below 0.25 % and 0.15% respectively.

Sensitivity analysis shows that such an accuracy will ensure that the fluid parameter influence on MPFM flow rates are negligible compared to other uncertainty contributors for most WLR and GVF ranges

5 CONCLUSION

A new concept for providing accurate fluid parameter input information to MPFMs in real-time is presented in this paper. The functionality of the concept has been verified through flow loop experiments. Sensitivity analysis shows that the fluids were characterized with sufficient accuracy to improve the performance of MPFMs significantly. However, it remains to test and verify the system with real hydrocarbon fluids under high pressure.

ACKNOWLEDGEMENT

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6 REFERENCES

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