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**A method for remote
in-line calibration of
water fraction meters**



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Abstract

A new method has been developed which is suitable for remote in-line calibration of water fraction meters. The method utilizes settling of water in a vertical line under no-flow conditions.

As water is allowed to settle in a hydrocarbon liquid, a repeatable, low, amount of water will remain solved in the hydrocarbon liquid. This amount of water can be determined, and the water in oil meter can be zero-point calibrated at this point. The method is suitable for installations where water cut meters are installed in a vertical pipe section, and where no flow conditions can be provided manually or happens in occasional shut downs without depressurization.

Current methods for calibration require entering a well-defined test fluid or air into the meter and/or that representative samples are taken and analyzed in a laboratory. This is especially challenging with unstable hydrocarbon liquid or low-density condensates. Current methods also require the presence of competent personnel at the site.

This new method is suitable for remote operation, and only requires available trend curves and remote access to the metering system / water fraction meter. The new method for inline calibration represents relatively large cost reduction and reduction of HES risks relative current methods. It is expected that the uncertainty of the method can be within fiscal requirements (0.05 [vol %]) for well-known fluids.

1. Introduction

The method described herein was developed to overcome significant problems with performing a satisfactory calibration of a water fraction meter installed downstream an inlet separator at a metering station used for allocation metering.

The process conditions at the metering station were the following:

- Pressure: 100 [Barg]
- Temperature: 30 [DegC]
- Density: 600 [kg/m3]

The following make in-line calibration of the water fraction meters challenging, as it makes it real difficult do take a representative sample and analyze it at standard conditions using Karl Fisher analysis:

- The condensate is not stable. When a sample is depressurized a large amount of the liquid will change to gas phase.
- Due to large difference in density and low viscosity water separates real fast from the condensate.

Further the water fraction meter is installed inline with no possibility to remove the meter or to fill the meter with a reference fluid without shutting down production.

2. The Challenge

The Handbook of water fraction metering presents the main causes that might bring a water fraction meter out of calibration. Ref.: Handbook of water fraction metering revision 2. Section 9. Calibration.

Calibration may generally be required to determine (and – in the case of adjustment – to compensate for) the effect on the measured % Water of any of the following three main elements:

- 1. Mechanical wear and ageing of components*
- 2. Contamination of sensor section by scaling, asphaltenes etc.*
- 3. Changes in fluid composition due to non-hydrocarbon components*

... This handbook also seeks to make the calibration and adjustment of the WFM independent of conventional sampling and analysis (cf. Section 9.1.2).

The method of the handbook basically prescribes the following steps for getting and maintaining a calibrated meter.

- *Primary calibration (performing adjustment and recording footprint)*
- *Reproducibility check (verifying meter against footprint)*
(Ref: Section9 Calibration)

Primary calibration:

- The purpose of the primary calibration is to:*
- *Record the footprint of the WFM with a repeatable reference material*
 - *Establish the error of the measured WLR on a stabilised field oil sample*
 - *Perform adjustment of the WFM with a stabilised field oil sample*
- (Ref: Section 9.1 Primary calibration)

Reproducibility check:

- The purpose of the reproducibility check is to verify that the most recent primary calibration (adjustment) of the WFM is still valid. Such verification is achieved through reproduction of the WFM footprint in the field, and comparing this with the footprint from the primary calibration certificate.*
- (Ref: Section 9.2 Reproducibility check)

The main challenge with following the Handbook in this case is that the meter is installed inline with no possibilities to fill the meter with a reference fluid without shutting down production, opening the flow line and filling the reference fluid into the meter.

Further a stabilized field oil sample will have significantly different density than the unstable fluid at operating conditions. A change of density by 1 [kg/m³] will alter the measurement by 0.027 [vol%]. Ref. RFM WCM Installation and operating instructions section 3.2.3. The zero point of the water fraction meter would therefore be significantly affected by this change in density. However this could be compensated for.

The prescribed procedure also requires a detailed procedure, planning, and coordination of personnel, documentation, competent personnel onshore and offshore. All in all the process becomes laborious, expensive and the risk of failing becomes significant. In this case it would also involve building of scaffolding and HES risk related to opening the flow line.

The method to perform inline calibration by taking a representative sample, analyze it in the laboratory and adjusting the meter accordingly is not achievable as the condensate is far from stabilized, and water settle real fast making it very difficult to inject a representative sample into the Karl Fisher apparatus.

3. The operating principle of the water fraction meter

The meter used in this case was a full bore microwave water fraction meter made by ROXAR.

The operating principle of this meter is described in the Installation and operating instructions. Ref. RFM WCM Installation and operating instructions section 3.1.1

3.1.1 Operating principle

1. The Meter is factory calibrated with vacuum (air) frequency of sensor
2. A discrete sweep over the measurement range from high to low frequencies is done by transmitting a frequency on one antenna while measuring power on the other.
3. A curve fit on the resulting peak power measured is done to achieve highest accuracy
4. Temperature, pressure and mixture density (Optional) is input to the meter
5. Water and oil basic configuration data is converted to line conditions and the respective dielectric constants are calculated using a Roxar patented method
6. The mixture dielectric constant is calculated from measured frequency
7. The water cut is calculated using the Bruggemann equation

$$WC = 1 - \frac{\epsilon_{mix} - \epsilon_{water}}{\epsilon_{oil} - \epsilon_{water}} \cdot \sqrt[3]{\frac{\epsilon_{oil}}{\epsilon_{mix}}}$$

The uncertainty obtained solely by entering dry density at operating conditions is specified by the manufacturer to be:

Fixed density method

- $\pm(0,3 \% + 5 \% \text{ of reading})$
- Max. 1 % absolute
- Effect of oil density variations: $\pm 0,027 \% \text{ abs. per } 1 \text{ kg/m}^3$

However it will require calibration to verify that this uncertainty is maintained in operation.

The uncertainty can be further reduced down to the uncertainty of the reference method by performing inline calibration. Inline calibration is performed by taking a sample, analyzing the sample in a laboratory and adjusting the meter reading to the laboratory result. If combined with a density meter the effect of oil density variations can be eliminated.

4. The metering station used for the tests

The metering station is placed downstream of the Skirne / Byggve inlet separator at Heimdal. The separator is operated at 100 [Barg] and approximately 30 [DegC]. The metering station is measuring condensate at approximately 605 [kg/m³] from the separator.

The condensate metering station is equipped with a densitometer, an ultrasonic flow meter, and a full bore inline water fraction meter. The density meter and the water fraction meter are installed on a vertical part of the flow line. The ultrasonic meter is installed in a horizontal part of the flow line.

These instruments are connected to a fiscal supervisory system. The system is accessible from intranet or internet (Virtual Private Network).

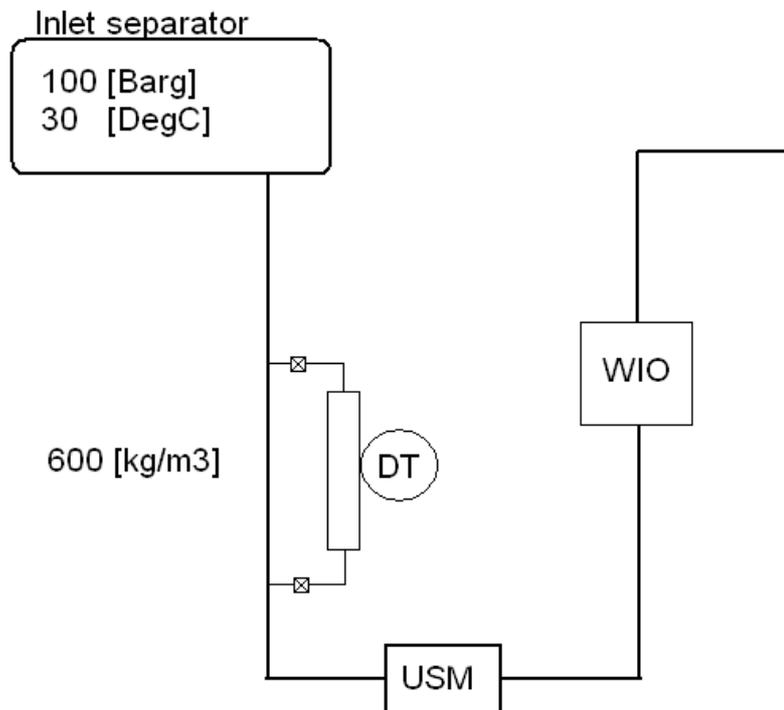


Figure 1. Principle sketch over the metering station.

5. Hypothesis

The following two hypotheses were formed as basis for the new method for calibration.

Hypothesis: When water is allowed to settle in a hydrocarbon liquid a repeatable, low amount of water will remain solved in the hydrocarbon liquid (in this case condensate). The water fraction meter can then be calibrated at this point.

Hypothesis 1:

Expected repeatability of remaining water in condensate when water is allowed to settle out: better than 0.05 [%]

Hypothesis 2:

Theory about liquid liquid equilibrium of water and hydrocarbons will predict that the expected water fraction remaining in the condensate when water is allowed to settle out is less than 0.2 [%].

6. Tests

It turned out that occasionally the process was shut down without depressurization of the flow line. By investigating the trend curves it turned out that the measured water fraction rapidly fell and stabilized. As the pressure fell by 2.5 [Barg] gas bubbles will form. It is anticipated that the gas bubbles will rapidly rise through the vertical section. Further it is anticipated that the change of density following this formation of gas will be negligible.

The water fraction meter was first calibrated to show 0.00 [%] at a no flow condition without depressurization at 2006/03/11 21:16. Before calibration water was allowed to settle for approximately 2 hours.

The first test was performed at 2006/04/03 09:35. The following figure is a trend curve from the metering system showing a no flow condition without depressurization. Figure 2 represents a test of hypothesis 1:

Hypothesis 1:

Expected repeatability of remaining water in condensate when water is allowed to settle out: better than 0.05 [%]



Figure 2. Trend curves from a no flow condition without depressurization.

Red	Volume flow rate (USM nr. 1)
Yellow	Measured Density at process conditions
Green	Calculated net condensate density
Blue	Measured water fraction from water in oil meter
Magenta	Pressure
Orange	Line temperature
Turquoise	Volume flow rate (USM nr. 2)
White	Calculated volume flow rate at standard conditions.

As can be seen from the figure, water rapidly settles out, and water fraction stabilizes at 0.01 [%]. Figure 2 therefore gives support for hypothesis 1.

A similar test was performed 2006/06/26 23:34 with measured water fraction at no flow condition equal to 0.01 [%]. This gives strong support both for the stability of the water fraction meter and hypothesis 1. It even indicates that the hypothesis is conservative, and that an even better repeatability is achieved for this condensate.

Another test was performed by using trend curves to check calculated net condensate density against measured density on a pressurized sample at an onshore accredited laboratory.

In the onshore laboratory, the density is measured by heating and applying pressure on the cylinder until it reach process temperature and pressure. The density is than measured at process pressure and temperature by using appropriate equipment the sample cylinder is

kept still to allow water to settle out. The objective of the measurement is to measure net condensate density.

Intertek West Lab report reference: 2006-03308

The sample was taken: 20.06.2006, 21:00 hrs.

The reported density from Intertek West Lab is 605.3 [kg/m³]

Trend curve from the metering system shows a calculated net condensate density of 605.4 [kg/m³] at the time where the sample was taken.

The difference of 0.1 [kg/m³] in density account for a difference in water fraction of approximately 0.025 [vol%], if all the density difference is explained by difference in water fraction. Again this gives strong support for hypothesis 1.

Unfortunately, none of these tests are suitable for testing hypothesis 2 as the remaining water fraction in condensate in theory could be repeatable and still be higher than 0.2 [%]:

Hypothesis nr 2:

Theory about liquid liquid equilibrium of water and hydrocarbons will predict that the expected water fraction remaining in the condensate when water is allowed to settle out is Less than 0.2 [%].

An internet and article search was performed by the author in order to look for experimental data / theoretical results about the liquid-liquid equilibrium of water and hydrocarbons. The solubility of water in 50 different hydrocarbons at 20 [DegC] are presented in the article: "Nonlinear Dependence of the Solubility of Water in Hydrocarbons on the Molar Volume of the Hydrocarbon." [3]. Experimental results referred to in this article for the water fraction at equilibrium, range from approximately 0.005 [%] to approximately 0.05 [%] for Benzene. The article seems to give support hypothesis nr. 2, however the article does not provide data for multi component hydrocarbons nor does it provide data for solubility at higher temperatures.

The article "Liquid-liquid equilibria of water-hydrocarbon systems from cubic equations of state" [4] turned out to be disappointing regarding hypothesis nr. 2. In section "3.2 Multi component systems" it is stated that "Few multi-component data are available for liquid-liquid equilibria of water-hydrocarbon systems." As few data are available it will be hard to verify that theoretical calculation of the liquid-liquid equilibrium of our condensate is precise within required uncertainty. It is also pointed out that the solubility of water will increase with increasing temperatures. Further the calculation of the liquid-liquid equilibrium seems to be quite laborious.

Even though Hypothesis 2 still seems to be reasonable, the author has still not found sufficiently support for hypothesis nr.2 by general theory / experimental data. This leaves us with the only possibility to measure the amount of water in solution with the condensate to provide a traceable calibration of a water fraction meter. However, when it comes to representative sampling and analysis it will be much easier to determine the amount of water in solution with condensate than it is to determine a larger amount of water mixed with condensate.

As the densitometer can be isolated from the flow the original idea was to isolate the densitometer, allow water to settle out from the condensate and then measure the density of condensate without water. The metering station continuously calculates the net density of condensate by compensating for the water fraction. This calculated net density is then expected to be equal to the measured net density. Calibration of the water fraction meter could then be performed by adjusting meter reading until the calculated net condensate density equalled the measured net condensate density. This is an indirect method which probably also could be used for calibration of the water fraction meter. The uncertainty of this method would be somewhat higher than direct calibration of the water fraction meter at no flow conditions.

7. Conclusions

A new method for remote inline calibration of water fraction meters has been established. A vertical installed water fraction meter, measuring water in condensate, can be calibrated from remote by using trend curves and occasional no flow conditions without depressurization.

The performed tests give strong support to hypothesis 1:

Hypothesis 1:

Expected repeatability of remaining water in condensate when water is allowed to settle out: better than 0.05 [%]

The performed tests even indicate that the repeatability can be as low as 0.02 [%].

Hypothesis number 2 still seems to be reasonable, but is still not sufficiently supported to replace laboratory measurement of water fraction by Karl Fisher analysis:

Hypothesis 2:

Theory about liquid liquid equilibrium of water and hydrocarbons will predict that the expected water fraction remaining in the condensate when water is allowed to settle out is Less than 0.2 [%].

The amount of water in solution with condensate has to be determined by analysis. However it seems far easier to measure the amount of water which remains in solution with condensate than it is to perform representative sampling and analysis of the two immiscible liquids at higher water fractions.

When a representative sample is shipped onshore the analysis can most likely be performed by a laboratory onshore, as the amount of water in solution with condensate seems to be repeatable within 0.02 [%].

8. Method for remote inline calibration of water fraction meters

Large reductions of costs and HES risks can be achieved by adapting this new method for calibration. However the method requires that no flow conditions without depressurisation either occur naturally or can be created. Further the repeatability of water in solution with the hydrocarbon liquid will have to be checked.

The method is described by the following:

9. Establish the liquid liquid equilibrium of water in hydrocarbon by letting water settle out and measure the amount of water in solution with the hydrocarbon liquid by Karl Fisher or equivalent method.
9. Verify acceptable repeatability.
9. Use trend curves to find a no-flow condition without depressurisation.
9. Use trend curves to establish meter reading when water has been allowed to settle out.
9. Adjust meter reading of water in equilibrium with the hydrocarbon liquid by the difference to the Karl Fisher result.

9. Implications for design of future metering stations

New metering stations should be designed for this method by:

1. Installing water fraction meters vertically
2. Ensuring remote access to the metering system.
3. Ensuring remote access to the water fraction meter.
4. Ensuring that shut downs with no flow conditions and without depressurization will occur.
5. If shut downs without depressurisation will not occur naturally, valve arrangement should be designed so that no flow conditions can be created without shutting down production.
6. Calibration interval can be prolonged by duplicating water fraction meters and using condition based maintenance.

Automatic systems for calibration can possibly be made by:

1. Duplication of water fraction meters in a master meter configuration.
2. Using automatic operated valves to regularly create a no flow condition without depressurisation.
3. Automatically calibrate one of the two meters by the method.
4. Raise alarm if deviation between the meters exceeds a preset limit.

5. References

- [1] Handbook of water fraction metering Revision 2. www.nfogm.no
- [2] Water fraction meter user manual: RFM WCM Installation and operating instructions
- [3] Liquid-liquid equilibria of water-hydrocarbon systems from cubic equations of state; NASRIFAR Kh. ; MOSHFEGHIAN M.
- [4] Nonlinear Dependence of the Solubility of Water in Hydrocarbons on the Molar Volume of the Hydrocarbon; Paul Ruelle and Ulrich W. Kesselring.