# PRESENTATION OF THE HANDBOOK OF WATER FRACTION METERING

Eivind O. Dahl, Christian Michelsen Research AS, Bergen, Norway
Ronny A. Albrechtsen, Christian Michelsen Research AS, Bergen, Norway[1]
Erik Malde, PPCoN, Stavanger, Norway

## 1. ABSTRACT

A new NFOGM publication, *Handbook of Water Fraction Metering* [1], for continuous measurement of water fraction in produced and transported hydrocarbon liquid is presented. The increased availability of Water Fraction Meters (WFM) for continuous measurement represents a new challenge. It is of utmost importance to acquire reliable data for fiscal measurements. The uncertainty of the water fraction measurement is a fundamental aspect of the total crude oil measurement and it is essential in assessing the quality aspects of the production. It is also of great importance to be able to continuously monitor and analyse the water content of the crude oil during the optimisation process for both operation and transportation.

Until recently, a representative sample of crude oil and water has been used for calibration and adjustment of WFMs. Utilising sampling and analysis techniques as a reference has restricted the performance of the new technology, i.e. the applied technology in WFMs has a potential for less uncertainty than the reference techniques.

The *Handbook* sets out recommendations for continuous determination of water fraction in hydrocarbon liquids. It describes the recommended installation, calibration and adjustment methods for both fiscal and allocation water fraction measurements.

## 2. BACKGROUND

The Norwegian Society for Oil and Gas Measurement (NFOGM) brings further the tradition of providing the members of the society and others with special interest publications. The first publication, *Handbook of multiphase metering*, were released in 1995 [2], which was later followed by the *Handbook of uncertainty calculations - Fiscal metering stations* [3], published in 1999. This was subject to a minor revision in 2000, and a new revision in 2002 is currently being discussed. This paper, however, presents the latest addition to the series, the *Handbook of water fraction metering* [1] which is now downloadable from the NFOGM web-pages.

A workgroup for writing the handbook was established in 1999 with representatives from oil companies (PPCoN, BP Amoco, Norsk Hydro, Statoil), vendors (Roxar Flow Measurement – formerly Fluenta and Roxar, both participating as separate companies during this project) and Christian Michelsen Research AS (CMR). In this project, CMR has provided the workgroup with background and detail information regarding the uncertainty of the two in-line water fraction meters currently available, which also represent different technologies, and co-ordinated the work with the handbook.

---

[1] Statoil Bygnes, Norway from September 1st, 2001.

For the sake of completeness, we should also mention that a new handbook, *Handboook of Uncertainty Calculations – Ultrasonic fiscal gas metering stations,* is currently being developed by NFOGM and CMR. The work with this new handbook is carried out by CMR and was initiated in 2001. The intention is to release the first revision of this new handbook in 2002.

## 3. INTRODUCTION

The development of Water Fraction Meters (WFM)[2] during the last two decades has now reached a level where the low uncertainty and high reliability of the meters are considered to be in the same order of, or even better than, the method involving sampling and analysis (e.g. Karl Fisher titration), which until recently has been used to calibrate the WFMs. In fact, the uncertainty of the calibration method itself, especially the sampling method, may introduce a higher uncertainty to the meters than what is achieved by the factory calibration. Thus, today's reference techniques for calibration and adjustment are expected to limit the meter performance, and there is a need for improved and independent calibration and adjustment procedures for fiscal and allocation water fraction measurements.

Water fraction measurements with as low uncertainty as possible is motivated not only from a fiscal point of view, but also with respect to process optimisation. Generally, the transport of water costs the same as the transport of oil, causing additional increased costs in terms of increased needs for water treatment facilities and water disposal at the receiving end.

A project was therefore initiated with the following objectives:

a) Uncertainty evaluation of the available in-line WFMs: Fluenta WIOM-350 and MFI WaterCut Meter.
b) Establish a workgroup for developing a handbook for Water Fraction Meters.

Detailed analytical and technical descriptions were made by CMR for the WFMs: Fluenta WIOM-350 [4] and MFI WaterCut Meter [5]. These two meters represent the state of the art of in-line meters, and have been subject to a theoretical evaluation of the combined uncertainty in accordance with the *"Guide to the expression of uncertainty in measurement"* [6]. The two reports have been reviewed by the workgroup, and the recommendations given in the *Handbook of Water Fraction Metering* are based on these reports. The *Handbook* sets out recommendations for continuous determination of water fraction in hydrocarbon liquids, covering e.g. installation, calibration and adjustment methods, simple means for qualitatively determining flow homogeneity and a recommended WFM performance specification. The procedures and installations given in the *Handbook* have been prepared for both fiscal and allocation water fraction measurements.

On behalf of the NFOGM the workgroup issued a draft of the *Handbook* in March 2001 for comments and reviewing, and revision 1 was issued June 2001 [1]. The main findings and recommendations in the *Handbook* are described and discussed in this paper.

---

2 Water Fraction Meter: A device for measuring the phase area fractions of oil and water of a two-phase oil/water flow through a cross-section of a conduit.

## 4. TWO-PHASE OIL/WATER FLOW

The type of flow considered in the *Handbook* is oil continuous two-phase flow with water content in the range 0 - 10 %, generally less than 5%. The physical measurement principle of most of the known Water Fraction Meters require that the water concentration is the same over the entire pipe cross-section, i.e. homogeneous oil/water flow, with no velocity slip between the phases. This requires that the water phase be finely dispersed as small droplets in the continuous oil phase. In practice, however, a concentration gradient may exist, especially in horizontal lines, and ±5 % deviation from the mean can be considered as a homogeneous mixture [7].

As the flow homogeneity is important for the performance of the in-line WFMs, the *Handbook* gives a description of two prediction methods that can be used to determine whether a water-in-oil mixture is homogeneous or not in horizontal and vertical flow. One of the methods is based on a procedure given by the ISO 3171 standard [7], and it is applicable for horizontal lines. The other method is based on flow pattern models developed by Flores *et al.* [8]-[10] for vertical and inclined pipes, though it is claimed that the model is independent of inclination angle. Generally, the two methods predict that homogenisation of water in oil is promoted by high velocity, high oil viscosity, high oil density, low interfacial tension and small pipe diameter.

The turbulence, which exists naturally in a pipeline, can be sufficient to provide adequate mixing of water in the oil phase. The minimum natural turbulent energy for adequate mixing depends on the fluid flow rates, pipe diameter, water concentration and fluid properties (density, viscosity and interfacial tension).

### 4.1 Horizontal pipes

This method is based on the ISO 3171 standard [7] for predicting the degree of homogenisation in horizontal water-in-oil dispersions. Adequate oil and water mixing is, according to ISO 3171, characterised by uniform dispersion. I.e., the water concentration at the top, $C_1$, and the bottom, $C_2$, in a horizontal pipe is approximately equal. A concentration profile in a horizontal pipe can be estimated by forming a simple equation that balances the downward flux of water droplets due to gravity with the upward flux due to turbulent diffusion. By applying models for the settling velocity of water droplets and the turbulence characteristics of the flow, which is given in the ISO 3171 standard[3], it is possible to arrive at a single analytical expression for the minimum liquid velocity, $V_c$, that will maintain an oil/water mixture with a given dispersion degree $G$:

[3] The method described in the ISO 3171 standard for estimating homogeneous flow conditions is a step procedure involving numerous calculations, which may be quite elaborate. Eq. (1) above has been derived to simplify the procedure for calculating the homogeneous flow conditions.

$$V_c = K_1 \cdot G^{0.325} \cdot \sigma_{ow}^{0.39} \cdot \frac{(\rho_w - \rho_o)^{0.325}}{\rho_o^{0.283}} \cdot \frac{D^{0.366}}{\mu_o^{0.431}} \tag{1}$$

$$\beta < 10\text{-}15\,\%$$

where

$G = -\frac{1}{\ln(C_1/C_2)}$ $C_1/C_2$ is the ratio between the water concentration at the top and the bottom of the pipe. ($G$ = 10 $\Rightarrow$ $C_1/C_2$ = 0.9).

$V_c$ Critical (minimum) velocity for maintaining a dispersion degree $G$

$K_1$ Constant depending on unit system ($K_1$= 2.02 for SI units)

$\sigma_{ow}$ Interfacial (surface) tension between oil and water

$\rho_o$, $\rho_w$ Oil and water density, respectively

$D$ Inner pipe diameter

$\mu_o$ Oil viscosity

$\beta$ Volumetric water fraction in per cent

A $C_1/C_2$ ratio of 0.9 to 1.0 indicates very good dispersion, which respectively correspond to $G$ = 10 and $G \rightarrow \infty$. A ratio of 0.4 or smaller indicates poor dispersion with a high potential for water stratification.

By using Eq. (1) it is possible to calculate the critical (minimum) liquid velocity corresponding to a defined degree of dispersion when the fluid properties and the pipe diameter are known quantities. The value $G$ = 10 gives a concentration ratio 0.9, and is recommended by ISO 3171 [7]. This corresponds to ±5 % deviation from the mean concentration and it is in practise considered as a homogeneous mixture.

The handbook of water fraction metering contains diagrams where the critical velocity has been calculated and plotted for different values of the model parameters. Figure 1 shows one example where the variation in the critical velocity has been calculated and plotted as a function of the oil density for given values of the dispersion degree, pipe diameter, oil viscosity, water density and interfacial tension.

The general trend is that the minimum liquid velocity required to maintain a dispersion corresponding to a concentration ratio of 0.9 ($G$ = 10) decreases with the oil density (see Figure 1) and the oil viscosity, and increases with the interfacial tension and the inner pipe diameter.

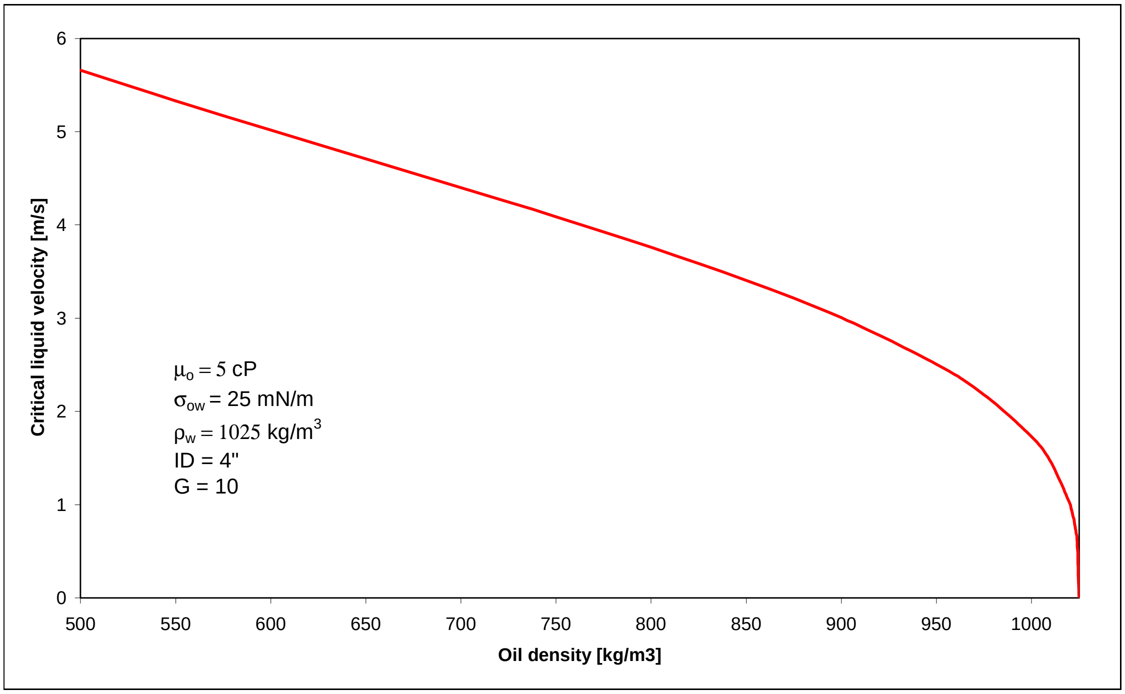



Figure 1 Critical liquid velocity as a function of the oil density in order to maintain a concentration ratio of 0.9 (G = 10) between the bottom and the top of a horizontal pipe. The flow will be homogeneous as long as the actual liquid velocity is greater than the critical velocity given by the diagram. The model is only expected to be valid for water fractions below 10-15 %.

If additional turbulence is introduced to the system in form of bends, valves, contractions etc, the critical velocity may be reduced considerable. Confer the ISO 3171 standard [7] for procedures to handle such cases.

## 4.2 Vertical and inclined pipes

In vertical pipes, the dispersion is normally better than in horizontal lines due the absence of a gravity component normal to the flow direction. In horizontal flows the gravity component in the transversal flow direction promotes stratification. In inclined pipes, the gravity plays a role depending on the inclination angle.

The approach used in horizontal pipes can also be used for vertical and inclined pipes if a very conservative estimate is desired. However, a flow pattern model for vertical and inclined pipes has recently been developed and tested by Flores *et al.* [8]-[10] in the multiphase flow loop at the University of Tulsa.

Flores *et al.* developed a mechanistic model to predict the transition to the flow regime *Very Fine Dispersion of Water in Oil* (VFD W/O). This flow regime is characterised by a flow with very small water droplets distributed in a continuous, fast moving, oil phase over the entire cross sectional area of the pipe. Hence, this flow can be considered as homogeneous mixture. The transition to VFD W/O occurs at relatively high flow rates of the oil phase and is essentially independent of inclination angle in the range 45° – 90° from the horizontal.

The transition mechanism to the VFD W/O flow regime is following: The turbulent forces in the oil phase have to be sufficiently large to overcome the interfacial tension forces of the water droplets, with the restriction of a minimum droplet diameter to keep the spherical droplet shape. Based on these criteria Flores *et al.* [8]-[9] derived a single formula for the VFD W/O flow regime transition expressed in terms of superficial oil and water velocities.

Expressing the model in terms of the mixture velocity and the water fraction instead of superficial velocities yields the following formula for the critical (minimum) velocity $V_c$ that is required to maintain a homogeneous flow in a vertical, or inclined pipe (45° – 90° from the horizontal plane):

$$V_c = K_2 \cdot \frac{\beta^{0.556}}{(100-\beta)^{1.556}} \cdot \sigma_{ow}^{0.278} \cdot \frac{(\rho_w - \rho_o)^{0.278}}{\rho_o^{0.444}} \cdot \left(\frac{D}{\mu_o}\right)^{0.111} \qquad (2)$$

$$\beta < 20 \text{ - } 25\,\%$$

where

| | |
|---|---|
| $V_c$ | Critical (minimum) velocity for maintaining homogeneous flow |
| $K_2$ | Constant depending on unit system ($K_1$= 2910 for SI units) |
| $\sigma_{ow}$ | Interfacial (surface) tension between oil and water |
| $\rho_o$, $\rho_w$ | Oil and water density, respectively |
| $D$ | Inner pipe diameter |
| $\mu_o$ | Oil viscosity |
| $\beta$ | Volumetric water fraction in per cent |

Eq. (2) are not expected to be valid beyond 20 - 25 % water content in oil, since the water droplets would not remain spherical, but forming larger droplets that causes the mixture to be inhomogeneous when the water fraction exceeds approximately 25 %. See Flores *et al.* [8] - [10] and the Handbook of water fraction metering [1] for more details about the derivation of the flow regime model.

By using Eq. (2) it is possible to calculate the critical (minimum) liquid velocity for a given water fraction when the fluid properties and the pipe diameter are known quantities. Eq. (2) is plotted in diagrams in the Handbook of water fraction metering [1] for different values of fluid properties and pipe diameter with the water fraction as a parameter. Figure 2 shows an example where the varying parameter is the oil density and the water fraction. Generally, the critical (minimum) liquid velocity that can be allowed in order to maintain homogeneous flow decreases with increasing oil density (see Figure 2) and viscosity, and increases with increasing interfacial tension and pipe diameter. These trends are similar to the trends observed in horizontal flow, though the two models are based on different physical principles.

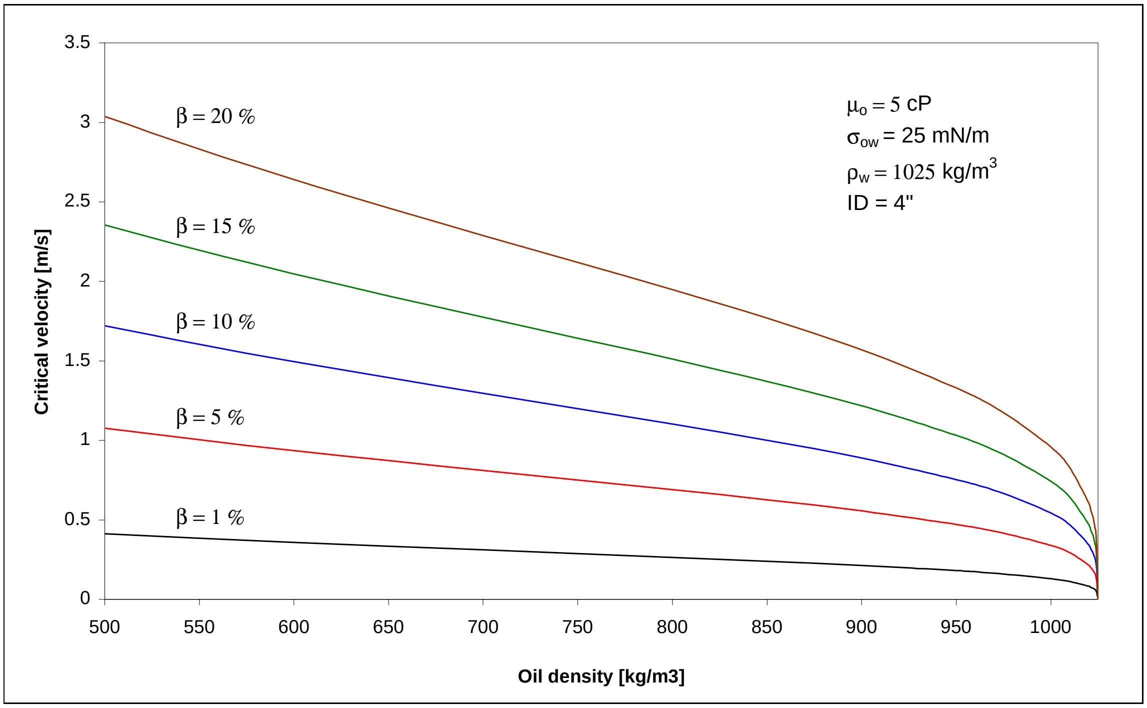



Figure 2 Critical liquid velocity for different water fractions β as a function of the oil density in vertical or inclined pipes (45° - 90° from the horizontal plane). For a given water fraction β, the flow will be homogeneous as long as the actual liquid velocity is greater than the critical velocity given by the diagram. The model is expected to be valid for water fractions below 20-25 %.

The models (Eqs. (1) and (2)) for predicting homogeneous water-in-oil mixtures in horizontal and vertical pipe flow can be applied to assess whether a water in oil mixture fulfils the requirement of WFMs regarding homogeneous flow. However, it is important to emphasise that both models are based on simplified and semi-theoretical models that may have restricted validity. A conservative approach is strongly recommended when estimating acceptable limits for adequate dispersion, i.e. use the worst-case conditions expected (lowest liquid velocity, lowest oil density, lowest oil viscosity and highest interfacial tension).

## 5. APPLICATIONS

The handbook contains a chapter where operational conditions typically experienced by on-line WFMs are discussed, with indication of the operational advantages that can be obtained by using this technology compared to traditional manual sampling and analysis. Two main areas are covered:

- Fiscal applications - sales & allocation measurement.
- Test separator applications.

The Fiscal applications discussed are typically those subject to regulations, e.g. the Norwegian Petroleum Directorate (NPD) Regulation for fiscal measurement [11]. In addition, limits on allowable water fraction are normally stated in contracts between Seller, Pipeline operator and Buyer. The section is further divided in two main groups: sales metering and fiscal/allocation metering of petroleum products. The first is characterised by fiscal metering of stabilised crude oil, either continuous operation (pipeline) or batch loading (offshore/onshore tanker loading), and the second characterised by NGL and condensate applications with typically low water content, low density, low viscosity, high vapour pressure and high thermal expansion.

## 6. PERFORMANCE SPECIFICATION

A recommended performance specification sheet is included in the handbook in order to provide a means for more uniform uncertainty specification of WFMs. Vendors are recommended to use this uncertainty specification format when quoting for fiscal applications, simplifying the comparison of different WFMs and securing that the required information is provided and documented. The recommended performance specification sheet is shown in Table 1 (The values in *italic* are sample values).

Table 1 Recommended performance specification sheet for fiscal WFMs.

| **Uncertainty** @ 95 % confidence level (k = 2) | | | | |
|---|---|---|---|---|
| 0 - *1* | % Water | ± | *0.05* | % abs. |
| *1* - 10 | % Water | ± | *5* | % of reading |

| **Repeatability** (assuming fixed **Typical process data** as suggested below) |
|---|
| *0.01* % abs. |

| **Resolution** |
|---|
| *0.005* % abs. |

| **Sensitivity** to errors in input parameters 1) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Input parameter** | **Input type** 2) | **Typical process data** | | **Input error** | **0,10 %** | **1 %** | **10 %** | **Ref.** |
| Temperature | *Live* | *45* | deg. C | +/- 1 C | *-/+ 0.0055* | *-/+ 0.0054* | *-/+ 0.0065* | |
| Pressure | *Fixed* | *30* | BARG | +/- 10 BARG | *-/+ 0.000015* | *-/+ 0.00015* | *-/+ 0.0016* | |
| Dry oil density | *N/A* | *830* | kg/m3 @ 15 C | +/- 1 kg/m3 | *N/A* | *N/A* | *N/A* | |
| Mixture density | *Live* | *810* | kg/m3 @ TP | +/- 1 kg/m3 | *-/+ 0.034* | *-/+ 0.034* | *-/+ 0.035* | |
| Water density | *N/A* | *1025* | kg/m3 @ 15 C | +/- 10 % | *N/A* | *N/A* | *N/A* | |
| Water conductivity | *Fixed* | *50* | mS/cm @ 20 C | +/- 10 % | *-/+ 0.000039* | *-/+ 0.00048* | *-/+ 0.014* | |
| | | | | | | | | |
| | | | | | | | | |

| **References** (documentation of sensitivity to errors in input parameters) | |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |

| **Available output parameters** | |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |

| **Notes** |
|---|
| 1) Effect of **Input error** on % Water value at 3 different ranges (enter *N/A* if **Input type** is *N/A*) |
| 2) **Input type** may be one of the following: |
| *Live* - Continuous digital input signal |
| *Fixed* - Values entered in menues |
| *N/A* - Input parameter not used or calculated from other input parameter |

Furthermore, the handbook defines specific requirements for uncertainty evaluation of WFMs to be used in fiscal applications with respect to combined uncertainty in measured water fraction.

Such an uncertainty evaluation must include the uncertainties of the quantities input to the WFM and the functional relationships used. This evaluation should also include the implementation of the models and measurement procedures in the WFM, in order to consider the meter as it really operates in a fiscal application. The uncertainty calculations must be performed according to the principles of the *ISO-Guide* [6].

In addition to traditional quantitative uncertainty evaluation, it is required to perform an evaluation (quantitative if possible, otherwise qualitative) of the suitability of the technology for use in fiscal applications, and to consider the influence on the WFM by different unwanted flow effects. Such unwanted effects may be free gas, salinity variations, in-homogeneity, scaling/wax, or other relevant factors.

## 7. INSTALLATION

The main requirement for installation of WFMs is to achieve an automatic and continuous measure of the water content of the stream for all flow rates. In general, a WFM can be installed in horizontal or vertical pipes, and these two installation methods are in principle equal. However, the necessary fluid velocity required for adequate oil and water mixing is less with vertical installation than horizontal (see section 4). Field calibration routines have the possibility to have a simpler operation in vertical installations, but may require a platform for easy maintenance and service, as there shall be access to all instruments.

Different philosophies regarding installation of instrumentation systems will be part of the basis for selection of installation type, e.g. whether emphasizing given types of maintenance or measurement comparison philosophies. However, the handbook describes a wide range of important issues to be regarded when installing a WFM in a fiscal application, and three types of general installations are discussed along with their advantages and disadvantages. These three general types are:

1. WFM installed up-/downstream of the metering station.
2. WFM installed up-/downstream of a flow meter in a meter run.
3. WFM installed in a fast loop.

The handbook describes three different configurations of the type WFM installed up-/downstream of a metering station: 1) Continuous comparison with by-pass loop, 2) Series installation for continuous metering and comparison and a 3) master solution. Sketches of these three configurations are shown in Figure 3 to Figure 5, respectively, while Figure 6 and Figure 7 show examples of the two other types of installations.

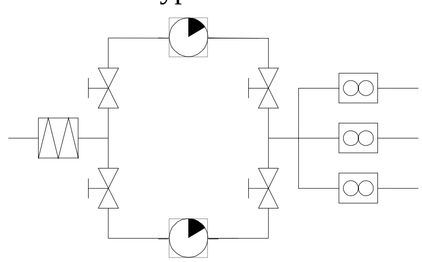


Figure 3 Water Fraction Meter upstream the metering station. Continuous comparison with by-pass loop.

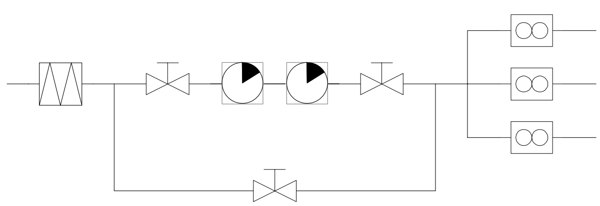


Figure 4 Water Fraction Meters installed upstream the metering station for continuous metering and comparison.

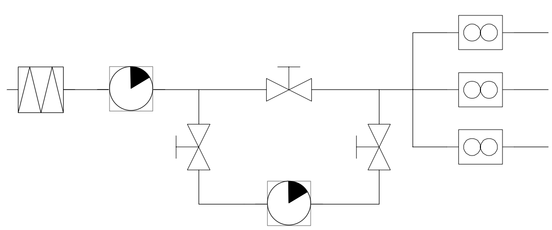


Figure 5 Water Fraction Meter upstream the metering station. Master solution.

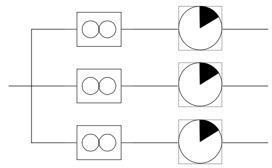


Figure 6 Water Fraction Meter in each meter run.

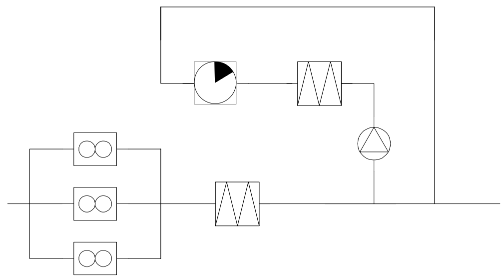


Figure 7 Water Fraction Meter downstream the metering station.

It should be emphasized that the installation type shown in Figure 7 is not in accordance with the recommendations for fiscal applications set out in NORSOK standard I-105, paragraph 6.1.3 [12]. For installations of the type shown in Figure 7 the by-pass sampling may cause an additional uncertainty. Hence, this type of installation may be considered for non-fiscal applications where slightly increased measurement uncertainty is acceptable.

## 8. FIELD CALIBRATION

As mentioned, the development of new improved and independent calibration and adjustment procedures for fiscal and allocation water fraction measurements has been one of the main targets of the workgroup. Hence, a new procedure for field calibration avoiding the use of water fraction determination by means of in-line sampling and analysis is presented. Manufacturers may recommend specific ways of field calibration and adjustment, and the handbook covers field calibration in general terms.

During a calibration of a WFM the manufacturer or operator will perform certain operations in order to establish the relationship between measured response from the WFM and a set of certified reference materials. For WFM's covered by this handbook certified reference materials will typically be non-conducting media with different permittivity values (air, oil or similar).

The purpose of the field calibration is to verify that the performance of the WFM is still within the acceptable level of uncertainty. The manufacturer should establish a procedure that describes how this task can be performed with the WFM still installed in the field. The calibration certificate shall specify acceptance criteria for relevant parameters (primary variable, e.g. frequency or permittivity) and their corresponding uncertainty in terms of water fraction.

This handbook recommends two levels of field calibration:

1. Intermediate Calibration - can be performed with short intervals, typically on a monthly basis.
2. Main Calibration - is in all respects a full calibration, identical or close to a factory calibration.

Historical data may form the basis for a decision on alternative intermediate calibration intervals, and it will typically be a one- or two-point calibration. It will enable the operator to determine if the performance of the WFM is acceptable or not. If the intermediate calibration is not acceptable, a main calibration should be performed.

A main calibration will typically be performed on a yearly basis. Calibration in the field may be possible provided that the operator has access to calibration reference standards or materials (calibration oils or similar), and that the required traceability of these standards and supporting calibration equipment are met.

## 9. ADJUSTMENT

If the result from main calibration is not acceptable, this may indicate the need for adjustment. Adjustment of the meter may comprise software, mechanical and/or electrical modifications. For example this may require filling the sensor unit with liquids of known properties (reference materials).

Traceable calibration certificates are required for equipment, reference standards or materials used during calibration and adjustment.

## 10. CONCLUSION

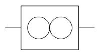
The major intention and motivation for starting the work with the *Handbook of water fraction metering* has been to arrive at new improved and independent procedures for calibration and adjustment of water fraction meters in fiscal applications. The work with, and release of, the handbook presented in this paper comprises a large step towards this goal, where new calibration and adjustment procedures and recommendations for continuous determination of water fraction in hydrocarbon liquids are published.

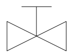
## 11. ACKNOWLEDGEMENTS

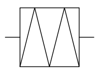
The authors would like to express great appreciation to the workgroup participants Eivind Dykesteen (Fluenta, now Roxar Flow Measurement AS), Endre Jacobsen (Statoil), Hallvard Tunheim (Norsk Hydro), Morten Brandt (Fluenta, now Roxar Flow Measurement AS), Sidsel E. Corneliussen (BP Norge), Ottar Vikingstad (Roxar, now Roxar Flow Measurement AS), for their important contributions to the handbook and financial support. The authors would also like to thank NFOGM and Svein Neumann (PPCon, Stavanger) for financial support for developing this handbook as part of the NFOGM handbook series.

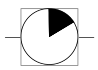
## 12. SYMBOLS

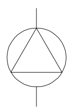
The following symbols are used in the schematic drawings, where the symbol for the WFM is proposed as a new symbol for WFMs by the workgroup.


Flow meter


Valve


Static mixer


Water Fraction Meter


Pump

## 13. REFERENCES


[1] Norwegian Society for oil and Gas Measurement (NFOGM): *Handbook of water fraction metering.* Rev. 1., June 2001, http://www.nfogm.no/

[2] Norwegian Society for Oil and Gas Measurement: *Handbook of Multiphase Metering*, 1995 http://www.nfogm.no/

[3] Norwegian Society for Oil and Gas Measurement: *Handbook of uncertainty calculations – Fiscal metering stations*, Rev. 1., 1999, ISBN 82-91341-28-1, http://www.nfogm.no/.

[4] Albrechtsen R. A., Dahl E. O.: *Uncertainty evaluation, Fluenta WIOM 350*, Christian Michelsen Research, Report No.: CMR-00-A10003, February 2001.

[5] Dahl E. O., Albrechtsen R. A.: *Uncertainty evaluation, MFI WaterCut Meter*, Christian Michelsen Research, Report No.: CMR-00-A10002, February 2001.

[6] ISO (International Organisation for Standardisation): *Guide to the expression of uncertainty in measurement.* On behalf of BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML. ISBN 92-67-10188-9, 1995.

[7] ISO 3171: *Petroleum liquids – Automatic pipeline sampling.* 2$^{nd}$ edition, 1988.

[8] Flores, J. G.: *Oil-water flow in vertical and deviated wells.* PhD thesis. University of Tulsa, USA, 1997.

[9] Flores, J. G., Chen, T., Sarica, C. & Brill, J. P.: *Characterization of oil-water flow patterns in vertical and deviated wells.* SPE 38810. Annual technical Conference and Exhibition, San Antonio, USA, 5-8 Oct 1997.

[10] Flores, J. G., Sarica, C., Chen, T. & Brill, J. P.: *Investigation of holdup and pressure drop behaviour for oil-water flow in vertical and deviated wells.* Journal of Energy Resources Technology, ASME, Vol. 120, pp 8-14, 1998.

[11] Norwegian Petroleum Directorate (1999), *Regulations relating to fiscal measurement of oil and gas etc.*,47 pp., English and Norwegian text. ISBN 82-7257-598-1.

[12] NORSOK Standard I-105 (1998): *Fiscal measurement systems for hydrocarbon liquid*, Rev. 2.