
Measurement of multiphase fluid flow

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 28, *Petroleum and related products, fuels and lubricants from natural or synthetic sources*, Subcommittee SC 2, *Measurement of petroleum and related products*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The need for multiphase flow measurement in the oil and gas production industry has been evident for many years. Multiphase meters have been developed since the early eighties by research organizations, meter manufacturers, oil and gas production companies and others: different technologies and various combinations of technologies have been employed. Some technologies have been abandoned, whereas other meters have become commercially available: the number of applications and users is increasing.

The first Norwegian Society for Oil and Gas Measurement (NFOGM) handbook of multiphase metering (hereafter simply called the Handbook) was published in 1995 (see Reference [16]). Since then, multiphase flow measurement has matured. New applications of multiphase flow meters (MPFMs) have emerged, from simply being a replacement for the conventional test separator shared by a number of wells, towards more compact and low-cost meters with application on a one-per-well basis and installations on shore, topside and subsea.

Since multiphase flow metering technologies and applications had developed significantly since 1995, NFOGM updated the Handbook in 2003-5 to reflect these improvements and to make it the main guide for state-of-the-art multiphase flow measurement. That work was financed by NFOGM and The Norwegian Society of Chartered Technical and Scientific Professionals (Tekna).

Following calls from industry to produce an ISO document, NFOGM very generously allowed ISO to use the Handbook as the basis for this document.

This document is intended to serve as guidance for users, designers and manufacturers of multiphase metering systems.

The document can also serve as an introduction to newcomers in the field of multiphase flow measurement, with definition of terms and a description of multiphase flow in closed conduits being included.

Even if the individual flow rates of each constituent are of primary interest, often their ratios (e.g. water liquid ratio, gas oil ratio) are useful as operational parameters. Total hydrocarbon mass flow rate can be required in particular applications. Constituents other than oil, gas and water flow rates or ratios of these are not dealt with in this document.

The performance of a multiphase flow meter in terms of uncertainty, repeatability and range is of great importance, as this enables the user to compare different meters and evaluate their suitability for use in specific applications. [Clause 8](#) covers this issue in detail and proposes standard methods to describe performance.

Testing and qualification of MPFMs are required to verify performance. Guidance is provided to help optimize the outcome of such activities. Since MPFMs measure at line conditions, the primary output is individual flow rates and fractions at actual conditions (i.e. at the operating pressure and temperature). Conversion of these actual flow rates to flow rates at standard conditions requires knowledge of composition and mass transfer between the liquid and the gas phases, which can require sampling.

The clauses logically proceed from an introduction to multiphase flow measurement, via selection of technology, design considerations and performance specifications, to field installation and commissioning, and finally the operation of MPFMs.

The definitions in [Clause 3](#) have been extended and split into definitions relating to multiphase flows in a closed conduit (see [3.1](#)) and definitions relating to metrology that can be useful in characterizing the performance of a multiphase flow meter.

[Clause 5](#) provides a general introduction to multiphase flows. This clause includes extended descriptions of flow regimes and slip effects in multiphase flows.

[Clause 6](#) covers the aims of multiphase flow measurement, giving the reasoning for selection, installation and operation of multiphase flow metering systems in various applications.

[Clause 7](#) presents guidelines for designing MPFM installations using the two-phase flow map and the composition map.

Standardized performance specification of MPFMs is essential, both for comparison of measuring ranges and measurement uncertainties, but also for more efficient selection of technology ([Clause 8](#)).

[Clause 9](#) covers all aspects of testing, calibration and adjustment of MPFMs.

[Clause 10](#) provides recommended procedures and practices for field installation and commissioning of MPFMs. Although MPFMs cannot easily be sent to a test facility for recalibration, there is a need for regular testing to verify the meter performance.

The purpose of [Clause 11](#) is to provide guidelines on how to verify meter performance in the field during operation, assuming no test separator is readily available.

[Annex A](#) includes brief descriptions of the most commonly used measurement principles in MPFMs currently available on the market. Guidance on selection of technology and maintenance requirements is also provided. [Annex B](#) gives relevant information on hydrocarbon phase behaviour.

Aspects of safety are not dealt with in this document. It is the responsibility of the user to ensure that the system meets applicable safety regulations.

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Measurement of multiphase fluid flow

1 Scope

This document establishes a common basis for, and assistance in, the classification of applications and multiphase meters, as well as guidance and recommendations for the implementation and use of such meters.

The so-called in-line multiphase flow meters (MPFMs) that directly measure the oil, water and gas flow rates, as well as the partial- and full-separation MPFMs are the main focus of this document. Conventional two- or three-phase separators are not included in this document. Only limited reference is made to wet-gas meters, since although wet-gas flow is a subset of multiphase flow, wet-gas measurement is covered by ISO/TR 11583 and ISO/TR 12748.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1 Terms related to multiphase flow metering

3.1.1

actual conditions

meter *in-situ* process operating conditions of pressure and temperature, at which measured flow rates are reported, without conversion to a standard or reference fluid state

3.1.2

composition map

graph with *gas volume fraction* (3.1.9) and *water liquid ratio* (3.1.42) along the x- and y-axis, respectively

Note 1 to entry: Both the GVF and WLR are at *actual conditions* (3.1.1).

3.1.3

dispersed flow

flow where a particular *phase* (3.1.23) is broken up into multiple small bubbles or droplets carried within the body of another phase

Note 1 to entry: Examples of such flows are bubble flow and mist flow.

3.1.4

emulsion

colloidal mixture of two immiscible fluids, one being dispersed in the other in the form of fine droplets

Note 1 to entry: In multiphase fluids, discrimination should be made between oil-in-water emulsion and water-in-oil (3.1.21) emulsion; they respond differently to permittivity measurements.

3.1.5

flow regime

dynamic spatial and velocity distribution of flowing fluid *phases* (3.1.23) within a conduit

Note 1 to entry: This is also known as flow pattern.

Note 2 to entry: For example, in two-phase oil/water stratified flow in horizontal pipes free water occupies the bottom of the conduit with *oil* (3.1.21) or oil/water mixture flowing above.

3.1.6

gas

hydrocarbons in the gaseous state at the prevailing temperature and pressure

3.1.7

gas oil ratio

GOR

ratio of *gas* (3.1.6) *volume flow rate* (3.1.38) and *oil* (3.1.21) *volume flow rate*

Note 1 to entry: Both *volume flow rates* should be converted to the same pressure and temperature [generally at *standard conditions* (3.1.35)]. GOR is expressed in volume per volume, F_{GOR} , e.g. scft/bbl or m^3/m^3 .

3.1.8

gas void fraction

ratio of the cross-sectional area in a conduit occupied by the *gas* (3.1.6) *phase* (3.1.23) and the cross-sectional area of the conduit

Note 1 to entry: This is also known as gas hold-up.

3.1.9

gas volume fraction

GVF

gas (3.1.6) *volume flow rate* (3.1.38), relative to the multiphase *volume flow rate*, at *actual conditions* (3.1.1)

Note 1 to entry: The GVF is normally expressed as a fraction or percentage.

3.1.10

homogeneous multiphase flow

multiphase flow in which all *phases* (3.1.23) are evenly distributed over the cross section of a closed conduit

Note 1 to entry: A homogeneous multiphase flow is, therefore, one in which the composition is the same at all points in the cross section and where the liquid and *gas* (3.1.6) velocities are the same (no-slip). Note that bubbly multiphase *flow regimes* (3.1.5) are probably the best approximation to homogeneous multiphase flow.

3.1.11

intermittent flow

flow characterized by being non-continuous in the axial direction, that is, exhibiting unsteady *phase* (3.1.23) hold-up locally

Note 1 to entry: Examples of such flows are plug, churn and slug flow (see [Figures 1](#) and [2](#)): the *flow regimes* (3.1.5) are all hydrodynamic (see [5.1](#)) two-phase gas-liquid flow regimes.

3.1.12

liquid hold-up

ratio of the cross-sectional area in a conduit occupied by the liquid *phase* (3.1.23) and the cross-sectional area of the conduit

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3.1.13 liquid volume fraction LVF

liquid volume flow rate (3.1.38), relative to the multiphase volume flow rate, at *actual conditions* (3.1.1)

Note 1 to entry: The LVF is normally expressed as a fraction or percentage.

3.1.14 Lockhart-Martinelli parameter

X

square root of the ratio of the liquid inertia to the *gas* (3.1.6) inertia if the *phases* (3.1.23) flowed alone at *actual conditions* (3.1.1), that is

$$X = \frac{q_{V,\text{liquid}}}{q_{V,\text{gas}}} \sqrt{\frac{\rho_{\text{liquid}}}{\rho_{\text{gas}}}} = \frac{1-F_{\text{GVF}}}{F_{\text{GVF}}} \sqrt{\frac{\rho_{\text{liquid}}}{\rho_{\text{gas}}}}$$

where

$q_{V,\text{liquid}}$ is the volume flow rate of the liquid;

$q_{V,\text{gas}}$ is the volume flow rate of the gas;

ρ_{liquid} is the density of the liquid;

ρ_{gas} is the density of the gas;

F_{GVF} is the GVF.

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Note 1 to entry: The Lockhart-Martinelli parameter has a long and complicated history. There are several different definitions for this parameter, and they are not equivalent. This includes the original definition by Lockhart-Martinelli which is different from the definition stated above. The definition supplied in this document is now commonly used. Nevertheless, this issue continues to cause confusion in the industry. The different definitions are described in detail with historical context in References [30] and [13].

Note 2 to entry: In the second formula above, the relationship of the Lockhart-Martinelli number and the *GVF* (3.1.9) is a function of the density ratio.

Note 3 to entry: An increasing value of X means an increasing liquid content or wetness of the flow.

3.1.15 mass flow rate

mass of fluid flowing through the cross section of a conduit in unit time

3.1.16 measuring envelope

areas in the *two-phase flow map* (3.1.37) and the *composition map* (3.1.2) in which the *MPFM* (3.1.18) performs according to its specifications

3.1.17 multiphase flow

flow consisting of two or more *phases* (3.1.23) flowing simultaneously in a closed conduit

Note 1 to entry: This document deals in particular with multiphase flows of *oil* (3.1.21), water and *gas* (3.1.6) in the entire region of 0 % – 100 % of the *GVF* (3.1.9) and 0 % – 100 % of the *WLR* (3.1.42).

3.1.18
multiphase flow meter
MPFM

device for measuring the individual *oil* (3.1.21), water and *gas* (3.1.6) flow rates in a *multiphase flow* (3.1.17)

Note 1 to entry: The total package of measurement devices for composition and velocity, including possible conditioning unit, should be considered as an integral part of the meter.

3.1.19
multiphase mixture velocity

ratio of the *multiphase volume flow rate* (3.1.20) and the cross-sectional area of the conduit

Note 1 to entry: This is a fictitious velocity: only in *homogeneous multiphase flow* (3.1.10) does this velocity have a meaningful value. Multiphase mixture velocity is the sum of *gas* (3.1.6) superficial velocity and liquid superficial velocity.

3.1.20
total volume flow rate
multiphase volume flow rate

total volume flowing through the cross-sectional area of a conduit per unit time

3.1.21
oil

hydrocarbons in the liquid state at the prevailing temperature and pressure conditions

3.1.22
oil-continuous flow

flow in which water is distributed as droplets surrounded by *oil* (3.1.21)

Note 1 to entry: Electrically, the mixture acts as an **insulator**.

3.1.23
phase

one constituent in a mixture of several

Note 1 to entry: In particular, the term refers to *oil* (3.1.21), *gas* (3.1.6) or water in a mixture of any number of the three. It is recognized that the terminology of the multiphase industry is different from that in much of science.

3.1.24
phase area fraction

cross-sectional area locally occupied by one of the *phases* (3.1.23) of a *multiphase flow* (3.1.17), relative to the cross-sectional area of the conduit at the same local position

3.1.25
phase flow rate

amount of one *phase* (3.1.23) of a *multiphase flow* (3.1.17) flowing through the cross section of a conduit in unit time

Note 1 to entry: The phase flow rate may be specified as *phase volume flow rate* (3.1.38) or as *phase mass flow rate* (3.1.15).

3.1.26
phase volume fraction

phase (3.1.23) *volume flow rate* (3.1.38) of one of the phases of a *multiphase flow* (3.1.17), relative to the *multiphase volume flow rate* (3.1.20), at *actual conditions* (3.1.1)

3.1.27
production envelope

areas in the *two-phase flow map* (3.1.37) and the *composition map* (3.1.2) that are determined by a number of well trajectories or specified as possible flow rates and compositions that occur in a certain application

3.1.28 proving

set of operations that establish, under specified conditions, the relationship between the values of quantities indicated by a device and the corresponding values as determined by a traceable reference device (proving system)

3.1.29 reconciliation

process whereby pieces of information that include some redundancy are matched together to satisfy constraint formulae

Note 1 to entry: In *oil* (3.1.21) and *gas* (3.1.6) production, reconciliation is the process in which oil, water and *gas* (3.1.6) production figures that have not been measured with high *accuracy* (3.2.1) are recalculated to match production figures that have been measured with high accuracy (e.g. custody transfer measurements).

3.1.30 reference conditions

conditions, in terms of pressure and temperature, at which fluid properties or *volume flow rates* (3.1.38) are expressed

3.1.31 salinity

amount of dissolved salts that are present in water

Note 1 to entry: Salinity is normally expressed in units g/kg.

Note 2 to entry: Sodium and chloride are the predominant ions in seawater, and the concentrations of magnesium, calcium, and sulfate ions are also substantial.

3.1.32 slip

flow condition that exists when the *phases* (3.1.23) have different average velocities

Note 1 to entry: The slip may be quantitatively expressed by the average phase velocity difference between the phases. See 5.3.

3.1.33 slip ratio

ratio between two phase-average velocities

Note 1 to entry: See 5.3.

3.1.34 slip velocity

phase (3.1.23) velocity difference between two phases

Note 1 to entry: See 5.3.

3.1.35 standard conditions

conditions, in terms of pressure and temperature, at which fluid properties or *volume flow rates* (3.1.38) are expressed

EXAMPLE 101,325 kPa and 15 °C.

3.1.36 superficial phase velocity

quotient of the *phase* (3.1.23) *volume flow rate* (3.1.38) and the pipe cross-sectional area

3.1.37

two-phase flow map

graph with superficial velocities of *gas* (3.1.6) and liquid along the x- and y-axes, respectively

Note 1 to entry: An example is the Mandhane flow map (see Reference [37]) for horizontal *multiphase flow* (3.1.17).

Note 2 to entry: Alternatively, the actual *gas* (3.1.6) and actual liquid *volume flow rates* (3.1.38) can be used.

3.1.38

volume flow rate

volume of fluid flowing through the cross section of a conduit in unit time

3.1.39

water-continuous flow

flow in which *oil* (3.1.21) is distributed as droplets surrounded by water

Note 1 to entry: Electrically, the mixture acts as a conductor.

3.1.40

water cut

WC

water volume flow rate (3.1.38), relative to the total liquid volume flow rate [*oil* (3.1.21) and water], both converted to volumes at standard pressure and temperature

Note 1 to entry: The WC is normally expressed as a percentage.

3.1.41

water fraction meter

WFM

device for measuring the *phase* (3.1.23) area fraction of water of a *multiphase flow* (3.1.17) through a cross section of a conduit

Note 1 to entry: The *phase area fraction* (3.1.24) is expressed as a percentage of the total pipe area.

3.1.42

water liquid ratio

WLR

water volume flow rate (3.1.38), relative to the total liquid volume flow rate [*oil* (3.1.21) and water], at *actual conditions* (3.1.1)

3.1.43

water volume fraction

WVF

water volume flow rate (3.1.38), relative to the multiphase volume flow rate, at *actual conditions* (3.1.1)

Note 1 to entry: The WVF is normally expressed as a fraction or percentage.

Note 2 to entry: A small absolute *error* (3.2.4) in the value of the WVF may be a large relative error, e.g. where the measured and reference values of the WVF are 1 % and 0,5 % respectively, the absolute error is only 0,5 %, but the relative error is 100 %; in this example the measured water volume flow rate is twice the reference value although the absolute error is only 0,5 %.

Note 3 to entry: $F_{WVF} = F_{WLR} \times F_{LVF} = F_{WLR} \times (1 - F_{GVF})$

Note 4 to entry: where

F_{WVF} is the WVF;

F_{LVF} is the LVF;

F_{WLR} is the WLR.

3.1.44**well trajectory**

production profile of a well over time in a *two-phase flow map* (3.1.37) and *composition map* (3.1.2)

3.1.45**wet gas**

gas (3.1.6) containing free liquids

Note 1 to entry: Generally wet gases are defined as gas/liquid systems with a *Lockhart-Martinelli parameter* (3.1.14) lower than approximately 0,3.

Note 2 to entry: Hydrocarbon gas that contains heavy components that condense during further processing (but at a particular pressure and temperature, behaving as a pure gas) is not considered to be a wet gas from a measurement point of view.

3.2 Terms related to metrology**3.2.1****accuracy**

closeness of agreement between a measured quantity value and a true quantity value of a *measurand* (3.2.6)

Note 1 to entry: The concept 'measurement accuracy' is not a quantity and is not given a numerical quantity value. A measurement is said to be more accurate when it offers a smaller measurement *error* (3.2.4).

[SOURCE: JCGM-VIM:2012, 2.13]

3.2.2**adjustment**

set of operations carried out on a measuring system so that it provides prescribed indications corresponding to given values of a quantity to be measured

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Note 1 to entry: Types of adjustment of a measuring system include zero adjustment of a measuring system, offset adjustment, and span adjustment (sometimes called gain adjustment).

Note 2 to entry: Adjustment of a measuring system should not be confused with calibration, which is a prerequisite for adjustment.

Note 3 to entry: After an adjustment of a measuring system, the measuring system must usually be recalibrated.

[SOURCE: JCGM-VIM:2012, 3.11]

3.2.3**calibration**

operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a *measurement result* (3.2.11) from an indication

Note 1 to entry: A calibration may be expressed by a statement, calibration function, calibration diagram, calibration curve, or calibration table. In some cases, it may consist of an additive or multiplicative correction of the indication with an associated measurement *uncertainty* (3.2.13).

Note 2 to entry: Calibration should not be confused with *adjustment* (3.2.2) of a measuring system, often mistakenly called "self-calibration", nor with verification of calibration.

Note 3 to entry: Often, the first step alone in the above definition is perceived as being calibration.

[SOURCE: JCGM-VIM:2012, 2.39]