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Natural Gas — Wet gas flow measurement in natural gas operations

Gaz naturel — Mesurage du débit de gaz humide dans les opérations de gaz naturel

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Foreword

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The committee responsible for this document is ISO/TC 193, *Natural Gas*, Subcommittee SC 3, *Upstream Area*.

Introduction

Oil and gas companies started developing Wet Gas Flow Meters (WGFMs) and Multiphase Flow Meters (MPFMs) through extensive R&D activities in the late 1980s. During this period, WGFMs and MPFMs were typically perceived as two distinct technologies for different applications: MPFMs were designed for liquid continuous flow conditions and WGFMs were designed for gas continuous flow conditions. In recent years, however, the operating range of these two technologies has increasingly overlapped, blurring the distinction between a WGFM and MPFM. As wet gas flow is presently considered a subset of multiphase flow, a WGFM is an MPFM that specializes in gas-dominant multiphase flow conditions. In this Technical Report, such technologies will be referred to as WGFMs.

There are many factors that contributed in the decision to replace a separator with a WGFM, with each application warranting careful consideration. A well-designed and maintained separator working within an appropriate flow condition range should produce accurate flow measurements. A primary concern for oil and gas companies was to reduce costs by replacing complex and bulky test separators, as well as to further simplify the upstream infrastructure, in particular for offshore and subsea projects. WGFMs typically require lower capital[1]) and operational[2]) expenditures than fully equipped test separators. More savings in CapEx may be achieved by omitting dedicated test lines in satellite developments. In addition, there is a significant benefit for offshore developments, in terms of weight and space conservation, by using the much smaller footprint of WGFMs.

Due to various operational problems, a conventional test separator does not continuously provide accurate and reliable well test data, giving only relevant information when the well is switched to the test separator. With the use of WGFMs testing well production more frequently or even continuously becomes possible. WGFM developments and extensive testing over the last two decades have resulted in WGFM technology that is a viable alternative to a test separator. Modern WGFMs now offer continuous well monitoring (per installation on individual wells).

WGFM technology is an attractive option for multiphase wet gas flow measurement. Over the last two decades, some WGFMs have been developed from prototypes into very mature, robust, advanced, and field-proven measurement devices, increasing their application scope. Although originally intended for use mainly in reservoir and well production allocations, WGFMs have evolved into a technology that spans even fiscal product allocation. In the latter case, the output of a WGFM is used to determine money transactions between operating companies or between an operating company and a host government.

This Technical Report focuses on the measurement of wet gas flow, i.e. terminology, models, and principles, and the design, implementation, testing, and operation of WGFMs.

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1)   Capital expenditure (CapEx) or costs for purchasing and installing a WGFM/MPFM includes all hardware to operate the WGFM (data transmission, verification facilities, sampling arrangements, etc.)

2)   Operating expenditure (OpEx) or costs to operate a WGFM/MPFM (maintenance, verification processes, sampling for fluid properties, etc.)

Natural Gas — Wet gas flow measurement in natural gas operations

1 Scope

This Technical Report describes production flow measurement of wet natural gas streams with WGFMs in surface and subsea facilities. Wet natural gas streams are gas-dominated flows with liquids like water and/or hydrocarbon liquids[3) (see 2.67 for a detailed definition). This Technical Report defines terms/symbols, explains the various concepts, and describes best practices of wet gas flow meter design and operation. It addresses metering techniques, testing, installation, commissioning, and operation practices such as maintenance, calibration, and verification. It also provides a theoretical background of this comprehensive, challenging and still evolving measurement technology.

There are four general methods in measuring wet natural gas flow. Each approach is detailed below.

— Single-phase gas flow meter with correction factor: Uses a single-phase gas flow meter (often a conventional gas flow metering device) with a correction factor for the effect of liquid on the metering system. In these cases, the liquid flow rate required to determine the correction factor, should be estimated from an external source.

— Two-phase WGFM: The gas and liquid (both water and hydrocarbon liquid combined) flow rates are predicted with no additional external information regarding the liquid flow rate required. This is generally known as a two-phase WGFM and will be referred to in this Technical Report simply as WGFM.

— WGFM: A flow meter that measures the gas and liquid flow rates, and also the gas, water and hydrocarbon liquid ratios (or "phase fractions") with no external information required regarding the liquid flow rate.

— Phase separation/Measurement after phase separation: This traditional and conventional method of wet gas flow metering uses a two- or three-phase separator with single-phase flow meters measuring the outgoing single-phase flows.

The first three of these methods, which emerged in the last two decades, may be described as in-line wet gas flow metering, i.e. wet gas flow measurement is executed with WGFMs without separating the gas and liquid phases. This Technical Report discusses in detail these first three methods. Several best practice documents have already been issued to describe, among other topics, wet gas flow measurement[9][10][11][12].

The last method is more conventional and describes wet gas flow measurement after the gas and liquid phases have been separated. Wet gas meters can be used in multiphase flow metering systems that utilize partial separation technologies. This method is only briefly discussed in this Technical Report.

2 Terms and Definitions

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

2.1
adjustment
act of altering an instrument's performance in any way, e.g. software, mechanical or electrical modifications, in order for the instrument's indication to match the reference values indicated by a test stand

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3)   In this Technical Report, the term hydrocarbon liquid includes both oil and condensed hydrocarbons.

2.2
calibration
set procedure under specified conditions where the output/performance of an instrument is checked against a reference, usually a test stand

Note 1 to entry: The result of calibration determines the deviation between the instrument indication and the references. This deviation can assign an uncertainty value to the measurand and could indicate a requirement for an adjustment.

2.3
capacitance
the ability of a body to store an electrical charge

Note 1 to entry: Any object that can be electrically charged exhibits capacitance (e.g. a parallel-plate capacitor).

2.4
composition map
map with *water liquid ratio* or *WLR* (2.63) along the horizontal axis (0 % ≤ WLR ≤ 100 %) and *gas volume fraction* or *GVF* (2.22) along the vertical axis (0 % ≤ GVF ≤ 100 %); used to show WGFM operating envelopes and/or *well trajectories* (2.65)

Note 1 to entry: The combination of a *two-phase flow rate map* (2.59) and a composition map is beneficial to evaluate WGFM applications. See 8.1.3.

2.5
conductivity
ability of a material to conduct electrical current

Note 1 to entry: In isotropic material, conductivity is also the reciprocal of resistivity, sometimes called specific conductance.

2.6
density ratio
DR
ratio of gas density to liquid density at line conditions, or

$$\mathrm{DR} = \rho_g / \rho_l$$

Note 1 to entry: In multiphase wet gas flows, the liquid density is typically considered to be the density of a homogenous mix of liquid components. See Formula (6).

2.7
dry gas
fluid that is solely in a gaseous phase

Note 1 to entry: The mix of fluid components flowing may cause the gas to have a finite relative humidity but the flow at the flow meter is only in a gaseous phase.

2.8
emulsion
colloid substance consisting of water and hydrocarbon liquid mixes

Note 1 to entry: Emulsions can be water continuous or hydrocarbon liquid continuous, as these have different characteristics.

2.9
equation of state
EoS
equations that relate the properties of a given substance to its thermodynamic condition

2.10
film thickness
thickness of the liquid film in annular flow

2.11
flow regime
flow pattern
physical dispersion of phases of a two-phase flow (either wet gas or multiphase) in a conduit

Note 1 to entry: For a particular case of wet gas flow, the flow regime descriptions usually discuss gas and liquid interaction only, with no individual mention of water and hydrocarbon liquid.

2.12
flow quality
dryness fraction
gas mass fraction
GMF
x
ratio of the gas mass flow rate to the total mass flow rate, or

$$x = \text{GMF} = \frac{\dot{m}_g}{\dot{m}_g + \dot{m}_l}$$

Note 1 to entry: In multiphase wet gas flows, the liquid flow rate is typically considered to be the sum of the liquid components (for example, hydrocarbon liquids, water and liquid chemical inhibitors).

2.13
flow regime (pattern) map
graph describing the wet gas flow regime across a range of flow conditions

Note 1 to entry: There is no agreed form for flow regime maps, and different maps can use different parameters on the graph axes. Gas and liquid superficial velocities are common choices. Flow regime maps are almost always created from experimental observation, and sometimes include theoretical considerations.

Note 2 to entry: to entry : Flow regime transitional boundaries/regions should be taken as approximations.

2.14
fluid
any substance that continuously deforms under a continuous infinitesimal sheer force.

2.15
foams
mixture of gas and liquids, where the gas is held in a liquid structure

Note 1 to entry: With wet gas, this tends to be more prevalent with gas/water flows than gas/liquid hydrocarbon flows due to the higher interfacial tension of water compared with that of liquid hydrocarbons.

2.16
free liquid
liquid components in a wet gas flow that are in a liquid form, not including evaporated liquid held as vapour state with the gaseous component of flow.

2.17
gamma rays
electromagnetic radiation of a kind arising from the radioactive decay of an atomic nucleus

2.18
gas
gaseous component of a wet gas flow, which includes any liquid vapour with relative humid gases

2.19
gas densiometric Froude number
square root of the ratio of the gas flow inertia (if it were to flow alone) to the liquid's weight, or

$$Fr_g = \sqrt{\frac{\text{Superficial Gas Inertia Force}}{\text{Liquid Gravity Force}}} = \frac{\bar{U}_{sg}}{\sqrt{gD}}\sqrt{\frac{\rho_g}{\rho_l - \rho_g}} = \frac{m_g}{A\sqrt{gD}}\sqrt{\frac{1}{\rho_g(\rho_l - \rho_g)}}$$

2.20
gas expansion factor
term used to indicate the volume change in gas between two different conditions, which may include standard conditions

2.21
gas to oil ratio
GOR
ratio of gas to hydrocarbon liquid volume flow rate

Note 1 to entry: GORs are stated at standard conditions, but may commonly use different units (e.g. sm^3/sm^3 or MMscf/bbls) resulting in different numerical values.

2.22
gas volume fraction
GVF
ratio of gas to total fluid volume flow rate at actual flow conditions, or

$$\text{GVF} = \frac{\dot{Q}_g}{\dot{Q}_g + \dot{Q}_l}$$

Note 1 to entry: The GVF is a dynamic measurement of volume flow rates that inherently accounts for slip (2.52) between the gas ($\dot{Q}_g$) and liquid ($\dot{Q}_l$) phases. The liquid volume flow rate consists of the sum of the liquid flow rates, e.g. hydrocarbon liquids, water, and liquid chemical inhibitors. This is **not** to be confused with *gas void fraction* (2.23). GVF may be expressed as a ratio or a percentage.

2.23
gas void fraction
α_g
ratio of gas cross sectional area to total pipe cross sectional area, or

$$\alpha_g = \frac{A_g}{A}$$

Note 1 to entry: Gas void fraction is a static measurement at a moment in time and it does **not** account for slip (2.52) between the gas and liquid phases. The existence of slip between the phases differentiates GVF from gas void fraction.

Note 2 to entry: Phase fraction devices in WGFM designs tend to measure the gas void fraction in the system's line-of-sight, not the GVF. The WGFM slip model then derives the GVF from inputs including the gas void fraction and other subsystem measurements.

2.24
homogeneous hydrocarbon liquid/water flow
flow of water and hydrocarbon liquid where the phases are evenly distributed throughout the fluid mix and there is no slip between the water and the hydrocarbon liquid

Note 1 to entry: The composition of a homogeneous water and hydrocarbon liquid mix is constant throughout the conduit. However, homogeneous distribution of the phases is rare.

2.25
infrared
electromagnetic radiation with longer wavelengths than visible light

2.26
intermittent flow
unsteady flow, where the GVF varies with time, e.g. slug flow

2.27
line conditions (actual, process, or operating conditions)
thermodynamic conditions of the fluid passing through the meter, i.e. the fluid conditions at line (metering device) pressure and temperature

2.28
liquid densiometric Froude number
square root of the ratio of the liquid flow inertia (if it were to flow alone) to the liquid's weight, or

$$Fr_l = \sqrt{\frac{\text{Superficial Liquid Inertia Force}}{\text{Liquid Gravity Force}}} = \frac{\bar{U}_{sl}}{\sqrt{gD}}\sqrt{\frac{\rho_l}{\rho_l - \rho_g}} = \frac{m_l}{A\sqrt{gD}}\sqrt{\frac{1}{\rho_l(\rho_l - \rho_g)}}$$

2.29
liquid hold up
α_l
ratio of liquid cross sectional area to total pipe cross sectional area, or

$$\alpha_l = 1 - \alpha_g = \frac{A_l}{A}$$

Note 1 to entry: The liquid hold up gives effectively the same information as the *gas void fraction* (2.23).

Note 2 to entry: The liquid hold up is a static measurement at a moment in time and it does **not** account for slip between the gas and liquid phases. That is the liquid hold-up gas and *liquid volume fraction* (2.31) differ due to the existence of slip between the phases.

Note 3 to entry: With multiphase wet gas flow the liquid hold up can be split into its constituent liquid components. For example, with a gas, condensate and water flow where hydrocarbon liquid hold-up (α_{hcl}) and water hold up (α_{water}) are:

$$\alpha_{hcl} = \frac{A_{hcl}}{A}$$

$$\alpha_{water} = \frac{A_{water}}{A}$$

$$\sum \alpha = \alpha_g + \alpha_{water} + \alpha_{hcl} = 1$$

2.30
liquid loading
qualitative description of the relative amount of liquid in a wet gas flow

2.31
liquid volume fraction
LVF
ratio of liquid to total fluid volume flow rate at actual flow conditions, or

$$LVF = 1 - GVF = \frac{\dot{Q}_l}{\dot{Q}_l + \dot{Q}_g}$$

Note 1 to entry: The LVF is a dynamic measurement of volume flow rates that inherently accounts for slip between the gas ($\dot{Q}_g$) and liquid ($\dot{Q}_l$) phases. The liquid volume flow rate consists of the sum of the liquid flow rates (for example, hydrocarbon liquids, water, and liquid chemical inhibitors). This is **not** to be confused with *liquid hold up* (2.29). LVF may be expressed as a ratio or a percentage.

2.32
Lockhart-Martinelli parameter
square root of the ratio of the liquid inertia to gas inertia if the phases flowed alone at line conditions, or

$$X_{LM} = \sqrt{\frac{\text{Inertia of Liquid Flowing Alone}}{\text{Inertia of Gas Flowing Alone}}}$$

that is:

$$X_{LM} = \frac{Fr_l}{Fr_g} = \frac{\dot{m}_l}{\dot{m}_g}\sqrt{\frac{\rho_g}{\rho_l}} = \frac{\dot{Q}_l}{\dot{Q}_g}\sqrt{\frac{\rho_l}{\rho_g}} = \frac{1-GVF}{GVF}\sqrt{\frac{\rho_l}{\rho_g}}$$

Note 1 to entry: The Lockhart-Martinelli Parameter has a long 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 stated definition here. The definition supplied in this Technical Report 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[12] and.[13]

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

2.33
mass flow rate
mass of fluid flowing through a conduit per unit time

2.34
measurand
particular quantities subject to measurement

2.35
meter operating envelope
areas in the *two-phase flow rate map* (2.59) and/or *composition map* (2.4) in which a WGFM is to perform/or stated to be capable of performing

Note 1 to entry: This envelope may vary with changing operating condition and fluid properties.

2.36
microwave
electromagnetic radiation, typically in the frequency range 0,3 GHz to 300 GHz

2.37
multiphase flow
flow of gas, water, and hydrocarbon liquid phases

Note 1 to entry: Each of these three components is designated as a separate "phase". Multiphase flows may also have other "phases" such as salinity of water or chemical injection phases. A multiphase flow is a subset of a two-phase flow where the liquid consists of two or more components, typically water and hydrocarbon liquid. There is no limit to the relative quantity of liquids in a multiphase flow, i.e. the GVF range is 0 % < GVF < 100 %.

2.38
multiphase flow meter
MPFM
device that measures the oil, water and gas flow rates in a multiphase flow

2.39
multiphase/phase fraction device
device that measures the phase area fractions of the individual phases of a multiphase flow

Note 1 to entry: These devices tend to measure the area occupied by a particular phase across a given cross-sectional area. This is not the same information as the phase volume flow rate ratios due to the existence of a *slip* (2.52).

2.40
oil continuous liquid
oil external emulsion
liquid flow consisting of the two "phases", hydrocarbon liquid and water, where the hydrocarbon liquid phase encases the water phase suspended in water droplets in the hydrocarbon liquid phase

2.41
operating envelope
see 2.35

2.42
over-reading
ratio of a single-phase gas flow meter's erroneous gas mass flow rate prediction (i.e. the "apparent gas mass flow rate") to the actual dry gas mass flow rate

Note 1 to entry: In the case of DP devices, this is often approximated to the square root of the wet gas to dry gas DP ratio.

2.43
permittivity
measure of the ability of a dielectric medium to be electrically polarized when exposed to an electric field

2.44
phase
used in WGFM applications to describe each of the three components gas, water and hydrocarbon liquid. Other components such as glycol and methanol can also be referred to as "phases"

2.45
phase flow rate
amount (in mass or volume) of a specific phase passing a referenced point in the conduit per unit time

2.46
phase mass fraction
ratio of the mass flow rate of one phase to the total mass flow rate

2.47
production envelope
collection of possible well production trajectories (gas flow rates and liquid flow rates) over time in the *two-phase flow rate map* (2.59), see Figure 23

2.48
relative humidity
ratio of water liquid vapour present in a gaseous fluid relative to the maximum (or saturated) amount of water liquid vapour possible for that given gaseous fluid to hold at a given thermodynamic condition

2.49
Reynolds number
Re
ratio of the inertial to viscous forces, or

$$Re = \frac{\rho U.D}{\mu} = \frac{4\dot{m}}{\pi\mu.D}$$