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Manual of Petroleum Measurement Standards Chapter 20.3

Measurement of Multiphase Flow

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0 Introduction

This standard addresses how the user measures (multiphase) flow rates of oil, gas, water, and any other fluids that are present in the production stream.

This document does not describe allocation or well testing methods. Refer to API MPMS Chapter 20.1 for direction on allocation methods and API MPMS Chapter 20.5 for direction on well testing.

This document does not describe the flow loop testing protocols or methods. Refer to API MPMS Chapter 22.7 for Flow Loop Testing Protocols

In this document, the use of multiphase metering systems is focused on the role they can play in production measurement and allocation applications. However, there are numerous other instances in which they can be extremely helpful. To preserve the focus on production measurement and allocation, these other instances will not be discussed in any depth.

1 Scope

This standard addresses inline multiphase flow measurement in the production environment, upstream of the custody transfer (single-phase) measurement point, where allocation measurement for onshore, offshore, or subsea is applied. For other multiphase flow measurement applications such as reservoir management, well tests, and flow assurance, the standard can be used as a reference or guide. However, the focus of this standard is on those applications where the accuracy of multiphase flow measurement for allocation systems is required.

This document refers to existing standards and recommended practices to supplement the guidance it provides in this subject area. The document addresses principles used in multiphase flow measurement, multiphase metering types and classifications, assessment of expected performance, and selecting and operating multiphase measurement systems. Operational requirements or constraints are addressed, including expectations for flow meter acceptance, calibration criteria, flow loop and in situ verifications, and other guidance

specific to different multiphase flow metering applications. The document does not address specific meter configurations.

2 Normative References

1. API MPMS Chapter 14.2 [12].
2. API MPMS Chapter 20.1 Allocation Methods
3. API MPMS Chapter 20.4 Phase Behavior
4. API MPMS Chapter 20.5 Recommend Practice for Application of Production Well Testing in Measurement and Allocation
5. API MPMS Chapter 22.7 Flow Loop Testing Protocol
6. The Norwegian *Handbook of Multiphase Flow Metering* [26]
7. GPA Standard 2145 [14]
8. AGA Report No. 8
9. API Publication 2566, *State of the Art Multiphase Flow Metering* [11]
10. ASME MFC19G, *Wet Gas Flow Metering Guideline* [13].
11. IAEA DS 379, Safety Standards for Protection Against Ionizing Radiation, or ISO 7205, Radionuclide gauges— Gauges designed for permanent installation.

3 Terms, Definitions, Abbreviations, and Symbols

3.1 Terms and Definitions

For the purposes of this document, the following terms and definitions apply. The definitions for many terms used in this document can be found in ISO/IEC Guide 98-3:2008 [15] unless specified otherwise.

actual conditions

Line conditions, flowing conditions, conditions of pressure and temperature of the fluid at the point where fluid properties or flows are measured.

allocation

The mathematical process of determining the proportion of produced fluids from individual entities (zones, wells, fields, leases, or producing units) when compared to the total production from the entire system (reservoir, production system, and gathering systems) in order to determine value or ownership to attribute to each entity.

allocation measurement

Measurement systems and procedures required to perform a fair and equitable allocation.

NOTE Such systems and procedures may not meet full custody transfer standards of measurement while still being sufficient for allocation purposes.

calibration

The process or procedure of adjusting an instrument, such as a meter, so that its indication or registration is in satisfactorily close agreement with a reference standard.

commingle

To combine the hydrocarbon streams from two or more wells, units, leases, production zones, or production facilities into common vessels or pipelines.

Conductivity

The ability of a material to conduct electrical current. In isotropic material conductivity is the reciprocal of resistivity. Sometimes called specific conductance in units of Siemens/m or S/m.

Emulsion

A suspension of fine particles or globules, or both, of one or more liquids in another liquid.’

Entrained water

Water suspended in the petroleum and petroleum products. Entrained water includes emulsions but does not include dissolved water.

Factory Acceptance Testing (FAT)

A series of functional tests and inspections that are performed by the manufacturer or third-party test facility prior to equipment acceptance. FAT are intended to demonstrate and verify that the equipment meets design and manufacturing specifications.

fiscal

Of or relating to financial matters. With respect to measurement, those that have a financial impact on custody transfer, allocation, royalty, or taxation.

fiscal measurement

Measurement systems and procedures required to determine a quantity that may be expected to have a direct financial impact to affected parties. Contrast with custody transfer measurement (as defined in *API Manual of Petroleum Measurement Standards [MPMS] Ch. 1, Second Edition* [9]).

flow regime

The physical geometry exhibited by a multiphase flow in a conduit, the geometrical distribution in space and time of the individual phase components, i.e., oil, gas, water, any injected chemicals, etc. For example, liquid occupying the bottom of a horizontal conduit with the gas phase flowing above.

Froude Number

The ratio of the square root of the inertial force divided by the square root of the gravitational force for a particular phase. (Need Equation)

gas-oil ratio GOR

The ratio of gas volume flow rate to the liquid hydrocarbon volume flow rate at any point, expressed at standard conditions, usually in standard cubic feet per barrel (scf / bbl) or standard cubic meters of gas per cubic meter of liquid hydrocarbon (m^3/m^3).

gas void fraction

The ratio of the local cross-sectional area in the conduit occupied by the gas phase divided by the cross-sectional area of the conduit at the same local position at line conditions, usually expressed as a percentage.

gas volume fraction GVF

The fraction of the gas volumetric flow rate to the total volumetric flow rate, at actual conditions, often expressed as a percentage $GVF = \frac{Q_g}{Q_g + Q_l}$

liquid hold-up

The ratio of the local cross-sectional area in the conduit occupied by the liquid phase divided by the cross-sectional area of the conduit at the same local position at line conditions, usually expressed as a percentage.

liquid volume fraction LVF

The fraction of the liquid volumetric flow rate over the total volumetric flow rate, at actual conditions, often expressed as a percentage. $LVF = \frac{Q_l}{Q_l + Q_g}$

Lockhart-Martinelli parameter

A dimensionless parameter (usually shown in equations as X) used to indicate the degree of “wetness” of a wet gas at actual conditions, defined as:

$$X_{lm} = \frac{Q_l}{Q_g} \sqrt{\frac{\rho_l}{\rho_g}} = \frac{m_l}{m_g} \sqrt{\frac{\rho_g}{\rho_l}}$$

multiphase flow

Flow of a composite fluid that includes natural gas, hydrocarbon liquids, water, and injected fluids, or any combination of these.

oil-continuous multiphase flow

Multiphase flow in which the water and any other liquids present are distributed as droplets surrounded by liquid hydrocarbons (oil) in the liquid phase.

operating envelope OE

A description of the operating range of a multiphase flow meter with its expected performance in liquid and gas flow rates, gas volume fraction, and water-liquid ratio.

phase

A term used in the sense of one constituent in a mixture of several. In particular, the term refers to oil, gas, water, or any other constituent in a mixture of any number of these.

phase mass fraction

The mass flow rate of one of the phases of a multiphase flow, relative to the total multiphase mass flow rate.

phase volume fraction

The volume flow rate of one of the phases of a multiphase flow at actual conditions, relative to the total multiphase volume flow rate, e.g., gas volume fraction (2.1.15).

pressure-volume-temperature (PVT) relationship

Application of equations of state (EOS) to a composite fluid to calculate the change in properties in going from one set of conditions (P and T) to another.

Reference measurement system

A system of equipment and/or devices such as a separator, a single meter, a group of meters, a MPFM, analyzers, monitors, or other equipment, with the specific purpose to determine a mass or volume, used in comparison to a measurement system or equipment under validation.

Salinity

The amount of all dissolved salts that are present in the water (kg/m^3). Sodium and chloride are the predominant ions in seawater, and concentrations of magnesium, calcium, and sulphate ions are also substantial and included in the salinity values.

SAT Site Acceptance Testing (SAT)

A series of specific tests and inspections that are performed at the installation site to demonstrate and verify that the system is functional in the intended working environment.

SIT System Integration Testing (SIT)

A series of tests performed to verify the behavior and functionality of the complete multiphase metering system's integrated hardware and software. This testing is conducted on a complete integrated system to evaluate the system's compliance with its specified requirements before it is installed on site.

slip

Conditions that exists when the phases have different velocities at a cross section in a conduit.

slip ratio

A means of quantitatively expressing slip as the phase velocity ratio between the phases. $S = \frac{u_g}{u_l}$

Standard Conditions

Pressure and temperature conditions used to normalize quantities for allocation and/or sales (e.g. 14.696 psia, 60°F; 101.325 kPa, 15°C).

superficial phase velocity

The flow velocity of one phase of a multiphase flow, assuming that the phase occupies the whole conduit by itself. It is defined by the phase volume flow rate/pipe cross-sectional area.

validation

The process or procedure of comparing a system of instruments to a reference measurement system to ensure its indication or registration is within a prescribed uncertainty.

verification

The process or procedure of comparing a single instrument to a single reference standard to ensure its indication or registration is in satisfactorily close agreement, without making an adjustment.

phase fraction

The cross-sectional area locally occupied by one of the phases of a multiphase flow, relative to the cross-sectional area of the conduit at the same local position, at actual conditions. (The phase fraction for gas is commonly called Gas Void Fraction. The phase fraction for liquid is commonly called the liquid hold-up.)

Water cut WC

The water volume flow rate, relative to the total liquid volume flow rate (oil and water), both converted to volumes at standard pressure and temperature. Water Cut is normally expressed as a percentage.

water-continuous multiphase flow

Multiphase flow in which the oil and other liquids present are distributed as droplets surrounded by water in the liquid phase.

water-liquid ratio WLR

The water volume flow rate, relative to the total liquid volume flow rate (oil and water), at the actual conditions (operating pressure and temperature), expressed as a percentage.

production profile

This production profile is a prediction of the range of flow rates, composition, and operating conditions over a period of time.

Wet Gas

A gas/liquid system with a Lockhart-Martinelli number smaller than approximately .3 and greater than 0. Hydrocarbon gases that contain heavy components that will condense out during further processing but behave as a pure gas at the measured pressure and temperature are not considered to be a wet gas.

3.2 Abbreviations and Symbols

For the purposes of this document, the following abbreviations and symbols apply.

A_{pipe}	pipe cross-sectional area
A_{gas}	cross-sectional area of pipe occupied by gas flow
A_{liquid}	cross-sectional area of pipe occupied by liquid flow
α_g	gas void fraction
α_l	liquid hold up
DP	differential pressure
EOS	equation(s) of state
FAT	factory acceptance test
GOR	gas-oil ratio
GUM	ISO Guide to uncertainty in measurement [20]
GVF	gas volume fraction
HC	hydrocarbon
I	system imbalance
LVF	liquid volume fraction
MCS	Monte Carlo simulation
MEG	monoethylene glycol
m_g	gas mass flow rate

m_l	liquid mass flow rate MPFM
m_o	liquid hydrocarbon (oil) mass flow rate
m_w	water mass flow rate
NFOGM	Norwegian Society for Oil and Gas Measurement
OE	operating envelope
P, T	pressure and temperature at actual conditions
P_{sc}, T_{sc}	pressure and temperature at standard conditions
PLET	pipeline end termination
psi	pounds per square inch
PVT	pressure-volume-temperature
– \bar{q}	mean value of a random variable q
Q_g	gas volume flow rate
Q_l	liquid volume flow rate
Q_o	liquid hydrocarbon (oil) volume flow rate
Q_w	water volume flow rate
ρ_g	gas density
ρ_l	liquid density
R	universal gas constant
ROV	remotely operated vehicle
S	slip ratio
SAT	site acceptance test
SIT	system integration test
U	velocity of liquid or gas in a pipe at actual conditions
U_l	liquid velocity at actual conditions
U_g	gas velocity at actual conditions
$U_{g,sc}$	gas velocity of gas at standard conditions
$U_{s,g}$	superficial velocity of gas phase of a multiphase flow in pipe
$U_{s,l}$	superficial velocity of liquid phase of a multiphase flow in pipe
WLR	water-liquid ratio
X_{lm}	Lockhart-Martinelli parameter
Z	<i>gas compressibility factor at actual conditions</i>
Z_{sc}	<i>gas compressibility factor at standard conditions</i>

4 Overview - Multiphase and Wet Gas Flow

4.1 General

In-line MPFMs are characterized by the measurement of the total or individual phase volume or mass flow rates which are performed directly in the multiphase line with no phase separation. Multiphase flow is referred to as “three phase,” and throughout this document multiphase measurement is referred to as a three-phase flow situation. This is a common practice and is the accepted vernacular within the multiphase industry. Although, there are normally only two phases: namely gaseous fluids and liquid fluids flowing together. Produced water is normally considered the third phase. However, the water is a portion of the liquid phase, making the liquid phase actually a mixture of water and hydrocarbon liquid.

Wet gas refers to a subset of multiphase flow in which gas is the dominant phase, with lesser quantities of liquid (oil/water) present. As such, for the sake of clarity, the term multiphase meter will be used to describe both a multiphase meter and a multiphase/wet gas meter throughout this document.

This standard will sometimes be used in conjunction with other standards or similar documents. When a need is encountered for addressing these situations, rather than directly discussing the subject in this document, the user is referred to the appropriate referenced documents for direction.

4.2 Multiphase Flow Fundamentals

4.2.1 Key Parameters and Definitions

For two-phase flow at actual conditions, the area fraction of gas or liquid that occupies the cross-sectional area of a pipe is known as the void fraction, α_g , and the liquid hold-up, α_l , respectively. These parameters can be calculated as shown in Equation (1) and Equation (2).

$$\alpha_g = \frac{A_{\text{gas}}}{A_{\text{pipe}}} \quad (1)$$

$$\alpha_l = \frac{A_{\text{liquid}}}{A_{\text{pipe}}} \quad (2)$$

The sum of the gas void fraction in Equation (1) and liquid hold up in Equation (2) should equal 1. The gas void fraction and liquid hold up are not to be confused with both the gas volume fraction, GVF, and the liquid volume fraction, LVF, as these parameters describe the relationship between the phase volume flow rate, Q_g or Q_l , and the total fluid flow rate, as shown in Equation (3) and Equation (4).

$$\text{GVF} = \frac{Q_g}{Q_g + Q_l} \quad (3)$$

$$\text{LVF} = \frac{Q_l}{Q_l + Q_g} \quad (4)$$

In Equation (3) and Equation (4), the phase volumetric flow rates can be determined by multiplying the cross-sectional area of the pipe with the respective phase superficial velocity, $U_{s,g}$ or $U_{s,l}$. These superficial phase velocities are determined by assuming an individual phase is flowing at a theoretical mean velocity if it occupied the entire conduit alone. A visual representation of the differences between the gas void fraction and liquid hold-up versus the gas and liquid volume fraction is shown in Figure 4.1. For the majority of the two-phase flow, the liquid hold-up will be larger than the liquid volume fraction and the gas hold-up will be smaller than the gas fraction due to slip. The slip ratio, S , can be determined from the ratio of gas and liquid velocities as shown in Equation 5.

$$S = \frac{U_g}{U_l} \geq 1 \quad (5)$$

Only under no-slip conditions, when $S=1$, will the two phases travel at equal velocities, and the gas void fraction or liquid hold-up will be equivalent to the gas and liquid volume fraction. The relationship between GVF, S , and gas void fraction, α_g , is shown Equation 6.

$$\text{GVF} = \frac{Q_g}{Q_g + Q_l} = \frac{A_g U_g}{A_g U_g + A_l U_l} = \frac{A_g}{A_g + \left(\frac{1}{S}\right) A_l} = \frac{\alpha_g}{\alpha_g + \frac{1}{S}(1 - \alpha_g)} \quad (6)$$

Rearranging Equation 6 and solving for α_{Gas} results in the relationship shown in Equation 7.

$$\alpha_g = \frac{1}{1 + S\left(\frac{1}{\text{GVF}} - 1\right)} \quad (7)$$

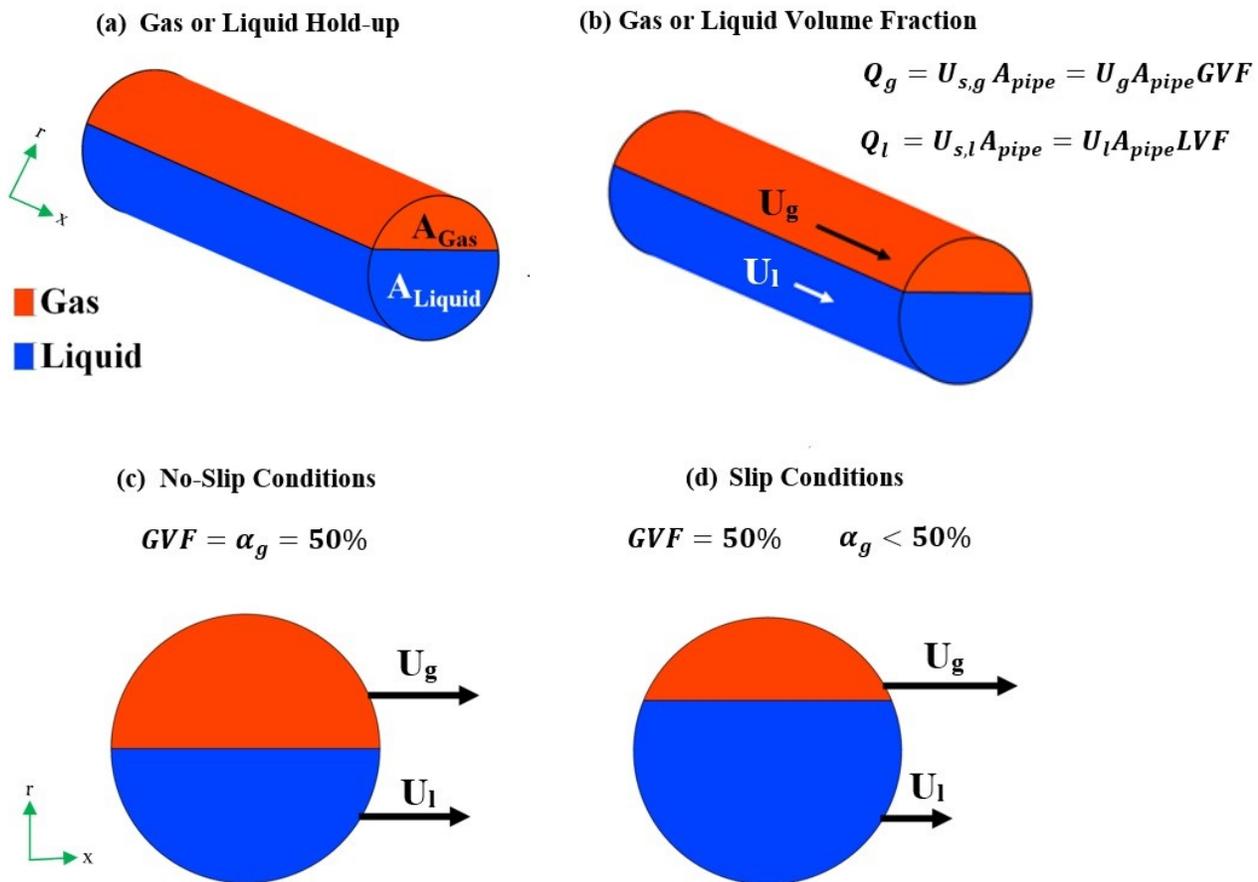


Figure 4.1 – (a) Gas Void Fraction and Liquid Hold-up (b) Gas or Liquid Volume Fraction (c) no-slip conditions (d) slip conditions

4.2.2 Flow Pattern Classification/Maps

Multiphase flow structures are often classified into different flow regimes, the characteristics of which depend on a number of different parameters. These flow regimes have a significant effect on the accuracy of the MPFM measurement within the designed operating conditions and operating envelope (OE), as well as the meter's response to transitional changes between flow regimes.

The main parameters associated in forming the different flow regimes are:

- transient effects as a result of changes in system conditions (e.g. valve opening and closing)
- pipeline geometry, inclination, or terrain effects,
- hydrodynamic effects (e.g. fluid properties and flow rates), or
- a combination of these.

Although many different combinations of the above parameters result in different flow patterns, the hydrodynamic multiphase flow regimes can be grouped into the following categories:

- dispersed flow (e.g. bubble flow, mist flow), See fig 4.2 below
- separated flow (e.g. stratified flow, annular flow), See Fig 4.3 below
- intermittent flow (e.g. elongated bubble, chum flow, slug flow), See Fig 4.4
- or a combination of these categories.

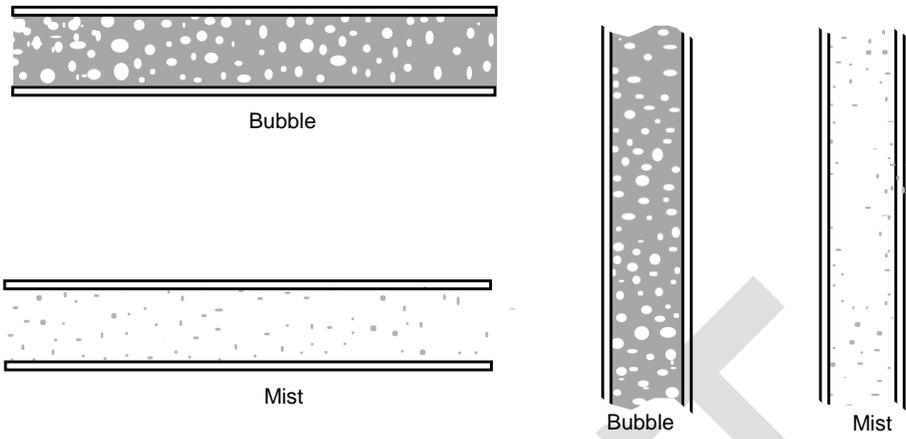


Fig 4.2 Dispersed

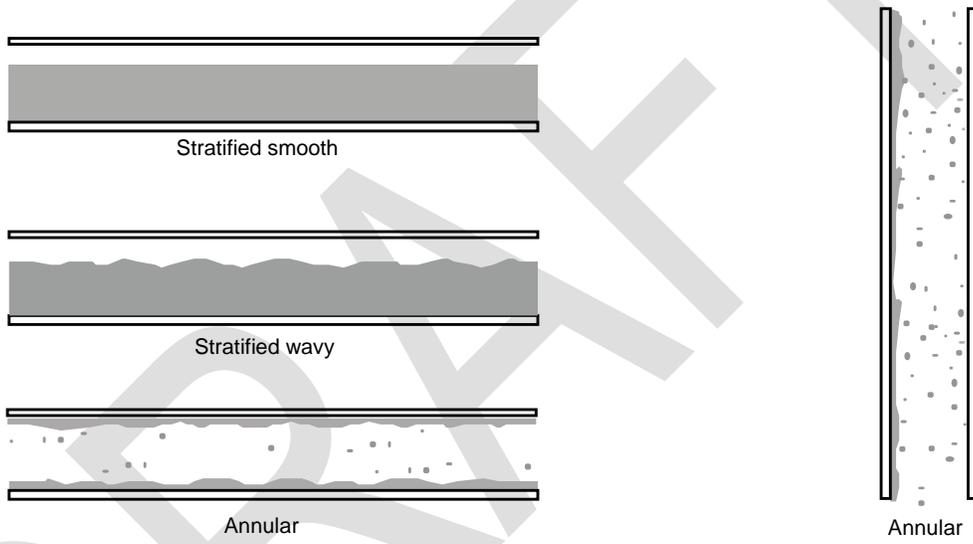


Fig 4.3 Separated Flow

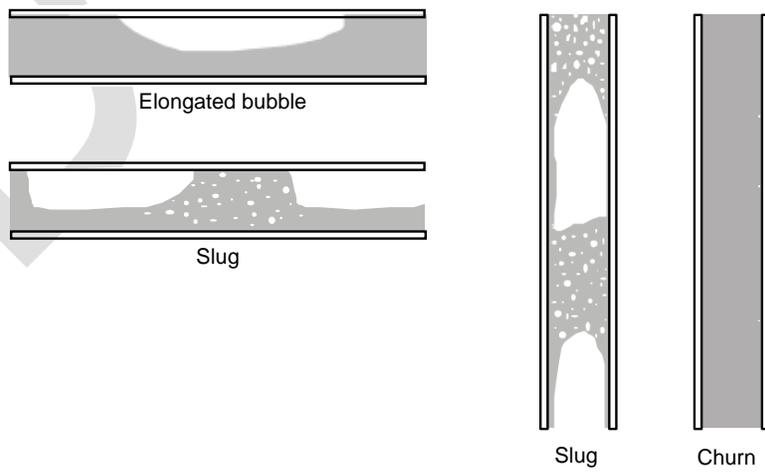


Fig 4.4 Intermittent flow

These multiphase flow regimes are typically represented in graphical format known as flow regime maps (refer to fig 3.5 below) or diagrams. Flow regime maps are commonly used to determine the flow patterns that exist within different operating and geometrical conditions, including the conditions in which the flow may transition from one regime to a different regime (e.g. changing from stratified to slug flow).

Many different flow regime maps exist and are published throughout industry. For example, The Norwegian *Handbook of Multiphase Flow Metering* [26], and the [SPE Applied Multiphase Flow Assurance – Oil and Gas Production, 2017]. They show qualitative illustrations of how flow regimes transition and are dependent on superficial gas and liquid velocities in either vertical or horizontal orientations. The boundary between flow regimes transitioning from one flow pattern to another is typically a function of factors such as pipe diameter, interfacial tension, and density of the phases, and is only valid for a specific pipe geometry, pressure, and multiphase fluid.

Flow regimes can have a significant impact on the MPFM's response, as the flow structures have direct influence on the meter's measurement accuracy. For example, impedance using absorption measurement techniques used to determine phase distribution can be greatly affected by flow regime. Additionally, flow patterns can transition to different flow regimes over a short timeframe and over short distances, as any given flow will need a significant length of pipe to reach a state of equilibrium (i.e. flow development).

The mixture of the liquids and gas produced can sometimes react to create other compounds and entrained fluid mixtures, some of which can be impactful to both the production process and measurement. These include fluid effects such as emulsions, foams, generation of hydrates, and/or the buildup of asphaltenes and waxes, which can cause a misrepresentation of the fluid flow regime.

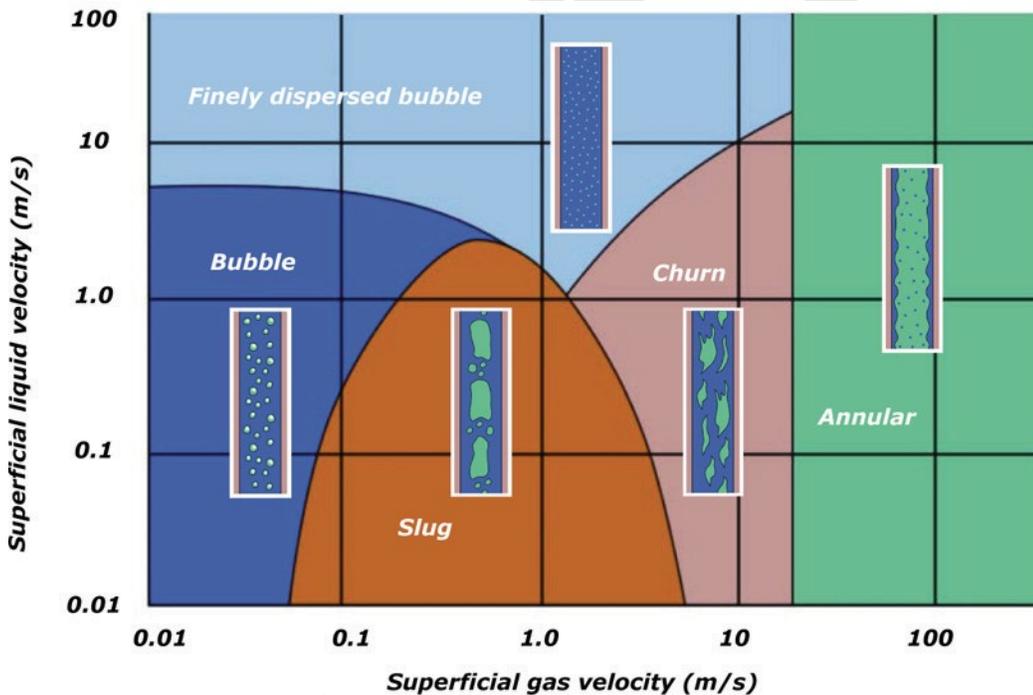


Fig 4.5 A Generic Two-phase Horizontal Flow Map, Log-log Scale

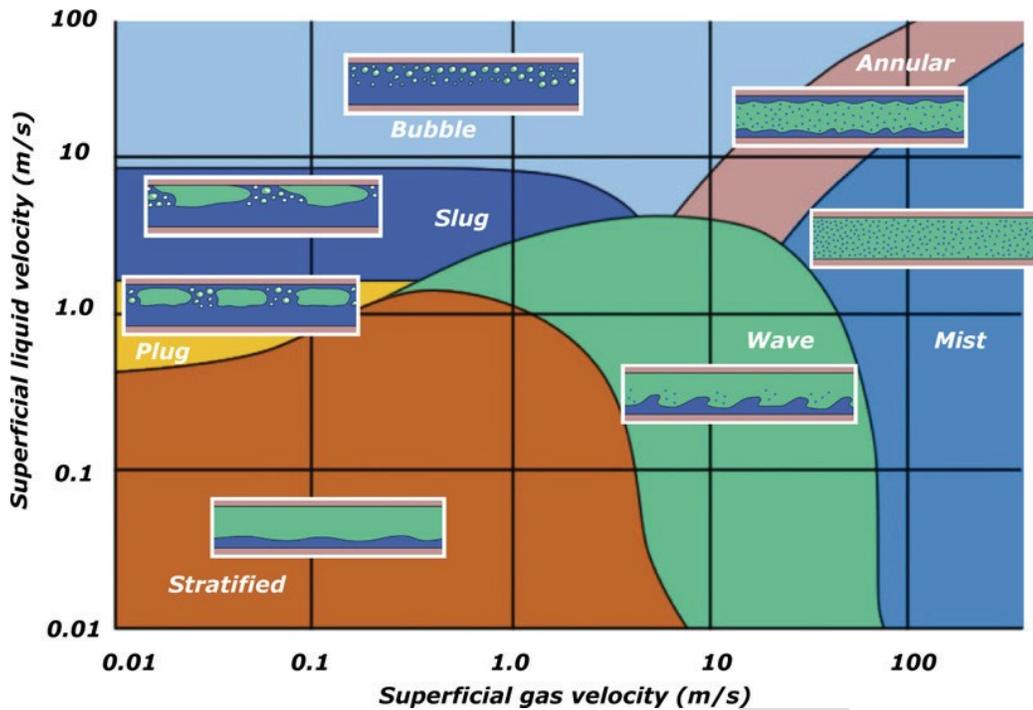


Fig 4.6 A Generic Two-phase Vertical Flow Map, Log-log Scale

4.3 Multiphase/Wet Gas Measurement Fundamentals

4.3.1 General

In-line MPFMs are characterized by the measurement of the total or individual phase volume or mass flow rates which are performed directly in the multiphase line with no phase separation.

In a typical gas/water/oil application, six parameters are needed—three phase fractions and three phase rates. Different in-line MPFMs use different methods or instruments to measure or infer the six parameters needed to solve the multiphase volume or mass flow rate calculation. These measurement parameters are discussed in detail in Section 4.3.4

Some MPFMs use the strategy to force all phases to travel at the same velocity, thus reducing the required number of measurements to the three area fractions and one common velocity. This is usually achieved through the installation of a secondary device such as a mixer or a positive displacement (PD) meter upstream from the metering section.

Some MPFMs utilize energy loss ratios (pressure drop and pressure recovery ratios) and empirical test data to determine gas and liquid flow rates and phase fractions.

Some MPFM's use impedance/conductance technology, gamma ray absorption, microwave resonance technology, infrared/spectral absorption, or other technologies to determine oil and water ratios.

A MPFM is intended to determine and output the following information:

- Pressure and temperature
- Phase volume fractions (e.g. GVF, WLR)
- Liquid and gas flow rates, either volume or mass

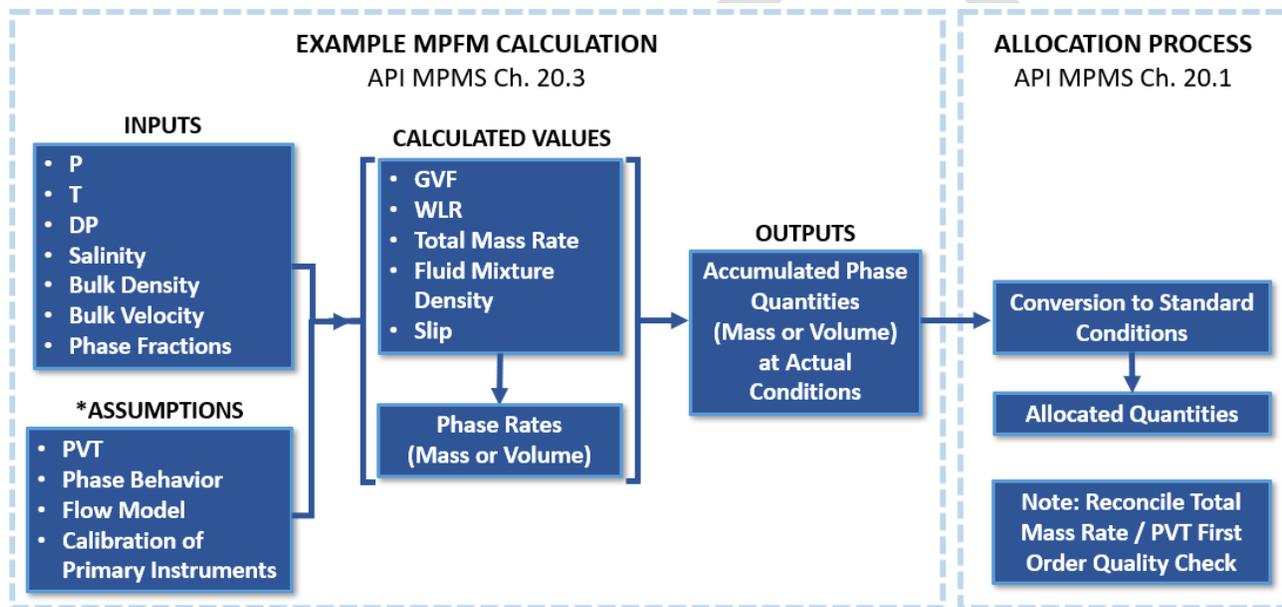
Since there is no one single instrument that exists which can measure all of these outputs, it is necessary to combine different technologies or devices that can measure or calculate all of these desired parameters. Multiple measurement technologies, as well as different types of measurement technologies, can be combined to generate the desired outputs. These measured parameters are discussed in the successive subsections.

4.3.2 MPFM Measurement Process

A process flow diagram depicted in Figure 4.7 shows the MPFM inputs, assumptions, calculated values and outputs, and how these MPFM output values are used for allocation measurement. Equations commonly used to calculate gas, water, and oil volumetric flow rates are described in Table 4.1. GVF, WLR, and total mass flow rate (m) are required to calculate the individual mass or volumetric flow rates. Note that flow rates are evaluated at line conditions and the density of the multiphase mixture, $\rho_{mixture}$, is directly measured or evaluated using volume fractions and a PVT model.

Table 4.1 – Equations for MPFM Calculated Values

Gas Volume Fraction: $GVF = f(\frac{\rho_L}{\rho_g}, \frac{\mu_L}{\mu_g}, \alpha_g, S)$	Gas Volumetric Flow rate: $Q_g = \frac{m}{\rho_{mixture}} \cdot GVF$
Water Liquid Ratio: $WLR = \frac{\alpha_w}{\alpha_w + \alpha_o}$	Water Volumetric Flow rate: $Q_l = \frac{Q_l}{\rho_l} \cdot WLR$
Total Mass Flow rate: $m = K \sqrt{const \cdot DP \cdot \rho_{mixture}}$	Oil Volumetric Flow rate: $Q_o = Q_l \cdot (1 - WLR)$



*Some primary measurements required as inputs to assumptions

Figure 4.7 – MPFM Measurement Process Flow Diagram

4.3.3 Composition and Fluid Properties

The knowledge of the fluid properties that pass through a MPFM in service is essential to ensure proper meter performance. These fluids include liquid hydrocarbons, water, and natural gas. The liquid hydrocarbons most commonly encountered by an MPFM fall into three general categories. These three liquid hydrocarbon categories and their basic fluid properties are detailed in Table 4.2.

Table 4.2 - Fluid Properties of Typical Produced Liquids at Standard Conditions

Type	Relative Density Range	API Gravity Range	Viscosity Range at 20°C
Gas Condensates	< 0.78	> 50°	<5 cP
Black Oil/Light Crude Oil	0.78 to 0.934	20° to 50°	5 cP to 1000 cP
Heavy Oil	> 0.934	< 20°	>1000 cP

The flow rate of black oils or light crude oils constitute most of the multiphase flow streams encountered. They are generally easier to measure than gas condensates or heavy oil systems. Condensates can become

challenging to measure, particularly if they are part of a gas-dominated flow or wet gas system. Measurement of heavy oil systems can also be difficult due to the low Reynolds numbers typical of these viscous liquids, resulting in a highly variable discharge coefficient. When water is present, these oils are prone to forming oil-water emulsions.

Water can be produced from a number of sources; it can present as a liquid in the reservoir, produced as vapor with natural gas, or injected as a liquid or steam for enhance production. A problem for measurement can occur when water from two or more sources are combined, with the resulting properties mixed and potentially variable. Water salinity has impact on both the density of the water and its electrical conductivity, which is commonly used to determine the WLR. Unknown changes in salinity can result in unpredictable errors with determining the WLR by the MPFM.

Natural gas mixtures that are encountered by the MPFM can contain both hydrocarbon (e.g. C1 though C6 molecules) and non-hydrocarbon molecules (e.g. hydrogen sulfide, carbon dioxide, inert gases). It is sometimes difficult to specify the properties of natural gas since these depend on the composition of the gas as well as the pressure and temperature. The composition of the gas mixture can affect the flow rate measurement through, for example, the density term. For more information on the physical properties of natural gas components and mixtures, refer to GPA Standard 2145 [14] and AGA Report No. 8/API MPMS Ch. 14.2 [12].

Changes in fluid properties can substantially impact meter performance depending on the type of sensors and technology used. When an MPFM is used for measuring multiple wells, changes in fluid properties between the wells, if not accounted for, can result in misrepresentation of fluid flow. When evaluating MPFM, changes in fluid properties shall be considered.

4.3.4 Measurement Principles

In a typical gas/water/oil application, an ideal MPFM will make the following primary measurements: phase fraction, phase velocity (or bulk velocity), and phase density. Generally, the three phase fractions and three phase velocities are physically measured while the density of the different phases are calculated using PVT data. With these measurements, the mass flow rate for the individual phases can be determined by combining the six measurements. The different measurement approaches, which can be used to determine these primary measurements within a MPFM, are described in Table 4.3.

Table 4.3 – Instruments Technologies Used to Determine Fractional Ratios and Flow Rates

Primary Measurement	Approach	Key Features
Fraction Measurements ($\alpha_g, \alpha_l, \alpha_o,$ GVF, WLR)	Gamma-ray absorption (Bulk Density Measurement)	<ul style="list-style-type: none"> • Direct bulk density measurement • Considerations for use with H₂S and salinity changes. • Assumes phases are homogeneously mixed or are in layers perpendicular to the beam
	Dual or Multiple Energy Gamma-ray (Mixture Mass Attenuation Measurement)	<ul style="list-style-type: none"> • Measures each phase fraction • Not affected by phase inversion • Requires in-situ measurement or fluid composition and calculations • Attenuation considerations for use with higher specific gravity fluids
	Optical (Near Infra-Red/Spectroscopy)	<ul style="list-style-type: none"> • Measures <i>WLR</i> • Allows for methanol injection • Window/gap at near wall locations assumes bulk liquid representation • Window/gap cleaning may be required to keep clear • No considerations needed for water salinity, or gas fraction • Considerations for use near phase inversion zone
	Low Frequency Electromagnetic <30 MHz Capacitance/Conductance-Inductance	<ul style="list-style-type: none"> • Capacitance is suitable for low <i>water phase fraction</i> measurement (below oil/water phase inversion) while conductance is suitable above the inversion point

	Mixture Permittivity/Mixture Conductivity	<ul style="list-style-type: none"> Fluid properties including water conductivity and gas phase fraction are required to evaluate water fraction Considerations near phase inversion zone and with highly mixed regimes
	High Frequency Electromagnetic ~2.4 GHz Microwave Mixture Permittivity/Mixture Conductivity	<ul style="list-style-type: none"> <i>Water phase fraction</i> derived from the simultaneous measurement of mixture permittivity and conductivity above oil/water inversion point. Only mixture permittivity is needed below the inversion point. Fluid properties including water conductivity and gas phase fraction are required to evaluate <i>water phase fraction</i> Considerations near phase inversion zone and with high mixing regimes Considerations of permittivity and conductivity with the continuous oil and continuous water phases respectively
Mass Flow Measurement (Direct and Indirect)	Venturi Meter/DP Meters	<ul style="list-style-type: none"> Established technology for single phase flow Considerations with piping configuration and beta ratio Considerations for discharge coefficient characterization for multiphase flow
Velocity (Bulk velocity)	Cross-correlation (Acoustic/Capacitance/Conductance)	<ul style="list-style-type: none"> Considerations with high gas phase fractions Signal-to-noise ratio subject to pressure, temperature, and phase changes Considerations with pipe vibration and mechanical noise
	Acoustic Non-Intrusive clamp on velocity measurement	<ul style="list-style-type: none"> Low pressure drop Consideration of PVT dependency for multiphase measurement Velocity measurement will show offset when placed close to accelerated flow or upstream restriction
	Fiber Optic	<ul style="list-style-type: none"> No measurement drift and no recalibration needed Bulk flow velocity measurement unaffected by presence of gas Volumetric rate considerations in partially filled pipes Dependency of speed of sound measurement on pressure and temperature
Other Measurements	High Frequency Magnetic Field Technique (Eddy current)	<ul style="list-style-type: none"> Consideration for use based on water fraction. Bulk measurement (total water content) A known water conductivity and temperature is needed to calculate accurate water fraction
	Nuclear Magnetic Resonance (NMR)	<ul style="list-style-type: none"> Full bore design Single measurement principle for velocity and hold-up Consideration for use with higher viscous fluids Considerations for use with turbulent multiphase flow
	Coriolis	<ul style="list-style-type: none"> Total mass flow and density Secondary phase fraction determination in limited operating range (e.g. lower performance when gas in liquid >~5-10% by volume) Established technology for single phase flow

5 Operating Envelope (OE) and Production Profile

5.1 General

To determine the MPFM's performance in a specific environment, the operator shall first determine the Production Profile of the well where the MPFM will be installed. This production profile is a prediction of the range of flow rates and composition conditions over which the well will operate over a period of time. The operator shall also determine any anticipated operational and flow-assurance concerns as well as PVT characterization.

When the Production Profile is coupled with the MPFM's operating envelope (OE), which is the range of flow rates and composition conditions over which the MPFM can perform acceptably, the operator can infer how well the MPFM will perform in the intended environment, or determine when, during the well's lifetime, the MPFM may need to be replaced or supplemented with another MPFM. Additionally, the well's trajectory, which is the best estimate of the path the production profile will follow over time, can be used to determine the performance of the MPFM over the well's lifetime.

It should be noted that some MPFMs are designed for liquid-dominant or gas-dominant multiphase flow (i.e., not for the full range of GVF). In such cases, if the production profile is likely to span from liquid-dominant to gas-dominant flow during the life of the well, the operator should consider the possibility that the MPFM may need to be replaced or updated.

A common (and effective) method of presenting MPFM performance (for the life of a given well) is through flow and composition maps as described below.

NOTE: While this section refers to a single well production profile, many MPFM applications measure flow from multiple wells (individually or commingled). The same concept applies to production profiles for a set of wells or an entire field.

5.2 Graphical Depiction on Flow and Composition Maps

Figure 5.1 illustrates the concepts of production profile, MPFM OE, and production profile relative to gas and liquid flow rates at line conditions on a two-phase flow map. The lines connecting the dots show the well's trajectory, with its associated uncertainty is shown as shading around the production profile. The operating envelopes of two candidate MPFMs (A and B) are also shown. By comparing these, one can assess the suitability of a MPFM for the life of the well.

It is important to understand what the expected production profile will be when selecting and sizing a MPFM. If artificial lift (i.e., gas or water injection) is anticipated it should be factored into the production profile.

The limits of the production profile shall be specified as part of the MPFM selection including maximum/minimum pressure, temperature, production phase daily volumes, and acceptable pressure loss. Other limits of the

production profile should be specified where applicable. For example, gas lift volume and composition, process chemistry variations and its impact on material selection.

It is important to understand the parameters which drive the limits of the MPFM OE. The manufacturer shall provide details of key parameters, such as DP, P, velocity, density ratio, that impact the MPFM OE.

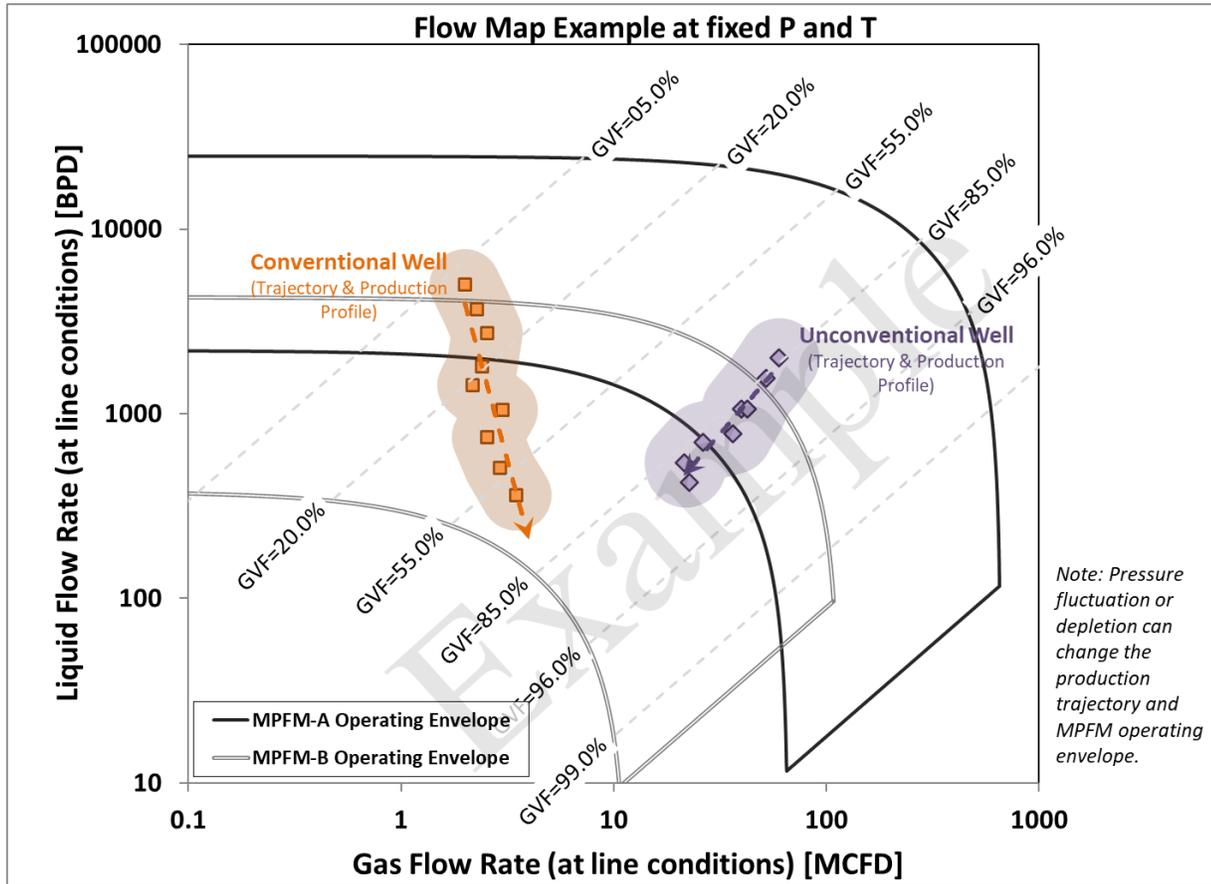


Figure 5.1 : Flow Map example with Production Profile and MPFM Operating Envelope.

Note, production profiles and MPFM OEs shown on the flow map are only examples, not actual field situations.

Figures 5.2-5.4 illustrate the concepts of MPFM uncertainties and production profile on composition maps, one for oil, gas, and water flow rate, with regard to GVF and WLR at line conditions. The lines connecting the dots show the well's trajectory, while the MPFM uncertainty (specified by the manufacturer) is represented by bubble size. As with the flow map, by comparing the production profile and MPFM uncertainties, one can assess how well a MPFM fits a particular application.

Note: MPFM uncertainty given in a composition map (i.e., at various GVF and WLR) are at line conditions because GVF and WLR, by definition, are line-condition parameters). Combining this uncertainty with well-specific PVT correlations (line-to-standard conversions) will yield MPFM uncertainty at standard conditions that may be needed for allocation (see Section 12).

The well trajectories and MPFM uncertainties shown on the composition maps (Figures 5.2 – 5.4) are examples, and do not represent an actual field situation.

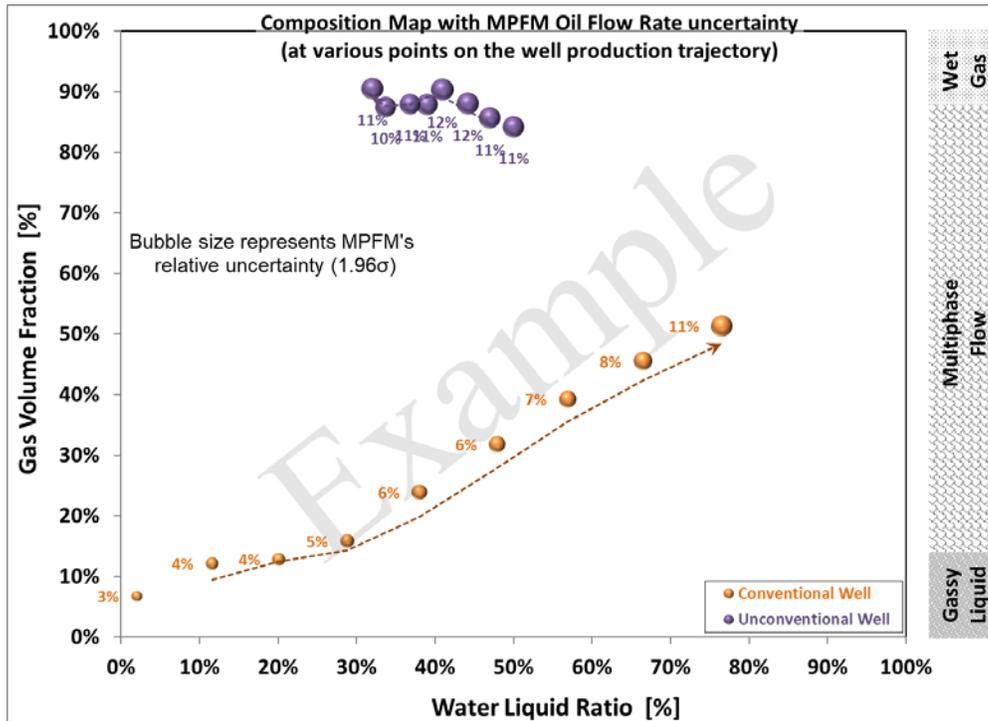


Figure 5.2 : Composition Map with MPFM Oil Flow Rate uncertainty at line conditions (at various points on the well production trajectory)

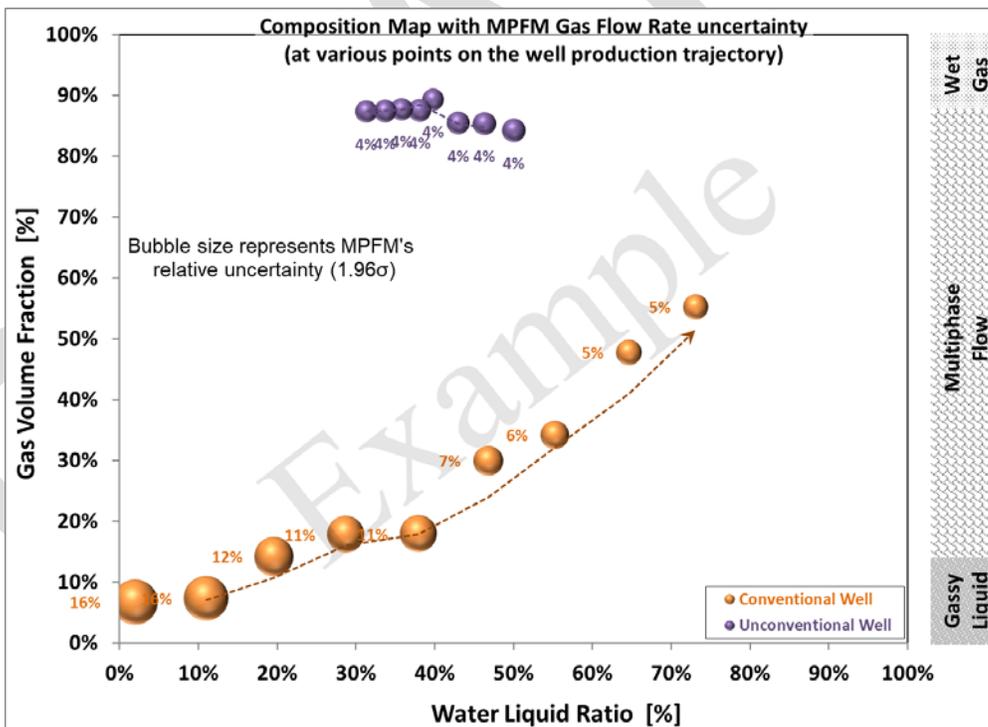


Figure 5.3 : Composition Map with MPFM Gas Flow Rate uncertainty at line conditions (at various points on the well production trajectory)

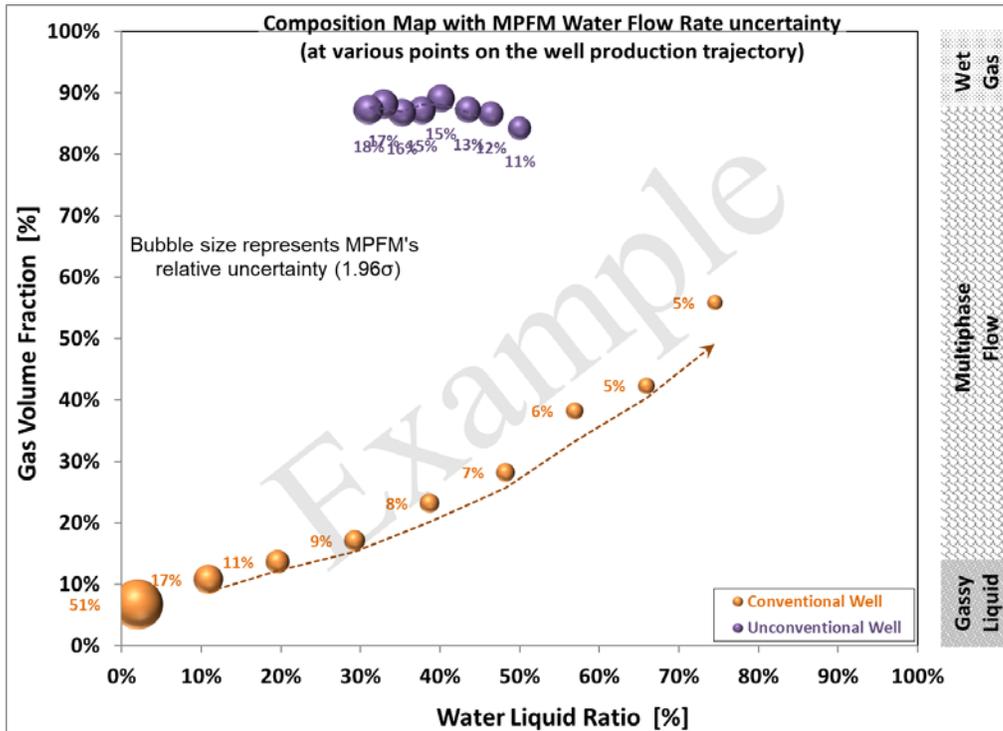


Figure 5.4 : Composition Map with MPFM Water Flow Rate uncertainty at line conditions (at various points on the well production trajectory)

6 Meter Selection

6.1 General Considerations for Meter Selection

The meter selection process starts with establishing the measurement performance requirements. Within a commercial and/or regulatory context, the performance requirements can set the limit of commercial or regulatory compliance. The user should carefully analyze what performance levels are achievable over the variety of flow conditions and operational scenarios anticipated.

In the case of MPFM applications, the selection process is multi-faceted. The combination of covering the entire production life, the possible large variability in the flow regime and the fluid properties variability, requires a substantial amount of input data and analysis which forms the operating envelope definition. Once the operating envelope is defined, a basic meter specification can be developed. The meter specification can then be used to select a potential MPFM. Once a potential MPFM is selected, one can assess the performance testing that has been previously performed on the selected MPFM against the OE. If the previous performance testing is inadequate or doesn't adequately cover the OE, additional performance testing can be proposed. Based on the performance tests, a performance prediction over the production life can be made and compared to the performance requirements. Figure 6.1 illustrates the basic meter selection process.

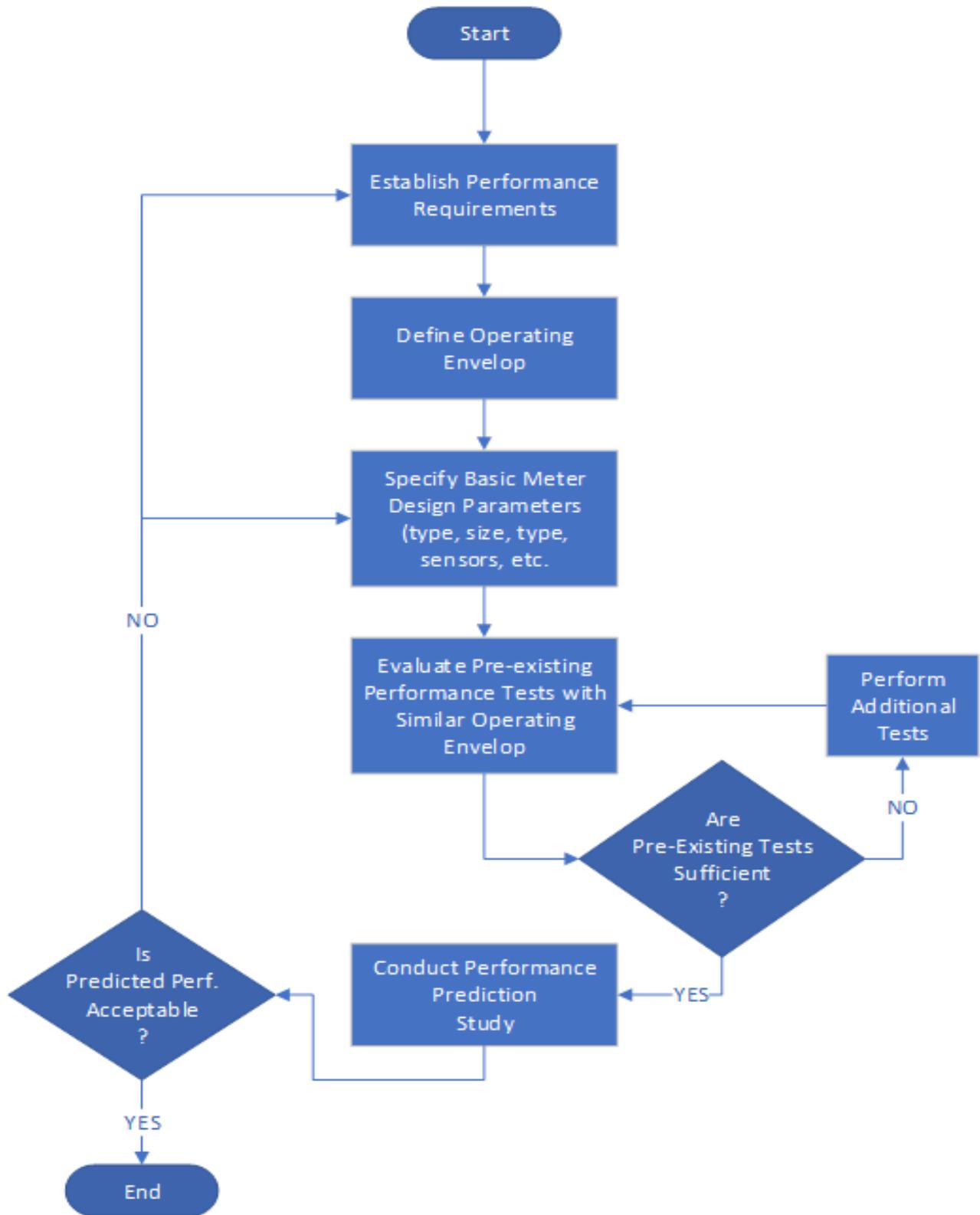


Figure 6.1 - Meter Selection Process

Because the primary purpose of a MPFM is to provide phase fractions rates (oil, gas, and water), establishing the measurement performance requirement is foundational for selecting an appropriate MPFM. Therefore, at a minimum, the user shall establish performance requirements for measurement uncertainty of the phase rates (e.g. oil, gas, water) for the operating envelope.

6.2 Production Profile and Operating Envelope Specification

6.2.1 Production Profile

User shall develop a Production Profile for the designed life of service and shall include at least the parameters of pressure, temperature, acceptable pressure drop, liquid hydrocarbon phase density, gas phase density, and gas, oil, phase fractions, and water flow rates for low, medium, and high production rates.

For oil and gas production flow rate determination at standard conditions, PVT shall be provided. Specifically, the user shall provide flash and other phase behavior calculations. Additionally, the user shall provide a prediction of GVF and WLR and all information available about the water chemistry.

6.2.2 Operating Envelope Specification

Stakeholders shall work together with MPFM manufacturer to develop an OE specification that meets the intended requirements. If the MPFM OE is limited to a proportion of the Production Profile, that shall be clearly stated in the specification.

The MPFM manufacturer shall describe meter sensitivity to fluid composition and chemical makeup. Refer to section 3.2.4 for high level overview of component technology sensitivities.

The user shall provide all the required fluid data as input to the MPFM, and the expected fluid property changes over the production life. However, because this data may not be based on adequate sampling and may include estimated values, the manufacture and user should jointly examine the quality of the data relative to the various sensitivities of the MPFM and justify the acceptance of the inputting data to the MPFM.

At a minimum, the user shall provide the parameters listed in Table 6.1. Some of the parameter values can change over the production life. Furthermore, the MPFM manufacturer shall confirm the user's calculations. All discrepancies shall be resolved before making a final meter selection.

Table 6.1 Operating Envelope Parameters

Parameter	Specific Parameters Examples
Pressure	Operating pressure, Maximum pressure (e.g. shut-in pressure)
Temperature	Operating temperature, Maximum temperature, Minimum temperature
Flow velocity or volume flowrate	Maximum, normal, and minimum velocity or volume flow rate for both gas and liquid flows
Permanent Pressure loss	Maximum allowable permanent pressure loss
Phase fraction rangeability	Minimum to maximum gas/liquid phase fraction (GVF) and WLR range on both a daily average and instantaneous (e.g. 10-minute average)
Flow Orientation	Up flow or down flow or horizontal flow depending on the MPFM location in the production network
Fluid composition	Mole fractions of the components of reservoir fluids.
Injected chemicals	Includes chemicals used to inhibit hydrates, corrosion, scale, asphaltenes, paraffins etc.
EOR fluids	Enhanced oil recovery fluids which can include water, natural gas, and CO ₂
Density	Bulk fluid, liquid phase, hydrocarbon liquid, gaseous hydrocarbons, and water densities
Viscosity	Viscosity for all phases and a bulk multiphase viscosity range if known
Flash calculations	Reservoir fluid flash calculation reports (single or multistage) preferably based on original reservoir fluid samples.

The manufacturer shall request, and user shall provide, any additional required data, for example:

- Water Chemistry: Salinity of water and other water dissolved chemicals that can affect WLR determination
- Wet Gas Parameters: Lockhart-Martinelli Parameter, Froude Number, Condensate-Gas Ratio (CGR)

- Phase Inversion: Fluid parameters in the inversion zone including viscosity changes and temperature dependency. (this impacts measurement technology selection for oil-continuous or water-continuous situations)

The user should review the fluid characterization and advise the MPFM Mfg. whether there is a possibility of a buildup of deposits (wax, scale, asphaltenes, etc.), or erosion by sand. The MPFM Mfg. shall provide assessment of the impact of these flow assurance challenges on performance expectation of phase rate determination.

6.3 Meter Sizing

The process of meter sizing can be viewed as a decision-making process as shown in Figure 2.

The MPFM Mfg. shall determine a maximum and minimum flow range (e.g. turndown ratio) and performance expectation over the production life for each MPFM. In selecting the meter size, the user and MPFM Mfg. should conduct a sizing effort to optimize measurement uncertainty together. In some cases, multiple meter sizes may be selected over the production life (e.g. early, mid, and late life) to maintain the performance. For applications with large turn down ratios, the MPFM Mfg. shall determine the overlap range while meeting the 'non-measurement' performance criteria.

Utilizing the production profile and other pertinent data as requested by the MPFM Mfg. and referenced in section 6.2 and table 6.1 above. shall provide an analysis showing what meter size is required to meet performance requirements over the life of service.

The user and MPFM Mfg. shall verify that the selected meter will not be influenced by any non-flow-measurement performance criteria. For example, concern of erosion due to high flow rates and entrained particles can be a critical issue. This is addressed in API RP 17S. Also, the permanent pressure loss induced by the meter can impact the flow of low-pressure wells enough to alter the production profile.

Performance expectation should consider production over life of service as well as artificial lift methods. For example, reduced natural production rates that are enhanced by use of lift gas can result in a larger gas fraction at the measurement point vs forecast production. As GVF and WLR change there will be variable uncertainty in pure phase flow rate measurements. In higher gas volume fraction (GVF), uncertainty in liquid rate determination will vary.

6.4 Measurement Performance Assessment

The user shall examine the flow range as predicted by the production profile data and identify any areas over the production profile that exceeds the performance expectation requirements. In estimating the performance, both the user and MPFM Mfg. should use performance test or field data for each meter type being considered. The average GVF and water cut should be used to link measurement uncertainty from MPFM's available test data and field experience to establish the measurement performance prediction.

If there are areas where the performance expectation is not known, the user should evaluate the value of independent testing to verify performance expectation by either repeating the study with a different meter size, repeat the study with a combination of meter sizes specific to the production life, or identify areas where the meter size will not accommodate the desired performance level. The user and MPFM Mfg. shall also re-examine the non-flow-measurement performance criteria for each meter size considered (see Figure 6.2 below).

Ultimately, if the meter sizing study indicates a portion of the production life will not meet the expected or required performance levels, the user shall estimate a MPFM performance level for these areas. In some cases a change in the meter size is necessary during the life of the production in order to maintain accuracy.

The user shall evaluate, and document measurement performance prediction based on performance tests including those resulting from API MPMS Chapter 22.7, and relevant field experience. In some cases, additional testing may be identified to fill in any associated gaps. Due to limitations on test facilities, interpolation, and extrapolation of the test data to the flow conditions indicated in the production profile may be used.

Evaluating the data from previous tests for current applications can require the user to develop data points other than those originally reported. This process can take on two forms, interpolation, or extrapolation.

1. Interpolation is the process where the desired (production profile) point falls between two previously tested points, one above and one below. Linearization and curve fitting techniques are applied to predict the meter's performance between the two previously tested points. Interpolation is an accepted technique; however, the uncertainty increases as the relative difference (span) between the two previously tested points increases. Intermediate flow phenomena lying between two previously tested points such as phase inversion zones, may invalidate interpolated values.
2. Extrapolation is the process where the desired (production profile) point falls outside two or more previously tested points. Linearization and curve fitting techniques are applied to predict the meter's performance beyond (above or below) the previously tested range. Extrapolation requires an assumption that the rate of change of the curve-fitted dependent variable (usually the meter's performance) is "reasonably" characterized by the independent variable. Extrapolations based on the underlying fundamental physical fluid forces generally have a higher probability of success than extrapolations based solely on curve fitting techniques.

While extrapolation is not a recommended process, there are times where it is the only process available. The user shall identify all points calculated by extrapolation, document the calculation process, and justify using extrapolated data in the meter specification process. Extrapolation should be handled with care especially at the extreme ends of low and high GVF or/and WLR as considerable meter performance changes are expected in these regions.

Performing supplemental or additional tests can be decided for a variety of reasons. For example, for new meter types there can be a lack of qualified data, the test matrix used in previous tests was not broad enough, fluid properties do not match, etc. For all new tests or supplemental tests performed refer to API Ch. 22.7 for Flow Loop Testing.

Users can also use field data where comparisons between MPMF and a reference measurement exist. The user shall provide reports on field data used in the performance predictions that establishes the uncertainty of the reference measurement. The user shall qualify that the operating envelopes associated in the field data is like the operating envelop and production profile parameters for the intended application.

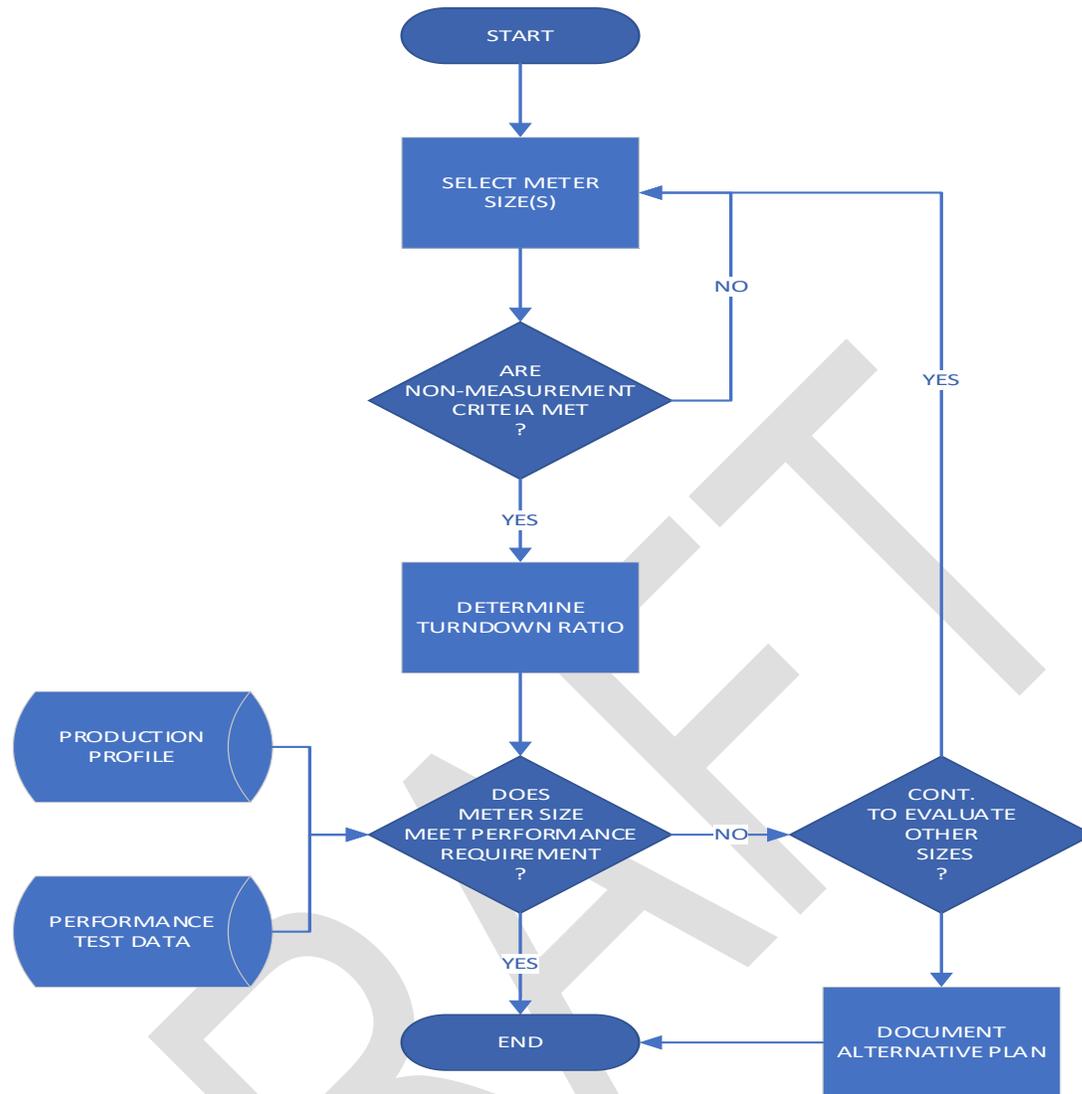


Figure 6.5 – Meter Sizing Process

6.5 Other Operational Specifications

The MPFM Mfg. and user shall collectively identify the fluid properties and the sampling requirements (frequency or event drivers) needed to maintain the measurement performance requirement.

Self-contained diagnostic data shall be evaluated when selecting a meter. For example, tracking water salinity can be an indicator of formation water versus injected water. Therefore, the manufacturer should identify diagnostic information that can be useful as well as tolerance/alarm set points.

The MPFM Mfg. shall state the number of individual configurations stored in the MPFM system.

The MPFM Mfg. and user shall collectively specify the requirements for data transmission, data processing (live or post processing), data archival, speed capabilities of data transmission, self-contained data archival, simulator and configuration software capability, redundancy, and local storage capability.

6.6 Manufacturing Codes

The MPFM Mfg. shall state the manufacturing codes and standards the MPFM complies with. For subsea applications, the MPFM Mfg. shall follow the additional requirements of API RP 17S

6.7 Environmental Considerations

The MPFM Mfg. shall specify the environmental conditions of temperature, pressure, hazardous environment that the MPFM is rated for.

Additional site-specific environmental conditions should also be considered when selecting the MPFM. The following are some of the possible conditions to consider, however, many more conditions and issues can arise.

- Background radioactivity that might interfere with MPFM nuclear detectors.
- Extreme ambient temperature, either high or low temperatures
- Rate of change of temperature
- Vibration
- Wind driven sand and dust
- Snow or sand drifts
- Saltwater environments and external condensation
- Electromagnetic interference
- Hazardous atmospheres

6.8 Original Configuration Files

The configuration file shall be defined and installed in the MPFM software prior to start-up. The MPFM Mfg. shall make a record of the configuration file as well as the fluid properties and other data supplied by the user to generate the configuration file. The user shall confirm the configuration data during commissioning activities and should also assure the file record is saved as the “original” configuration file. Having a confirmed record of the original configuration data can be an important tool for verification activities once the meter becomes operational. It is also important as an audit trail feature, especially for allocation measurement.

Sometimes the exact fluid properties are not known until after start-up. In this case, assumed data can be used to create a temporary configuration file and fluid property data. The user shall keep all configuration file data and meter raw data when using a temporary configuration file to facilitate post-processing of data with the permanent configuration file data. The user shall limit the time for using temporary files as much as practical. The use of temporary configuration file data shall be noted by the mfg. in the project documentation and should include a revision log of the configuration file.

It may be necessary to have more than one configuration file for a single MPFM. This is most common when one MPFM handles multiple wells, or wells have multiple zones. It may also be possible to establish a single configuration file for multiple sources. For example, if all the sources (e.g. wells) tied to the MPFM have similar properties, an average single field configuration might be suitable. In these cases, the user and MPFM Mfg. shall assess the variation in fluid data and evaluate the measurement impact. Based on the measurement impact, the user may pursue a single (average) field configuration file data set or opt for multiple files and data sets. If multiple file datasets are used, the user should include a revision log of the configuration file(s), for each data set.

6.9 Power

The MPFM Mfg. shall specify the minimum power requirements for the selected meter’s start-up and steady state conditions.

Because an MPFM is often used to make critical flow measurements, the user should consider utilizing a dedicated battery back-up system to power the sensors and flow computer such that the MPFM will continue to compute flow values and maintain the on-board memory during power outages. Power shall be cycled during testing steps (FAT, SIT, or Commissioning) to verify configuration files and data are restored as expected.

During acceptance testing at the factory or on site, the power will likely be clean from electrical noise. However, electrical noise can exist in actual operations. Therefore, the user and MPFM Mfg. should consider sources of electrical noise, like electrical submersible pumps or similar equipment, during the design so that issues are mitigated before installation in the field.

MPFM electronics may be able to run on AC or DC at various voltages. The user shall work with the MPFM Mfg. to understand options and limitations including cable length to understand potential issues. Power issues that can affect measurement accuracy shall be identified by the MPFM Mfg. and addressed by both the user and the MPFM Mfg. during the meter selection phase.

6.10 Communications

If redundant electronics are used, the procedural steps of how to switch between primary and secondary electronics shall be documented by the MPFM Mfg. If control system commands are required, the user shall assure the associated control system functionality. If the switching is controlled internally in the MPFM logic, the MPFM Mfg. shall assure proper functionality. In some MPFM system designs, both types of sensor switch control may be available. In all cases the user and MPFM Mfg. shall include testing of the functionality that they are responsible for prior to installation or start-up.

The increased data amount with MPFMs may cause communication issues, if not designed for. This can be a problem for the systems and equipment that receive the MPFM generated data. Therefore, the user with input from the MPFM Mfg. shall assure that the capability of the equipment receiving data from the MPFM meet the requirement and not lose data or mis MPFM generated data.

Data transfer with polling engines, or intermediate communication devices, can split information into different size packets. This can cause misalignment in the data transfer and result calculation errors. For example, if the user is calculating GVF with a liquid volume at time zero and a gas volume a minute later, the resulting value may not represent the condition in the MPFM. If both volumes are not in the same data packet at the same time, the calculation result can be errant. Therefore, the MPFM Mfg. shall ensure that data across packets is consistent

An MPFM can have both internal and external memory. If external memory is used, the user shall ensure that it is installed and able to write fast enough to keep up with electronics. Furthermore, external memory or other necessary external communications may not be allowed by IT security policy. Therefore, the user shall verify with IT or other departments the steps needed to comply with policies and mitigate any issues prior to start-up.

It can be a critical electronic data audit function to keep time stamped data between the MPFM and external systems synchronized. Therefore, most MPFM computers have the functionality to adjust the on-board internal clock to synchronize date and time with other (external) systems (e.g. SCADA systems). The user and MPFM Mfg. shall assure the capability of clock synchronization. Calendar events, like daylight savings or leap years, may be configurable and should be accounted for in the design.

The user shall specify requirements for data communication. This includes not only routine collection of those parameters required for assessment of oil and gas production, but what is necessary to achieve comprehensive meter diagnosis in a way that will meet operational needs.

The user shall specify the number and type of communication channels, data rates, and level of redundancy required. The MPFM Mfg. shall validate the MPFM capability to meet the specification.

6.11 Data Handling Plan

The output data set available from an MPFM is larger than typical metering end devices. The data typically displayed is only a subset of all the data stored in memory. An MPFM will likely have flow data relative to both line (actual) conditions and standard conditions. Plus, there can be a significant amount of diagnostic data available.

Therefore, the user shall with input from the MPFM Mfg. develop a data handling plan that addresses both data gathered routinely and data that is gathered on an as need basis as well as data capture and transmittal frequencies. Through the data handling plan the user shall ensure that the computation of results is sufficiently fast and robust enough for all anticipated conditions. The MPFM Mfg. shall inform the user of the data and frequency of data capture recommended for optimal meter performance for consideration in developing the plan.

The user should canvas the various users of the MPFM data and incorporate their needs into the data handling plan. Besides Measurement Engineers, the roles that can be interested in MPFM data include but are not limited to:

- Production and Reservoir Engineers,
- Operations and Facility Engineers,
- Operators,
- Hydrocarbon Accounting,
- Auditing, and
- Regulatory Compliance

Most MPFMs have data that is available to internal MPFM software and to external users. The limitations of MPFM software and data handling should be understood. At a minimum, a data handling plan shall accommodate the capture of all physically measured inputs and make them available for external query, either through diagnostic downloads or continuous data acquisition. The MPFM manufacturer should have a list of recommended variables to monitor externally.

Based on information provided by the MPFM Mfg., the user shall specify in the data handling plan, the minimum data set that will be collected during routine operations, and at what minimum frequency they are to be collected and transmitted. The data handling plan should specify these same quantities for other modes of operation, but especially for diagnostic activities. The data handling plan shall also specify transmittal frequency and other data transfer related parameters for downloading of information to the meter, as in firmware revisions.

7 Meter Installation Design Considerations

7.1 General

Meter installation design involves specifying the physical location and orientation of the meter in the pipework and considering environmental conditions. The installation design accommodates a variety of operational requirements, the operational readiness, and the ability to perform periodic validations of the MPFM system.

A variety of topics and issues that should be addressed during MPFM installation design include but is not limited to the following:

- Physical location and connections to perform validation checks against the reference measurement system
- Mounting the meter (e.g. skid mounted or a standalone mounted directly in the pipework)

- Access to the meter for maintenance, calibration, or fluid sampling
- Electronics interface console mounting / location (local on meter or remote)
- Inclusion of reference thermal wells and pressure tapping for verifying pressure and temperature devices
- Relative location to injected fluid streams (e.g. chemical injection, gas lift or processed fluids used in pigging)
- Location relative to upstream pressure reducing fitting (e.g. choke or backpressure valve) due to increased GVF
- Straight-run of upstream and downstream piping requirements.
- Overhead clearance requirements.
- Orientation requirements. (vertical flow up / Horizontal flow)
- Insulation and shielding requirements.
- Electronic protection from environmental exposure, e.g. heated enclosures with explosion proof ratings

For subsea installations, the user and MPFM Mfg. shall follow the specific guidance and requirements given in API RP 17S in addition to the requirements listed here that are not addressed in API RP 17S.

7.2 Meter Location

7.2.1 Flow Dynamics

For the chosen location, the user and MPFM Mfg. together shall assess the installation effects relative to the measurement uncertainty. The user shall describe the pipework in the vicinity of the meter including at a minimum:

- Valves
- Chokes
- Chemical injection
- Internal appendices such as thermowells or probes

Flow regimes and short duration flow regime variations (e.g. slugging) are caused by the inherent flow dynamics (e.g. well dynamics) but can also be made more severe due to upstream piping relative to the meter location. Therefore, the user and MPFM Mfg. shall assess the flow regimes (reference flow regime maps Fig 4.2, 4.3 and 4.4) that are likely to be experienced by the meter for any location considered. The assessment shall span over the life of the measurement system, and the MPFM Mfg. shall describe how the meter will respond in each regime, as well as during the transition from one regime to another. The results of these assessments can result in a review or reassessment of the meter selection described in section 6 above.

The meter should be located where all fluids move in the main flow direction through the meter. Furthermore, the meter should be located where large pressure and temperature variations are not likely to occur, such as immediately downstream of a large pressure reduction. If this type of location cannot be avoided, the MFPM Mfg. shall assess the impact to the meter measurement performance and any related long-term reliability issues.

7.2.2 Accessibility

This section is intended for MPFMs that are installed on land or in topside production applications.

If field MPFM validation is required, the user shall ensure accessibility to the meter, piping, and valving so the metered flow can be routed, in an isolated fashion, to a reference measurement system. The possibility of unintended bypass, for example internal leakage through closed valves should be assessed. Refer to section 10 for Methods of Onsite Validation.

The meter location shall be at a point where flow can easily be diverted with valving upstream and downstream of the meter. The location of the valves should be sufficiently close to the meter to minimize work associated with draining and venting process fluids. It may be required to have double valve isolation (e.g. double block and bleed valves upstream and downstream of the meter).

If an individual MPFM sensor(s) (e.g. gamma densitometer, capacitance / conduction probes, Microwave probes), require field calibration, maintenance or cleaning, the meter location shall be at a point where flow can be diverted and the meter isolated with valving. The meter shall be located to allow access to the internal components of the MPFM. This may require bypass piping and additional consideration of the overhead clearance requirements of the MPFM location relative to overhead piping, asset structural framework, MPFM skid members.

Although there is currently not a method for multiphase fluid sampling, there are fluid properties / characteristics that are useful in routine MPFM maintenance and surveillance. The location of the sampling point(s) should be accessible.

7.3 Environmental Considerations

The assessment of the environmental conditions, during the meter selection phase, in section 6.7 above should be re-assessed during the meter installation design. This reassessment should take into consideration the proposed physical meter location and ensure that any new, previously unknown, or environmental conditions that have changed are addressed. Results from this assessment may lead to a re-evaluation of the meter that was selected for this installation due to changes in the environmental conditions.

8 Manufacturer Factory Acceptance and Vendor System Integration Testing

8.1 General

The requirements in this section shall take place prior to the MPFM shipping to site.

8.2 Device Factory Configuration

An MPFM system typically relies on several individual devices, each of which can directly influence the overall quality of the multiphase flow measurements.

Individual devices which impact the required performance over the expected operating envelope of the multiphase measurements shall be calibrated by the manufacturer prior to installation in the MPFM. Such calibrations shall be performed using standards traceable to NIST or other equivalent relevant primary standard as long as such standards exist.

The end user shall be given the opportunity to review the calibration certificates measurement devices installed in a MPFM upon receiving the MPFM package. Multiple point calibrations may be required by the end user during the selection/procurement phase to cover a specific range of a given primary measurement.

- a. DP span: Min calibrate DP transmitter for span what does this entail
- b. conductivity in salinity range: minimum of a zero-flow calibration – what does that entail as a minimum
- c. gamma/MW in fraction range: minimum of a zero-flow calibration – what does that entail as a minimum

8.3 Factory Acceptance Test (FAT)

A Factory Acceptance Test (FAT) is a functional test which takes place prior to shipping the individual MPFM from the factory to verify that the MPFM has been manufactured, assembled, and configured according to the vendors procedure and the user requirements. It is typically the final step of the manufacturing process. An example of a FAT process flow diagram can be found in Figure 11.2.1.

FACTORY ACCEPTANCE TEST

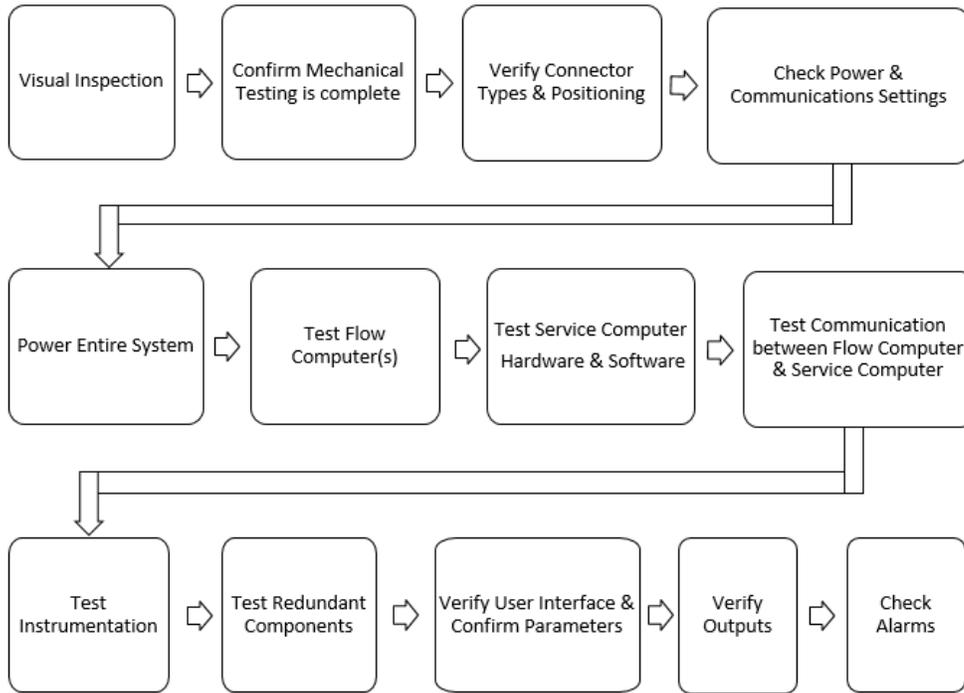


Figure 8.1 Flow Chart Representing a FAT Plan

MPFM shall undergo a FAT with the following requirements:

1. The vendor shall provide a concise FAT procedure which includes the functional testing and success criteria for critical components of the MPFM.
2. The FAT procedure and success criteria should be agreed with the user.
3. The vendor shall prepare a report documenting findings of the FAT and highlighting gaps, if any.
4. The user shall be given the opportunity to review the FAT report prior to MPFM leaving the manufacturers custody.

The FAT is a functional test and often includes a wet test in a small-scale flow loop. If a performance test is required (see section 8.5) it often takes place as part of the FAT.

Example of functional tests often included in MPFM FAT are:

- a. visual inspection confirming physical meter assembly & markings are per assembly drawings
- b. dimensional checks
- c. correct connector type, pin configuration & orientation
- d. mechanical integrity testing i.e. pressure tests
- e. verification of proper wiring and settings of power and communication as per interconnection diagram
- f. power-up test
- g. verification of settings on individual instrumentation and signal test
- h. communication test with meter flow computer
- i. software and user interface checks
- j. software version check and update if required
- k. verification of instrumentation calibration and associated documentation
- l. verification of meter communications interface setup
- m. verification of units of measure

- n. alarm checks
- o. verification of initial configuration with field fluid(s) properties and applicable PVT model
- p. packaging and preservation of equipment checks
- q. check that final meter communication setup matches client system requirements

8.4 System Integration Test (SIT)

8.4.1 General

The System Integration Test (SIT) is performed after the FAT and will typically repeat several steps already covered during the FAT. This is to verify that there has been no damage to the meter during transportation between the vendor and the system integrator/installation location, and that the communication setup matches the user's system (and not the vendor's system as would have been the case during the FAT).

It is normal practice to perform a pre-SIT in the form of power and communication test early in the project using an MPFM simulator, usually at the control system vendor location.

Brown field and subsea applications are usually done with simulators during SIT. Green field onshore or topside applications are usually done with actual infrastructure.

The MPFM should undergo a SIT prior to shipping to the site of final installation. Typical steps in a SIT include the following:

8.4.2 User

The user shall:

- a. Specify which other systems the MPFM will interface with
- b. Specify what test program will be used to verify correct meter operation as part of the complete system.
- c. Review and approve the SIT procedure and success criteria provided by the vendor/integrator

8.4.3 Vendor/Integrator

The vendor shall:

- a. Provide a concise stepwise SIT procedure.
- b. Agree SIT procedure and success criteria with user.
- c. Prepare a report documenting findings of the SIT and highlighting gaps, if any.
- d. Give the user the opportunity to review the SIT report prior to the MPFM removal from the system.

If a radioactive source is installed, a radiation survey should be performed.

An example of a SIT process flow diagram can be found in Figure 8.2.

Recommended SIT includes the following tasks:

1) Physical Interface Inspection

- a) Verify there is no visual damage to meter, seals or sealing surfaces
- b) Verify any retrievable component connections have functionality to be secured and detached
- c) Verify any running tools can be attached/detached and operate as designed
- d) Verify installation angle of meter in vertical/horizontal orientation meets vendor requirements
- e) Verify rotational alignment of meter meets vendor requirements
- f) Verify correct electrical connections are mated and fully secured
- g) Verify labeling is still in place. Pay special attention to radiation labelling location and required information

2) Electrical and data Connection Testing

- a) Verify the MPFM can be remotely accessed through the service computer and control system.

- b) Verify the MPFM can be updated with a new configuration file from the service computer, through the control system.
- c) Verify raw data and/or diagnostic data logging can be accessed and retrieved through the control system.
- d) Verify output parameters and units are correct.

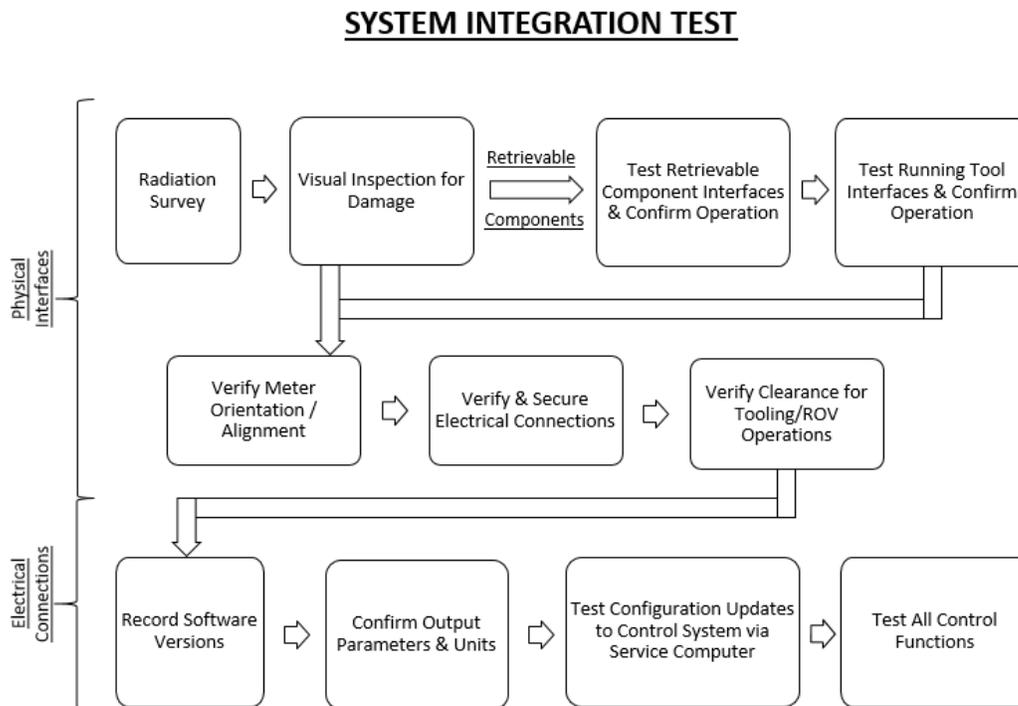


Figure 8.2 Flow Chart Representing a SIT Plan

9 Initial Commissioning and Site acceptance testing (SAT)

9.1 Commissioning

9.1.1 General

Following successful manufacturing, FAT and SIT the meter will be installed. The vendor will usually provide clear guidelines on installation requirements during the project phase. The user/contractor will therefore be able to install the meter independently and perform all required leak check at the operating pressure independently of the vendor.

After the MPFM has been installed in the field, it must be commissioned prior to operation. The term commissioning encompasses all the activities that are required to bring the meter online at its field location with confidence that it will perform to its best level in service once vendor and user measurement specialists have left the site.

9.1.2 Onsite initial Commissioning

The following sections describe the checking and testing activities performed on site after MPFM installation and hookup to control system. This consists of meter Commissioning before well is put on production followed by the Site Acceptance Test once the well starts flowing.

The user should be provided with a document describing procedures that will be carried out by the vendor when the MPFM is commissioned at the client's site. The scope of the on-site commissioning will normally include both

the field setup of the MPFM prior to initial flow, as well as the site acceptance test (SAT) described next. The test should be performed with the complete system installed. Communication and power should be tested in all scenarios during the commissioning process to ensure the reliability of the installation.

The vendor usually has a list of activities to be performed at commissioning. A generic sample of such a list might be as follows.

1. Pre-commissioning activities - The user should identify any special preparations or activities that have to take place at the site prior to meter installation and start-up; With the assistance of the meter vendor, the user shall describe the activities that will comprise the commissioning of the metering system, i.e. bringing the equipment into active measurement service, delivering a procedure that includes all steps needed to ensure that the meter delivered is installed and configured correctly for optimal operation.
2. System checks - The vendor shall connect to the MPFM via a service computer or equivalent, either a laptop or a permanently installed computer, to run various system checks specific to the MPFM.
3. System initial configuration - During commissioning, Fluid properties data can be entered as a part of the system initial configuration (often same data used during FAT). Single or multiple baseline references for the MPFM can be measured and compared to FAT results. This step should be repeated during the Site Acceptance Testing using actual produced fluids.
4. System test—all readings from the MPFM to the customer's supervisory system shall be checked. The communication system continuity can be checked by monitoring it over an appropriate period.
5. Leak check—on-site testing is the responsibility of the client and is ordinarily performed according to the client's procedure. The vendor should be consulted prior to pressure testing to reveal any limitations regarding test medium and test procedure.
6. Final testing—once all commissioning activities have been completed, the user can perform a thorough quality check of the first flowing data through the MPFM to ensure consistency of results, a task typically performed by the vendor.

The commissioning activities may include, but is not limited to, the following:

- a) visual inspection and verification that installation is according to vendor specifications (for topside meters)
- b) power-up test
- c) communication test
- d) individual instrumentation tests including communication test with meter flow computer
- e) installation of gamma source, surface radiation test and empty pipe calibration (for topside meters with radioactive sources)
- f) software and user interface checks
- g) software version check and update if required
- h) verification or update of field configuration. Depending on the type of MPFM installed, specific fluid calibrations to well fluids may be required. If such calibrations are a pre-requisite, careful planning must be undertaken in advance to ensure that fluid samples are available from the well in question – rather than from a comingled stream
- i) verification that required variables are read correctly by the control system to the correct precision and in the correct unit
- j) setup of raw data logging and file transfer for future recalculation of measurement data if needed. This is particularly important for MPFM used in fiscal allocation where the user may want a complete record of raw data for partner sharing traceability

After completed commissioning, the vendor shall issue a commissioning handover report to the client, describing in detail the various activities and checks performed. Values are recorded in the commissioning procedure and attached to the report. The formal commissioning report shows that the equipment has been commissioned on site and is ready for use by the client.

An example of a Commissioning process flow diagram is found in Figure 9.1.

COMMISSIONING

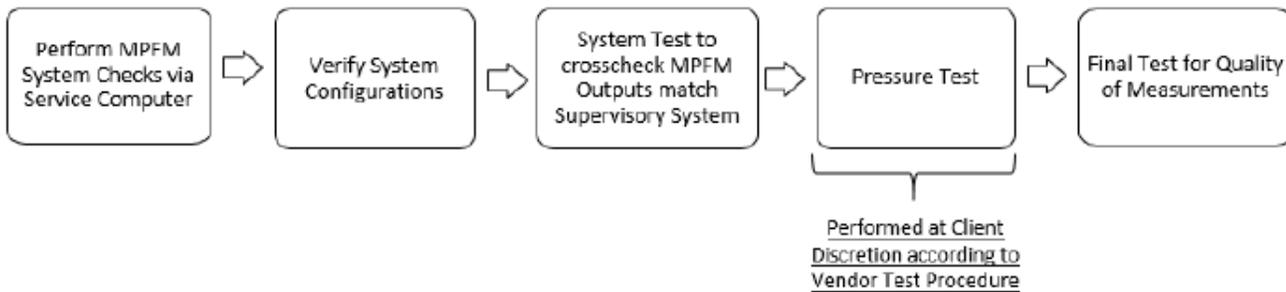


Figure 9.1. Flow Chart Representing a Commissioning Plan

9.2 Site Acceptance Testing

9.2.1 General

The user shall describe what test program will be used once the meter is installed to verify meter performance during commissioning and start-up.

Although it may not always be possible, an on-site verification of static and dynamic meter performance under controlled conditions may be carried out and can prove to be extremely valuable. During FAT or other flow loop testing, the meter's measurement performance will have been verified in controlled conditions using controlled fluids. During an SAT, the meter is exposed to reservoir fluids which provides a good opportunity to ensure that the meter is configured with the information that matches the flowing fluids. Where possible, the user shall compare the measurement results to a reference measurement system, such as a test or production separator, or in the case of a subsea MPFM, comparison may be made to a topside MPFM. Abnormal differences shall be reviewed to ensure that consistent results are obtained, otherwise that differences are quantified and understood.

The SAT during commissioning of subsea meters will be limited in scope due to the nature of the application where meters can be far away from the production platform with outputs that are often commingled. However, since this can be one of the few times when commingled subsea wells may be isolated for individual tests, careful attention shall be paid to the planning of the SAT in these cases.

For MPFMs that use nuclear sources, it is possible that the source for the FAT is different from that which will be used in the application. In this case it is important to ensure the nuclear instrument is verified at the site.

9.2.2 Site Preparation for Meter

Any special preparations or activities that have to take place at the site prior to meter installation and start-up should be identified. For example, for "brownfield" applications, significant preparation can be required to incorporate the meter. As another example, if the meter employs a radioactive source, the posting of radiation warning signs in the area may be required. A responsible party normally will be named to discuss radioactive sources handling plans with local oversight authorities.

As an example of SAT activities, piping the meter in series with separation facilities on the location can give early indications of any differences that might be observed once the device is in service. Of course, this form of verification has to be performed with great care, especially for accuracy comparison, as the use of field separators as a reference measurement system for meter comparison can be difficult.

The entire process of testing the meter at the field location can be formalized in a manner similar to that of the FAT or flow loop test, with formal checklists appropriate for the kinds of equipment and the conditions found at the site. For example, the reference measurement system will likely be a separation system, either the test

separator or one of the production separators, and the range of flow rates available can be somewhat limited.

9.2.3 Static Meter Correction with Production Fluids

The meter may require static meter correction with production fluids and with an “empty pipe.” The user should consider the fact that obtaining representative samples of the intended meter location can be an issue if production streams are commingled prior to the point where sampling is obtained. In these cases, users might use samples collected during post-drilling evaluation.

10 Method(s) of Onsite Validation

10.1 General

MPFM onsite validation processes are used to validate the device is operating as expected. There are several methods that can be used for MPFM verification including periodic static verification, periodic dynamic verification against a reference measurement system for example, facility production allocation or mass balance, a dedicated, or by difference reference measurement system. Continuous comparison against facility production allocation or mass balance is an alternative verification method. Ensure all inlet and outlet sources are being measured, accounted for, or removed from the MPFM or reference measurement system flow path (gas lift, blanket gas etc.)

Varying production profiles, operational configurations, and less than ideal flowing conditions can yield flow results that are more complex and leads to challenges when assessing the MPFM's performance.

10.2 Validation Plan

An onsite MPFM validation plan shall be developed for each facility based on the facility system design. The validation plan shall include the following.

10.2.1 Frequency

The plan shall document the frequency (time based, or event based) and duration of a MPFM validation.

If MPFM repeatedly fails validation after a defined number of occurrences, the validation plan and chosen validation method shall be reevaluated and updated in the validation plan and validation acceptance criteria.

If the MPFM validations are consistently meeting acceptance criteria after a defined number of occurrences, the frequency of the MPFM validation may be adjusted or reduced. If the MPFM and system material balance are continuously within the MPFM acceptance criteria, the validation may be performed on an exception basis.

Both commercial and regulatory requirements should be assessed prior to making any adjustments to the validation plan.

10.2.2 Method(s)

The plan may include more than one validation method, and, in this case, the primary and alternative(s) methods shall be identified.

The method(s) covered in this section are: Direct Validation to a reference measurement system with single phase meters, By Difference validation to a reference measurement system with single phase meters, Validation to a reference measurement system material balance and shall align with manufacturer validation procedures & requirements.

The method(s) shall consider location & accessibility of MPFM(s) (local on pad, remote off pad, subsea, topsides) and facility comparison hardware &/or data.

Physical performance and calibration of the MPFM and reference measurement system components shall be completed before validation.

Where a test separator is used as a reference measurement system refer to API MPMS Ch 20.5 for requirements.

10.2.3 Comparison conditions and units of measure

Comparison conditions and units of measure shall be stated. All values for comparisons, in mass or volume, shall be reported at the same conditions. (i.e. Standard or line conditions).

10.2.4 Fluid property verification

The thermodynamic path during MPFM validation, fluid characteristics / process conditions (stable or changing, single or multiple stages), fluid sample collection and analysis methods & frequency shall be stated.

Fluid phase behavior of the MPFM and reference measurement system should follow the same thermodynamic path (stages of separation) for temperature and pressure changes.

Fluid characteristics (composition & properties) should be determined at both the MPFM and the reference measurement system measurement point(s) including oil shrinkage factor, flash gas factor, oil, gas and water composition, density, and viscosity.

When equations of state or PVT models are used, they should be documented and deviations between MPFM and reference measurement system identified and the impact on reported volumes/masses quantified.

API MPMS Ch 20.4 should be referenced for additional guidance on setup and use of Phase Behavior Modeling.

Ensure the PVT properties that are being used are representative and consistently derived.

10.2.5 Performance acceptance criteria

Performance acceptance criteria shall be stated and shall consider MPFM manufacturer performance specification across full range of production life, and regulatory & commercial requirements.

Perform validation method quality check (i.e. compositions, sensor components, process conditions)

The validation acceptance criteria should be based on uncertainty estimates of both the MPFM and the reference measurement system.

MPFM and reference measurement system measurement components shall be maintained according to manufacturer guidelines or industry best practices.

10.2.6 Reporting and record retention.

Validation reporting and record retention method, frequency and duration shall be documented in the validation plan. This shall include record of validation performance results against the acceptance criteria, fluid properties and MPFM configuration updates if any.

MPFM configuration file management shall be defined in the validation plan. The configuration file data shall be recorded for as found prior to making any changes to the data and as left after the changes have been made.

10.2.7 Surveillance

Routine monitoring of outputs from the MPFM allows for the observation of measurement trends and can point to potential systematic errors.

A surveillance plan, establishing the MPFM monitoring activities and frequency, shall be documented within the MPFM validation plan based on manufacturer recommendations, and known best practices.

The following items should be considered when developing the surveillance plan:

- (1) Use of diagnostics to confirm meter health
- (2) Taking redundant measurements or integrating redundant equipment for comparison
- (3) Monitor changes in fluid properties or
- (4) Use of process monitoring for observing system balance trends.
- (5) Use of fluid sampling or density monitoring
- (6) Comparison of the MPFM outputs to well and/or production network models.
- (7) Calibration of individual MPFM sensors

10.3 Validation Execution

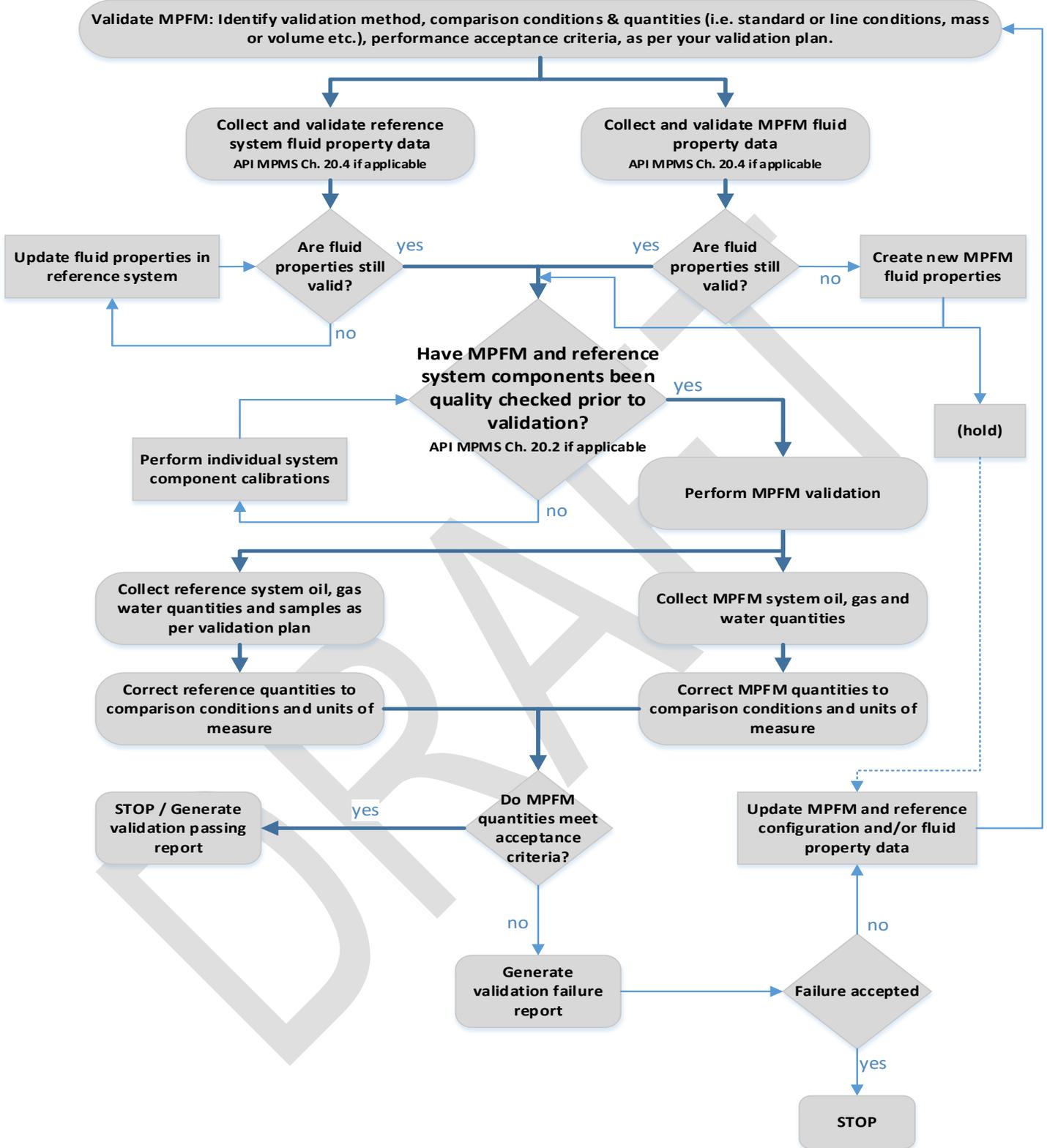


Figure 10.1 MPFM Validation Decision Matrix

10.3.1 Direct validation to a reference measurement system with single phase meters

This method shall be done on a mass or volume basis following the requirements listed below and can be used with fig 10.1 above. The direct validation of an MPFM to a reference measurement system can be accomplished by comparing the measured /calculated quantities from the MPFM with the measured /calculated quantities from the single-phase meters located on the reference measurement system. For the direct validation using a measured / calculated quantity comparison, the following steps should be taken:

- (1) Applicable sections of API MPMS Ch. 20.5 shall be followed including the following.
- (2) Fluid purging and flow stabilization
- (3) Ensure all inlet and outlet sources are being measured, accounted for, or removed from the MPFM or reference measurement system flow path (gas lift, blanket gas etc.)
- (4) Fluid samples from all outlet sources of the reference measurement system should be obtained to conduct compositional, phase behavior and fluid property analysis. These samples may be collected as composite samples, based on proportional to flow sampling, for the validation period. Spot samples may be used and represent a short moment of time in the validation period.
- (5) Determine fluid properties including shrinkage, flash gas, S&W, compressibility, fluid density and average temperature and pressure for the test duration.
- (6) Ensure all valves used to align the fluid for the MPFM validation are checked for leakage.
- (7) Determine phase quantities for the validation duration, for each measurement point, and correct to comparison conditions. Reference API MPMS Ch. 20.4 (Phase Behavior Modeling) when adjusting accumulated quantities using an EOS / Phase Behavior Model.
- (8) Sum the quantity for each phase gas, oil, and water. This may require accounting for (1) the quantity of water in the oil, and gas in the oil, and adding it to the total water and gas and (2) recirculated oil and gas quantities.
- (9) Assess results against the acceptance criteria as stated in the validation plan, see section 3.4
- (10) Document the results according to the record retention plan.

NOTE: If a representative reservoir fluid sample (PVT) is available, it can be used to validate the data from the MPFM. If a representative reservoir fluid sample is not available, gas and liquid samples from the separator can be collected and mathematically recombined into a single-phase stream based on respective flow rates. New samples are not required for every validation if representative samples are available. A representative sample is one in which the sample was taken at the flow rate condition, fluid properties (i.e. composition), and process parameters (i.e. temperature and pressure) that correspond to a hydrocarbon production stream in a non-transient state.

10.3.2 By difference validation to a reference measurement system with single phase meters

The by difference validation of an MPFM to a separator with single phase meters can be accomplished by flowing multiple MPFMs' (one or more MPFMs used as reference measurement system and one MPFM under test) commingled production through a reference measurement system with single phase meters and performing a subtraction of measured quantities of the reference measurement system MPFM's direct measurement sum total from quantities from the single-phase meters located on the separator. It is recommended that the reference measurement system MPFM to be subtracted to be the lower accumulated quantity to avoid introducing excessive uncertainty to the MPFM under test.

These quantities determined by difference can then be assigned to the MPFM under test quantities included in the original commingled quantity. This typically involves shutting in or diverting to another flowline the MPFM to be by-difference validated. For the by difference validation using a measured / calculated quantity comparison, the following steps should be undertaken:

- (1) Follow the steps outlined in section 10.3.1 above and API MPMS Ch. 20.5 for by difference testing for the commingled stream.
- (2) Remove the quantities for the MPFM under test and repeat the steps outlined in section 10.3.1 above and API MPMS Ch. 20.5 for by difference testing.
- (3) Assigning Uncertainty to the reference measurement system MPFM before subtracting from the reference measurement system total.
- (4) The MPFM(s) used as the reference measurement system for subtraction must be validated before being used as a reference measurement system.

By-difference MPFM validation refers to the practice of estimating MPFM quantities via subtraction of measured MPFM(s) quantities from a commingled measurement and an assignment of quantities to an unmeasured MPFM included in the original commingled measurement. This typically involves shutting in or diverting to another flowline the MPFM to be by-difference validated. This method is considered less accurate than the direct validation to a reference measurement system method, due to the added uncertainty of the additional MPFMs not under test.

10.3.3 System Material Balance

An alternative MPFM validation method can be performed against a reference measurement system material balance. This reference measurement system may be a single 2 or 3 phase separator (ex. bulk or test), a process train of multiple separators or, a complete process system. This method is based on the principal of conservation of mass and may be used as a stand-alone method or included as a reference check against other methods. This alternative method may be applied to a single or to multiple MPFMs. This method should only be used on MPFM production systems where the fluid; properties are similar, come from the same reservoir, follow the same thermodynamic path, and use MPFMs that are operating the same phase behavior model.

- (1) Follow the steps outlined in section 10.3.1 above and API MPMS Ch. 20.5 for direct or by difference testing.
- (2) Account for any quantity that is removed at each stage of separation in the reference measurement system (this is usually gas and water). Fluid contamination should be checked at each of these points by analysis of samples collected.

10.4 Assessing Results

The validation results from one or more methods shall be assessed against the success criteria at the prescribed frequency in alignment with the validation plan.

In the event the validation does not meet the acceptance criteria the reference measurement system and MPFM should be evaluated and may include:

- (1) Compare results against phase behavior modeling
- (2) Check the system material balance
- (3) Evaluate the reference measurement system meters operation and stability as described in API MPMS Ch. 20.5 Recommended Practice for Application of Production Well Testing in Measurement and Allocation.

- (4) Check for liquid or gas carry over, carry under or emulsion present in the reference measurement system separator as described in API MPMS Ch. 20.5
- (5) Look for measurement trends or any drifts between the MPFM and reference measurement system
- (6) Use flow maps (i.e. liquid versus gas rates) or composition maps (i.e. GVF vs. WLR) to look for patterns/clusters in the MPFM data as shown in API MPMS Ch 22.7 MPFM Testing Protocol
- (7) Identify potential sources that may be affecting MPFM or reference measurement system performance, which can include:
 - (i) Conditions outside the MPFM's operating envelope
 - (ii) Dynamic flow patterns or regimes (e.g. slugging)
 - (iii) Adverse process conditions (e.g. vibrations, acoustics, extreme temperatures)
 - (iv) Production chemistry (e.g. wax, asphaltenes, scaling)
 - (v) Chemical treatments (e.g. hydrate-inhibitors, demulsifiers)

In the event the success criteria cannot be met after troubleshooting the steps taken to troubleshoot shall be documented and the back-up volume determination method used.

11 Decommissioning

11.1 General

The user shall develop a radioactive source disposal plan that complies with local, national, and international regulations where applicable.

11.2 Safety Considerations

11.2.1 Radiation Safety

11.2.1.1 Overview

While multiphase meters are subject to the same kinds of safety issues as other devices placed in high-pressure flow lines, there is one aspect of their use that is somewhat unique, i.e. their fairly common use of radioactive sources of various types and activity levels (strengths). Their use in measurement is described in some detail in Section 4.

Because they are present in so many of the multiphase and wet gas meter offerings, it is important that an MPFM user understands the safety issues that accompany their use.

These can be summarized as:

11.2.1.2 Radiation safety when a source is installed within a meter,

- a) radiation safety when a source is being transported to or from installation in a meter, and
- b) assurance that there is no leakage from a meter in which a source is stored.

Fortunately, local regulations on these topics as well as some international standards exist that cover these kinds of occurrences.

11.2.1.3 Radiation Exposure From Source Installed in a Meter

For MPFMs that are permanently installed in an operational meter, there are numerous local regulations and some international standards that apply. The following standard may be useful:

— IAEA DS 379, Safety Standards for Protection Against Ionizing Radiation, or ISO 7205, Radionuclide gauges— Gauges designed for permanent installation.

Once installed in the meter and the meter is activated, radioactive source operating procedures that are supplied by the meter manufacturer and are in accord with both local regulations and IAEA DS 379, are normally followed. The radioactive sources are protected with lead or other radiation shields to the outside, but during operation its interior is exposed to radiation. Even though the meter source may be weak, exposure to radiation from a meter with an active, unshielded source cannot be tolerated. Therefore, the user should be prepared to take appropriate measures whenever an unintentional exposure to radiation may have occurred. Further, preventive measures should always be in place to prevent such an event, e.g. signage, blind flange endcaps, interlocks, etc.

11.2.2 Transportation of Radioactive Materials

In the case of radioactive sources that are transported to or from the site where they will be used, other local, national, or international regulations and standards are applicable. The following standard is often used:

— IAEA DS 387, Safe Transport of Radioactive Material.

Where possible, the radioactive source(s) is (are) typically transported separate from the meter body. If transported while incorporated in the meter, the complete meter assembly is considered part of the radioactive source system and therefore treated and handled accordingly.

NOTE Transport regulations apply also in those cases where a portable MPFM is used in a testing application by a well test service company.

11.2.3 Source Container Leakage Testing

The integrity of containers of radioactive source material such as MPFMs will normally be checked frequently by doing a so-called wipe test. This test is commonly required at least every 36 months, in some states and locations more often.

For subsea meters this requirement is generally waived.

12 Informative Annex

Worked Report Example

The intent of this worked example is to provide operators with a consistent and transparent approach for conducting, applying, and reporting MPFM Validations used in a measurement and allocation system. It is not intended to prescribe a particular MPFM

Validation method, particular EOS or Phase Behavior application to calculate quantities used in the MPFM Validation.

Direct Validation to Separator with Single Phase Meter example.

An MPFM was recently installed upstream of a choke for allocation measurement. A single-phase gas meter, a single-phase oil meter, and a single-phase water meter were installed downstream of a 3-phase separator (being used as a validation reference measurement system) to validate the MPFM's performance. See figure A 1. A pre-validation checklist was used to ensure the reference measurement system and MPFM components have been quality checked before beginning the validation. See figure 2. During the MPFM Validation, the MPFM gas, oil, and water actual volumetric flowrates at the MPFM's operating pressure and temperature are collected and then corrected to the line conditions of the single-phase gas meter using an EOS (Equation of State) software. The EOS software corrected for oil shrinkage and flash gas going from the line conditions of the MPFM to line conditions of the single-phase gas meter. The gas, oil, and water actual volumetric flowrates for the MPFM (at gas single-phase pressure and temperature) and the single-phase meters are then corrected to standard conditions, for convenience using the same EOS software. See figure 3 for the sequence of calculations. Figure 4 shows an example of the calculation results and Figure 5 shows an example of the report with results at the comparison conditions and units of measure, as well as the acceptance criteria, as stated in the MPFM Validation Plan.

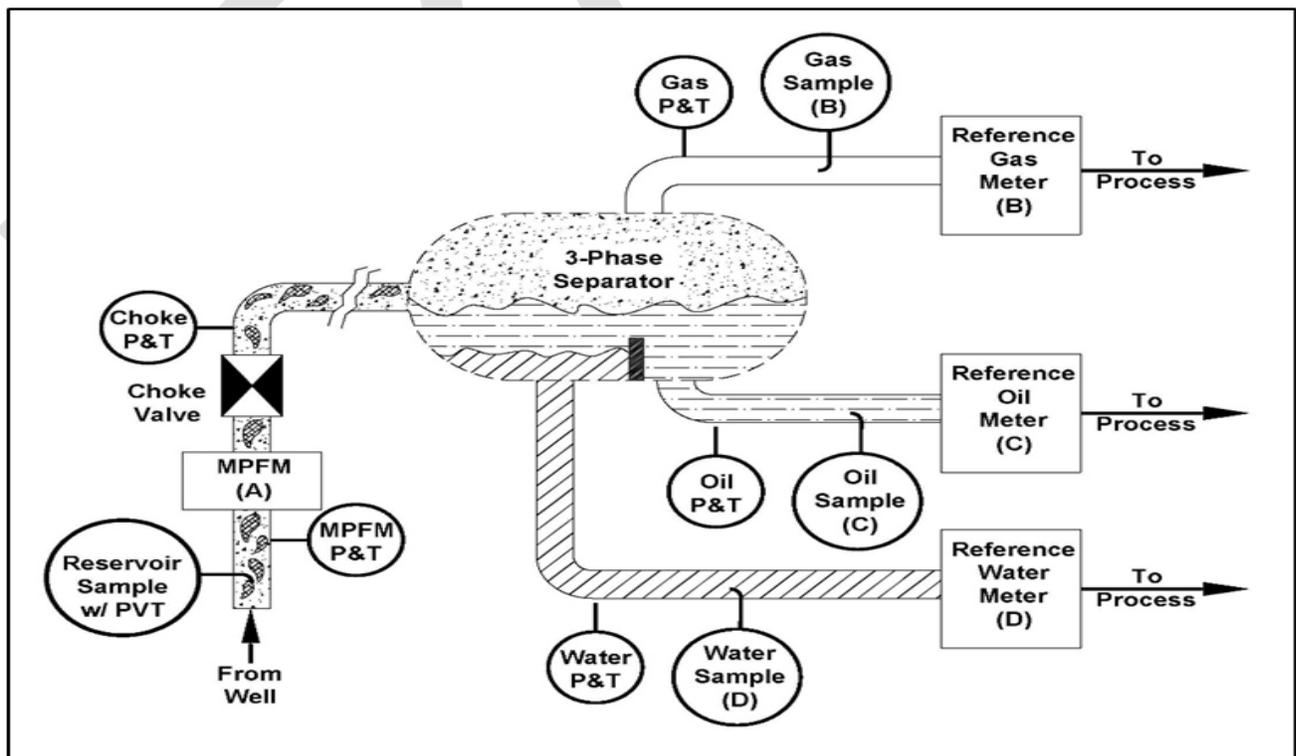


Figure A 1 Validation System Configuration

Sample Pre-Validation Checklist
Direct Validation to Separator with Single Phase Meters (Volume)
One Well Direct Validation w/3 Phase Separator

MPFM vs Reference System Acceptance Criteria		Value
Volumetric Gas Flow Rate at Standard Conditions:		±5%
Volumetric Oil Flow Rate at Standard Conditions:		±10%
Volumetric Water Flow Rate at Standard Conditions:		±10%

Process Setup:		Yes/No
Commercial and Regulatory requirements addressed:		Yes
All safety procedures met, All equipment below MOP:		Yes
All inlet and outlet sources are being measured and accounted for:		Yes
Well flow stability in accordance with API MPMS Ch. 20.5:		Yes
Choking pressure within acceptable range of desired choking pressure:		Yes
Has critical historical data from MPFM, well, and process been reviewed:		Yes

Reference System Setup:		Yes/No
Have separator efficiency calcs been performed and within acceptable limits:		Yes
Have diagnostic checks been performed on all single-phase meters:		Yes
Sampling bottles prepared for MPFM, and single phase meter locations:		Yes

MPFM Setup:		Yes/No
MPFM gas, oil, and water outputs within meter limits:		Yes
MPFM gas, oil, and water outputs within acceptable range of desired values:		Yes
Have MPFM diagnostic checks been performed:		Yes
Have MPFM DP's been statically verified:		Yes
Have MPFM temperature sensors been verified:		Yes
Have other MPFM sensor technologies been verified:		Yes
Have configuration files been updated and documented		Yes

Calculation Setup:		Yes/No
Has EOS software version been recorded:		Yes
Has uncertainty assessment been performed on MPFM and reference system devices:		Yes
Can the gas, oil and water acceptance criteria be achieved given MPFM, separator, and single-phase flow meter uncertainties:		Yes

Figure A 2 Pre – Validation Checklist

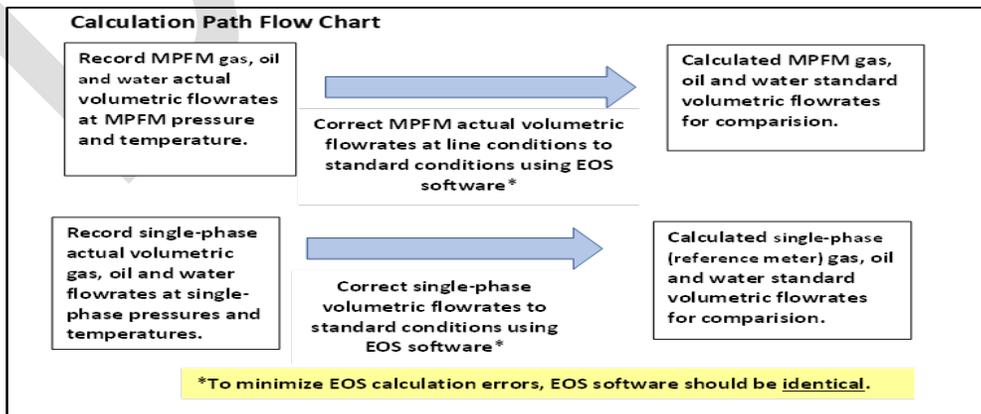


Figure A 3 Calculation Path Flow Chart

MPFM Validation Report					Reference PVT	Sample ID	Type	Well	
Test Date From:	1/1/2019 00:00	1	MPFM:	Well A-1 MPFM	Oil Sample:	9000000_O	Oil	Well A-1	
Test Date To:	1/1/2019 06:00		Reference:	Reference ID	Gas sample:	9000000_G	Gas	Well A-1	
Duration (hrs):	6		Well API#:	Well API number	EOS:	Peng Robinson			
R AC: Reference Actual Conditions	Measured (Reference)	Simulated (Reference)		Diff (Check)	Simulated [R AC → M AC]	Measured (MPFM)		Diff (Validation)	M AC: MPFM Actual Conditions
Temperature [R AC]	70.00	70.00	F	0.00%	90.00	90.00	F	0.00%	Temperature [M AC]
Pressure [R AC]	550.00	550.00	psia	0.00%	1,200.00	1,200.00	psia	0.00%	Pressure [M AC]
Oil Volume	15,456.00	15,456.00	barrel/day	0.00%	16,669.95	17,161.88	barrel/day	2.95%	Oil Volume
Gas Volume	9,000.00	9,000.00	kSCFD	0.00%	67.39	67.95	kCFD	0.84%	Gas Volume
Water Volume	855.00	855.00	barrel/day	0.00%	857.98	829.60	barrel/day	-3.31%	Water Volume
					6,707.68	6,846.31	ft3/hr	2.07%	HC Volume
					6,908.40	7,040.39	ft3/hr	1.91%	Total Volume
Volumetric GOR	582.30	582.30	scf/bbl	0.00%	4.04	3.96	ft3/bbl	-2.05%	Volumetric GOR
Oil Mass	174,039.65	173,259.98	lb/hr	0.45%	178,753.16	182,095.84	lb/hr	1.87%	Oil Mass
Gas Mass	18,874.02	18,661.28	lb/hr	1.14%	13,168.11	13,740.62	lb/hr	4.35%	Gas Mass
Water Mass	12,997.58	12,997.58	lb/hr	0.00%	12,997.58	12,975.82	lb/hr	-0.17%	Water Mass
HC mass	192,913.68	191,921.27	lb/hr	0.52%	191,921.27	195,836.46	lb/hr	2.04%	HC mass
Total mass	205,911.25	204,918.85	lb/hr	0.48%	204,918.85	208,812.28	lb/hr	1.90%	Total mass
Mass GOR	0.108	0.108	lb/lb	0.69%	0.074	0.075	lb/lb	2.43%	Mass GOR
Oil Density	48.13	47.92	lb/ft3	0.45%	45.84	45.36	lb/ft3	-1.05%	Oil Density
Oil API	51.84	52.67	-	-1.57%	61.03	63.07	-	-3.24%	Oil API
Gas Density	0.05033	0.04976	lb/sft3	1.14%	4.68967	4.85287	lb/ft3	3.48%	Gas Density
Water Density	64.98	64.98	lb/ft3	0.00%	64.76	66.86	lb/ft3	3.25%	Water Density
					28.61	28.60	lb/ft3	-0.03%	HC Density
					29.66	29.66	lb/ft3	-0.01%	Total Density
WLR	5.2%	5.2%	-		4.9%	4.6%	-	-5.80%	WLR
					40.6%	40.2%	-	-1.05%	GVF
OLR	94.8%	94.8%	-		95.1%	95.4%	-	0.30%	OLR
Reference AC to SC					Reference AC to MPFM AC to SC vs MPFM SC				
Oil Volume SC		13,783.58	stb/day		13,570.14	13,823.90	stb/day	1.87%	Oil Volume SC
Total Gas SC		12,598.50	kSCFD		12,883.69	12,570.25	kSCFD	-2.43%	Gas Volume SC
Water Volume SC		854.00	stb/day		854.00	825.00	stb/day	-3.40%	Water Volume SC
Volumetric GOR		815.12	scf/bbl		772.87	732.45	scf/bbl	-5.23%	Volumetric GOR
Volumetric GOR		914.02	scf/stb		949.41	909.31	scf/stb	-4.22%	Volumetric GOR
Oil Density SC		49.89	lb/sft3		50.03	50.82	lb/sft3	1.57%	Oil Density SC
Gas Density SC		0.05915	lb/sft3		0.06165	0.06014	lb/sft3	-2.45%	Gas Density SC
Water Density SC		65.07	lb/sft3		65.07	67.23	lb/sft3	3.32%	Water Density SC
Oil Shrink		0.8918	stb/bbl		0.8140	0.8055	stb/bbl	-1.05%	Oil Shrink
Oil Mass SC		160,869.89	lb/hr		158,828.19	164,339.53	lb/hr	3.47%	Oil Mass SC
Gas Mass SC		31,051.38	lb/hr		33,093.07	31,496.93	lb/hr	-4.82%	Gas Mass SC
Water Mass SC		13,000.00	lb/hr		13,000.00	12,975.82	lb/hr	-0.19%	Water Mass SC
Reference AC to SC adjustment factors					Reference AC to MPFM AC to SC adjustment factors				
Oil Shrink		0.8918	stb/bbl		0.8780		stb/bbl		Oil Shrink
Oil Flash		261.1	scf/stb		286.2		scf/stb		Oil Flash
Notes:					Standard Temperature (SC): 60.00 F Standard Pressure (SC): 14.696 psia				

Figure A 4 Example of calculation results

Method: Direct Validation to Separator with Single Phase Meters (Volume)

One Well Direct Validation w/3 Phase Separator

Well A-1 MPFM (Direct Individual)

Raw Data

	MPFM (STD)	Test Sep (LC)
A-1 MPFM Gas Vol (MSCF):	12,570	9,000 : Separator Gas Outlet (MSCF)
A-1 MPFM Oil Vol (BBL):	13,824	16,100 : Separator Oil Outlet (BBL)
A-1 MPFM Water Vol (BBL):	825	210 : Separator Water Outlet (BBL)
A-1 MPFM Liquids Vol (BBL):	15,825	16,310 : Separator Total Liquids (BBL)

Adjustment Factors for Reference Measurement

Oil S&W (%):	4%
Oil Shrinkage:	0.8780
Flash Factor (SCF/BBL):	286.2

Corrected Volumes to Standard Conditions

	MPFM (STD)	Separator (STD)	Balance	Acceptance Criteria
Gas Volume Corrected (MSCF):	12,570	12,884	-2.4%	+/-5%
Oil Volume Corrected (BBL):	13,824	13,570	1.9%	+/-10%
Water Volume Corrected (BBL):	825	854	-3.4%	+/-10%
Liquid Volume Corrected (BBL):	14,649	14,424	1.6%	+/-10%
Calculated S&W (%):	5.6%	5.9%		
GOR (SCF/BBL):	909			

Start Time:	1/1/2019 0:00
Finish Time:	1/1/2019 6:00
Length of test (hrs.):	6.00

Figure A 5 Final Passing Report using comparison conditions and units of measure, as well as the acceptance criteria as stated in the Validation Plan.

In the example above, it takes into consideration the initial separator efficiency and fluid representation before making Sep-MPFM comparisons for validation. The three panels, in the calculation worksheet of figure 4, clearly identify the steps as follows:

- 1) Equilibrium and Fluid validation

In this step the simulated Sep rates and fluid properties are compared with actual measurements to identify the proper functioning of separator or/and the validity of the fluid composition used in the EOS. Big differences would be showstopper requiring more investigations before proceeding to next step.

If no issues with measurement and Sep, then the fluid characterization could be the problem requiring sampling and analysis. In this case MPFM configuration with new sample results is necessary.

In this panel, measured and simulated Shrink and Flash can be added to the list to better isolate the source of discrepancies if due to fluid mischaracterization in the simulator.

Performance criteria will have to account for measurement uncertainty when defining the discrepancies trigger points.

2) Sep-MPFM validation at LC

This step consists of running the simulator a 2nd time, taking the separator volumes to MPFM LC. A direct comparison can be done using the MPFM measurements (from registries) and the Sep simulated data. A good match is necessary but may not be sufficient to completely validate the Sep-MPFM measurements. At line conditions only limited PVT data from the MPFM PVT model is used (e.g. densities at LC) which does not fully describe the PVT model representation of the flowing fluid.

A mismatch at this point can be seen as a showstopper to continuing the validation any further before correcting the problem.

3) Sep-MPFM validation at STD

This last step uses all other PVT conversion ratios from LC to STD that describe the conversion (B_g , R_s , FVF). These are essential components of the MPFM PVT model that become apparent at this step. Discrepancies at STD conditions could be indicative of an old configuration file in the MPFM based on old fluid sample.

Note that in this conversion step (from LC to STD) the instrumentation does not play as big role as the fluid representation.

By following the above validation path, the simulated Sep results to STD are considered valid because it is based on validated fluid representation (from step 1), however checking EOS tuning may be needed to ensure good match between PVT lab experimental results and the EOS calculations to STD.

Being the reference measurement system, the Sep performance is expected to exceed the MPFM best performance that is defined by the manufacturer (MPFM

Product Sheet). Knowing the expected performance (uncertainty) of MPFM outputs becomes necessary in defining the performance criteria adopted for the go/no-go validation decision.

(Mass balance at STD and LC is an important validation criterion as it links the volumes to densities evaluated at vastly different conditions. In this step both the fluid properties and the ratios are used in the MPFM PVT model)

BIBLIOGRAPHY

Put in list format:

1. The Norwegian *Handbook of Multiphase Flow Metering* [26], first published by the Norwegian Society for Oil and Gas Measurement (NFOGM) in 1995 and updated in 2005, is a rich source of material on multiphase flow in pipes and the technology and tools of its measurement. With permission of the NFOGM, some materials from the Norwegian *Handbook* have been incorporated into this standard.
2. Some sections from the *Guidance Notes for Petroleum Measurement* [27], originally published by the UK Department of Trade and Industry (DTI) (now the Department of Energy & Climate Change), may be relevant for those responsible for upstream measurement.
3. API Publication 2566, *State of the Art Multiphase Flow Metering* [11] and ASME MFC19G, *Wet Gas Flow Metering Guideline* [13].