

Recommended Practice for the Design, Testing, and Operation of Subsea Multiphase Flow Meters

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Introduction

Multiphase flow is a complex fluid phenomenon presenting many observable and distinctly different spatial patterns. These flow regimes are a function of fluid composition, velocity, flow orientation, geometry, and operating conditions. This creates a greater number of variables requiring measurement than single phase flow. Multiphase flow meters (MPFMs) use a combination of measurement principles and software models to delineate component parameters of the specific flow condition being measured. These elements are further combined to simultaneously resolve the total flow state and inform the user of the flow rate of each phase.

This document is intended for use by persons familiar with the principles of multiphase flow and the technologies used to measure its constituent parts. This Recommended Practice (RP) outlines a strategy for the correct sizing, specification, integration, and testing of MPFMs to maximize their performance for a specific application. Measurement techniques used in MPFMs are complex and only brief descriptions are included herein. It is recommended that the reader be acquainted with API *MPMS* Chapter 20.3 which describes in detail the technologies of multiphase metering, calibration, measurement uncertainty, and operation. API *MPMS* Chapter 20.3 is referred to in this document wherein the reader should seek further information or best practice. API *MPMS* Chapter 20.3 is not specific to subsea applications.

Various expertise is required throughout the life cycle of the MPFM to achieve optimal performance. Due to the number of interfaces and design parameters a strategy is required to ensure the meter is appropriate for its specific application. This RP acts as a guide outlining key parameters of the strategy that quantifies meter performance based on application, sizing data, technology constraints, and performance checks through manufacturer, independent facilities, and in-situ tests.

There is a distinct separation in ownership between MPFM specification, testing, and installation versus commissioning and operation. This RP addresses equipment design in Section 4 through Section 7 and commissioning/operational issues in Section 8 and Section 9. To ensure accuracy and functionality of the MPFM, a coherent handover between equipment design and long-term operations is required. Several operational issues are managed in this RP, as well as metering methodologies, but these are only intended as suggested interfaces to be addressed. This RP should be used in combination with appropriate measurement and operational standards to develop a comprehensive strategy for the design, installation, and long-term operation of an MPFM.

Recommended Practice for the Design, Testing, and Operation of Subsea Multiphase Flow Meters

1 Scope

This document provides recommendations for the sizing, specification, system integration, testing and operation of in-line subsea multiphase flow meters (MPFMs) for measurement of full stream, multiphase flow for well testing, allocation measurement, fiscal measurement, well management, and in flow assurance applications. This Recommended Practice (RP) includes wet gas flow meters as a subset of MPFMs.

2 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any addenda) applies.

API *Manual of Petroleum Measurement Standards (MPMS)*, Chapter 20.3—*Measurement of Multiphase Flow*

API Specification 6A, *Specification for Wellhead and Tree Equipment*

API Specification 17D, *Design and Operation of Subsea Production Systems—Subsea Wellhead and Tree Equipment*

API Standard 17F, *Standard for Subsea Production Control Systems*

API Recommended Practice 17H, *Remotely Operated Tools and Interfaces on Subsea Production Systems*

API Recommended Practice 17N, *Recommended Practice for Subsea Production System Reliability and Technical Risk Management*

API Recommended Practice 17P, *Recommended Practice for Subsea Structures and Manifolds*

API Recommended Practice 17Q, *Recommended Practice on Subsea Equipment Qualification*

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

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

3.1.1

accuracy

The degree of conformity of a measurement to a known standard for the unit of measurement.

3.1.2

actual conditions

measurement conditions

line conditions

flowing conditions

Conditions of pressure and temperature of the fluid at the point where fluid properties or flows are measured.

3.1.3

allocation

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

3.1.4

availability

The ability of an item to be in a state to perform a required function under given conditions at a given instant of time, or in average over a given time interval, assuming that the required external resources are provided.

3.1.5

fiscal measurement

Measurement system application designed and operated for the purpose of establishing the flowing fluid quantity for the purpose of custody transfer, allocation, royalty, or taxation.

3.1.6

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, or any injected chemicals. For example, liquid occupying the bottom of a horizontal conduit with the gas phase flowing above.

3.1.7

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.

3.1.8

pressure-volume-temperature PVT

The phase behavior and physical properties of hydrocarbon fluids at pressure and temperature.

NOTE Included are relative phase volume, gas-oil ratio (GOR), bubble point and hydrocarbon dew point, density, formation volume factors, compressibility, viscosity, and composition.

3.1.9

reliability

The ability of an item to perform a required function, under given conditions of production, environment, and usage, for a required time interval.

3.1.10

uncertainty

The parameter, associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand (the value being measured). See ISO/IEC Guide 98-3:2008 for a more complete definition.

3.1.11

validation

Confirmation, through the provision of objective evidence, that the requirements for a specific intended use or application have been fulfilled.

NOTE 1 The term “validated” is used to designate the corresponding status.

NOTE 2 The use conditions for validation can be real or simulated.

3.1.12

verification

Confirmation, through the provision of objective evidence, that specified requirements have been fulfilled.

NOTE 1 The term “verified” is used to designate the corresponding status.

NOTE 2 Confirmation can comprise activities such as:

- performing alternative calculations,
- comparing a new design specification with a similar proven design specification,
- undertaking tests and demonstrations, and
- reviewing documents prior to issue.

3.1.13

virtual meter

Predictive well rate modeling (virtual flow metering system) is a well rate determination method that utilizes computer-based predictive flow modeling techniques in conjunction with real-time well/process sensor and instrumentation data for continuous multiphase well rate estimation.

3.1.14

well test

The execution of a set of planned data acquisition activities to broaden the knowledge and understanding of fluid phase rates and hydrocarbon properties of a producing well from a reservoir.

3.1.15

well production trajectory

The trajectory of production parameters displayed by a well over time, sometimes shown in a flow or composition map.

3.1.16

wet gas

A subset of multiphase flow in which the dominant fluid is gas and in which there is a presence of some liquid.

3.2 Acronyms and Abbreviations

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

EFAT	extended factory acceptance test
ESS	electrical stress screening
FAT	factory acceptance test
FMECA	failure modes, effects, and criticality analysis
GOR	gas-oil ratio
MPFM	multiphase flow meter
MTBF	mean time between failure
PCU	Power and communications unit
PSL	production specification level
PVT	pressure-volume-temperature
RIT	receive inspection test
ROV	remotely operated vehicle
RSO	Radiation Safety Officer
SCM	subsea control module

SIT	system integration test
STP	standard temperature and pressure

4 Design Criteria

4.1 Operational Philosophy

The operator shall provide an operational philosophy that includes the following.

- a) Intended use of the MPFM data and the frequency of data transmission and accumulation.
- b) The number of wells to be measured with each MPFM.
- c) Location of the MPFM within the subsea architecture.
 - The location of the MPFM is dependent on its intended application and the overall field layout. For continuous measurement from individual wells, the MPFM may be located within a tree as part of a choke bridge/flow module/retrievable module, or as part of a jumper. Subsea MPFMs can typically be configured to measure multiple wells intermittently. In this case, the MPFM can be placed in a manifold with the capability to route the flow from individual wells to the MPFM.
- d) Access requirements for retrieving and installing MPFMs and MPFM electronic modules.
- e) Valve requirements (including operational reliability) for routing different wells through a single MPFM.
- f) Reliability requirements for the MPFM.
- g) Requirement to verify and calibrate the MPFM accounting for the uncertainty of any available in-situ verification methods—e.g. test separator or computational well model and availability of samples.
- h) Methods of accounting correctly for gas lift or washwater injection upstream of the MPFM, and the effect on the salinity of produced water.
- i) Production rates that the MPFM is to be designed for.
- j) Anticipated operational and flow-assurance concerns as well as PVT characterization.
- k) Details of any chemical injection regime (see 4.8).

The manufacturer and operator together shall specify the following.

- i) Methods of verification of MPFM capability to measure fluid flows within the specified uncertainty range, throughout field life (see Performance Testing, Section 7.5).
- ii) Methods of determining impact of change in fluid composition on performance.

NOTE Particular care is required for applications where hydrocarbon composition is expected to change over time, or where salinity of water is expected to change over time.

- iii) Methods of continuously monitoring MPFM performance and identifying anomalous readings.
- iv) Where production profile spans more than one MPFM performance range or size and consider designing for more than one MPFM to meet the performance and production objective noting that some MPFMs are designed for liquid-dominant or gas-dominant multiphase flow (i.e. not for the full range of GVF).

- v) Performance requirements for the MPFM including uncertainty, repeatability, and reproducibility. ISO/IEC Guide 98-3:2008 (GUM:1995) and ISO/TR 5168:2005 can be used to help understand uncertainty, repeatability, and reproducibility.

4.2 MPFM Functional Specification and Operating Envelope

A functional specification shall be provided by the manufacturer, which shall include the following.

- 1) Describe the measurements provided by the MPFM.
- 2) Provide an overview of the methodology used by the MPFM, including specific technologies used.
- 3) Describe any required inlet and outlet piping configuration.
- 4) Outline how constituent flow rates are determined from the meter in-situ physical measurements, flow models, and configuration input parameters.
- 5) Describe all required inputs, including specific fluid property data needed for the meter to perform to specification.
- 6) Illustrate the elements of the flow computation process.
- 7) Form the basis of meter sizing, performance testing, verification, and uncertainty determination for the MPFM.
- 8) Document the process for calibration of the MPFM, including proposed methods for obtaining calibration parameters required.
- 9) Describe the intended relationship between sensor functionality and flow model versus expected performance. This demonstrates that the measurement technology is capable of achieving a specific uncertainty for a particular flow regime based on reliable process information.

NOTE 1 MPFMs use various measurement technologies to ascertain different parameters regarding the flow stream, there is no one standard technology. API MPMS Chapter 20.3 provides an overview of various principles and measurement technologies.

The functional specification may also include a quantification (via a sensitivity study or similar) of how uncertainty in input variables impacts the uncertainty in output variables.

NOTE 2 All required inputs to the MPFM will have an inherent degree of uncertainty. The process of determining the impact of this uncertainty on MPFM performance is unique to each technology. Typically, this uncertainty is not addressed within the MPFM specification. Depending on data available for the fluid and application sensitivity to MPFM uncertainty, a sensitivity analysis to assess the impact of an error in MPFM configuration on overall measurement uncertainty may be completed.

The operating envelope and expected performance(s) shall be specified over the production profile by the manufacturer.

The impact of operational and flow-assurance concerns as well as PVT characterization shall be documented by the manufacturer.

4.3 Governing Specification

The design, qualification, manufacture, and factory acceptance testing of MPFMs shall adhere to the following standards in addition to vendor, local government, and project specific requirements:

— API 6A

- API 17D
- API 17F
- API 17N
- API 17Q

4.4 Standard Meter Design Parameters

MPFMs shall be designed in accordance with API 17D service conditions and product specification levels.

Relevant information for meter specification includes pressure rating; temperature classification; sour service designation and marking; and product specification level.

As a minimum, the following shall be provided to the meter manufacturer.

- a) Desired/required design life;
- b) Meter location, orientation, and expected piping configuration;
- c) Water depth;
- d) Production profile detailing case flow rate estimates for oil, water, and gas (see Annex A);
- e) Expected flowing pressure and temperature for various production cases over the meter life including shut-in pressure and temperature, as well as flowing pressure and temperature at the meter location for various production cases (see Annex A);
- f) Expected sand production rates;
- g) Potential changes in production cases due to enhanced oil recovery techniques or water breakthrough;
- h) Field life, i.e. expected meter life without planned maintenance accounting for erosion, corrosion, fatigue, and associated failure modes;
- i) Any specific shutdown/start-up scenarios that may effect the MPFM including injection of hydrate inhibitor, variance in gas lift, changes in water injection, and local injection of other chemical inhibitors;
- j) Material requirements, including any provision for sour service;
- k) Potential for wax/asphaltenes, scale formation/salt deposition;
- l) Interfaces with the production system including material interfaces, control system, power, and equipment retrieval.

NOTE Annex A provides a multiphase flowmeter generic data sheet.

All relevant flow assurance studies should be made available to the meter manufacturer where possible, including the system sensitivity study referenced in 4.2. This may include fluid information for PVT and equation of state modeling. Changes to the production profile and salinity due to water breakthrough, increased gas lift, and commingling from other wells and production zones can affect both meter models and configuration parameters.

4.5 Meter Sizing

MPFMs are sized at actual (line or operating) conditions.