

Use of Subsea Wet-gas Flowmeters in Allocation Measurement Systems

API RECOMMENDED PRACTICE 85
FIRST EDITION, AUGUST 2003

REAFFIRMED, OCTOBER 2013



AMERICAN PETROLEUM INSTITUTE

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Upstream Segment

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FOREWORD

This Recommended Practice is under the jurisdiction of the API Executive Committee on Drilling and Production Operations. It is intended to advise the user on various aspects of the use of subsea wet-gas flowmeters in allocation measurement systems. Marinization, operation, abnormal operation, and meter testing are important topics included here, but, foremost, this document proposes novel techniques to be used in the allocation of total production to individual contributing streams.

Deepwater oil and gas prospects often employ a form of development known as a subsea tie-back. In these applications, wells are completed subsea, and production flows to host facilities for processing, generally in shallower waters, and then on to export markets. In many cases, the host infrastructure already exists, although facilities modifications may be required. Certain of these developments require commingling flow from multiple wells, possibly from multiple fields and an assortment of owners. In order to allocate production in these cases, measurement of the full wellstream fluids may be required.

Add to this the greater uncertainty of, and lack of recognized standards for, multi-phase measurement, then place the meters subsea in deep water, and one quickly enters uncharted waters.

Key to the use of multi-phase and wet-gas meters (subsea or topside) is the ability of an allocation system to account for the differential uncertainty of all the metering devices in the system. Even with established standards and practices, the process of reaching agreement on single-phase measurement allocation methodology involving multiple leases and owners is difficult. It is important to understand that subsea wet-gas meters, or any metering system in such a remote and isolated environment, are very likely to experience a higher level of uncertainty, and will probably be exposed to longer periods of undetected, uncorrected bias errors than conventional topside metering systems. When these systems are placed in a commingled operation where they provide input for an allocation of production, the financial risk to the parties involved will be greater than is normally experienced with single-phase, accessible measurement systems. This RP presupposes that these risks are recognized, and that they have been accepted by the affected parties.

This RP presents a recommended allocation methodology that is technically defensible and mathematically optimized to best fit the application, and that equitably accommodates variances in the uncertainty level between meters in the system.

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Suggested revisions are invited and should be submitted to the standardization manager, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005. As it is intended for this RP to be updated within approximately one year, comments on this edition will be very much welcomed.

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Use of Subsea Wet-gas Flowmeters in Allocation Measurement Systems

1 Scope

1.1 WET GAS DEFINITION AND CLASSIFICATIONS

Defining *wet gas* is not an easy task. Historically multiphase flow where gas volume fractions (GVF) have exceeded 90% or 95% has been called wet gas. However, GVF is based on volumetric flow rates at actual conditions in the pipe, and doesn't account for relative differences in the gas and liquid densities. Since many successful devices used for wet gas measurement employ differential methods that are strongly affected by the densities of the gas and liquid relative to one another, the Lockhart-Martinelli parameter is often utilized in defining the boundary between wet gas and other multiphase flow. The Lockhart-Martinelli parameter is defined as

$$X = \frac{Q_l}{Q_g} \sqrt{\frac{\rho_g}{\rho_l}}$$

where Q_l and Q_g are the liquid and gas mass flow rates, and are the densities of liquid and gas at meter conditions. Since mass flow is volumetric flow multiplied by density, we can also define the Lockhart-Martinelli parameter of the wet gas flow in terms of actual volumetric flow rates Q_l^v and Q_g^v .

$$X = \frac{Q_l^v}{Q_g^v} \sqrt{\frac{\rho_l}{\rho_g}}$$

Based on experience gained in flow loop tests, it has been suggested that when the Lockhart-Martinelli parameter for a fluid remains below about 0.35, its behavior is such that many common methods employed for wet gas flow measurement work as they have been designed. Above this boundary these methods may begin to break down and cannot be counted on to yield reliable answers.

The magnitude of the effort that a producer should expend to estimate liquid hydrocarbon production should reflect its importance relative to the produced gas based on its mass flow rate. There will be a class of wet gas where the mass flow of liquid hydrocarbons is insignificant relative to that of the hydrocarbon gas. This shall be called Category 1 wet gas. There will also be a class of wet gas in which the liquid hydrocarbon mass flow is of sufficient magnitude to warrant its careful measurement and recovery. This shall be called Category 2 wet gas. The boundary between the two will normally be at a point where the mass flow rate of the hydrocarbon liquid is 5% of that of the gas.

1.2 LIQUID HYDROCARBON MEASUREMENT

A central problem that must be addressed for those using wet gas meters is the determination of the *liquid hydrocarbon* flow rates of a well stream. A key issue is that water and hydrocarbon liquids co-exist in the liquid phase of the stream. Furthermore, the liquid measured by the wet gas meter may contain injected chemicals (hydrate inhibitor, corrosion inhibitor, etc.), in addition to the condensate, oil, and/or water. In either case discussed below, the volume of injected chemicals flowing through the wet gas meter must be known and input to the computations.

Dependent on whether the wet gas that a particular well is expected to produce is Category 1 or Category 2, the effort to estimate liquid hydrocarbon flow rates will range from very little to very much. The general procedure will be as follows:

1. Determine if there is an online method of measuring water volume fraction available that can be used in the application.
2. Obtain and analyze a sample of the reservoir fluids for each well prior to the onset of normal production. Determine the gas-oil ratio (GOR) of each.
3. For Category 1 Wet Gas, an average GOR may be utilized across all producing wells in the system.
4. Using the GOR derived from these samples and adjusted to each allocation meter's conditions, apply these factors to the gas production for each well to obtain the liquid hydrocarbon production for each.
5. For Category 2 Wet Gas, if the liquid hydrocarbon imbalance grows beyond a predetermined threshold, one of two avenues must be pursued:

a. Actions must be taken to remedy the imbalance. This could involve acquiring a new sample from a well or all wells in the system, or re-estimating the GOR from secondary data sources. Strategies for doing this are considered in Chapter 7 on Abnormal Operations,

or

b. A justification acceptable to all interested parties must be made to explain why choosing (a) is not appropriate.

In the general case, a project will consist of a combination of Category 1 and Category 2 wells, therefore the plans for production must account for this.

1.3 SCOPE SUMMARY

Until a better alternative is found, liquid hydrocarbon measurement will be accomplished by utilizing whatever sampling information is available to determine the well's water volume fraction and GOR. Dependent on the degree of difficulty in obtaining the sample and on the importance of the liquid hydrocarbon production, repeating this activity to

obtain new information on the fluid properties may be done infrequently. Although an operator will certainly have a production sample acquired from each well at its startup (i.e., from a wireline sample-taking tool, or from the flow back to the completion rig) unless the system falls out of balance, there is no requirement to take further samples.

Another problem that must be addressed is the fact that the conditions at the subsea meter will be quite different from those at the reference measurement point at the host processing facility. PVT analyses must be applied to account for phase changes incurred due to the tieback flowline length and differential water depth, as well as any other changes in pressure and temperature that might alter the phase state of the fluid. This will affect both the liquid and gas measurements, and will increase the difficulty of the task. This whole subject of mass transfer between phases and its effect on measurement uncertainty is addressed in Appendix A.

2 Referenced Publications

API

- RP 17A *Design and Operation of Subsea Production Systems*
Manual of Petroleum Measurement Standards (MPMS),
 Chapter 20 "Allocation Measurement"

ISO¹

Guide to the Expression of Uncertainty in Measurement

Basil, M. and A.W. Jamieson, Uncertainty of Complex Systems Using the Monte Carlo Techniques, North Sea Flow Measurement Workshop, Gleneagles, Scotland, October 1998.

3 Definitions and Nomenclature

3.1 DEFINITIONS

3.1.1 allocation: The (mathematical) process of assigning portions of a commingled production stream to the sources, typically wells, which contributed to the total flow.

3.1.2 allocation meter: A flow measurement device used for the specific purpose of measuring the flow rates from a single well or input flowline; not to be confused with the reference meter.

3.1.3 commingle: To combine the hydrocarbon streams from two or more wells or production facilities into common tanks or pipelines.

3.1.4 Equations of State (EOS): Equations which relate the compositions, pressures, temperatures, and various other physical properties of gases and liquids to one another, and are used to predict the transformation of physical state when conditions change (see PVT Analysis).

3.1.5 error: The difference between the result of a measurement and the true value of the measurand.

3.1.6 estimate: A measurement which has been corrected to remove the effects of influence factors.

3.1.7 gas-oil ratio (GOR): The ratio of produced gas flow rate to the liquid hydrocarbon flow rate at any point, measured in standard cubic feet per barrel (SCF/BBL) or standard cubic meters of gas per cubic meter of liquid hydrocarbon (m³/m³).

3.1.8 gas (liquid) volume fraction, GVF (LVF): The fraction of the total volumetric flow at actual conditions in the pipe which is attributable to gas (liquid) flow.

$$\text{GVF} = Q_g^v / (Q_g^v + Q_l^v) \quad \text{LVF} = Q_l^v / (Q_l^v + Q_g^v)$$

3.1.9 imbalance upper/lower control limit: A limit on System Balance that is established for the purpose of maintaining control of the overall process.

3.1.10 individual allocated quantity (A_i): A contributing meter's share of the master quantity (Q_Z) that incorporates a calculated share of the system imbalance (I), so that the sum of all the allocated quantities (ΣA_i) equals the master quantity (Q_Z).

3.1.11 individual quantity (I_{Q_i}): The quantity determined by an individual contributing meter or measurement point.

3.1.12 individual theoretical quantity (Q_i): The quantity represented by an individual contributing meter or measurement point after conversion to a theoretical value by applying an Equation of State (EOS) or other correction factor, usually done in order to adjust the measured quantity for comparison at the same pressure and temperature base as the Master Quantity (Q_Z).

3.1.13 influence factor: A quantity which is not the measurand, but which will affect the result of measurement.

3.1.14 Lockhart-Martinelli Parameter: A parameter (usually shown in equations as X) used to indicate the degree of "wetness" of a wet gas, defined as

$$X = \frac{Q_l}{Q_g} \cdot \sqrt{\frac{\rho_g}{\rho_l}}$$

3.1.15 master quantity (Q_Z): The quantity measured by the reference meter(s) after commingling the individual streams.

Note: Ordinarily, measurements of this quantity exhibit a distinctively lower relative uncertainty than do the individual measurement points, since the master quantity measurements are made after commingling.

¹International Standards Organization, 11 West 42nd Street, New York, New York 10036, www.iso.ch.

ration processing, and under pressure and temperature conditions that ensure single-phase conditions.

3.1.16 mean value: The result one would obtain if a measurement were made an infinite number of times and the arithmetic average of the measurements were calculated; an estimate of the mean value based on averaging n samples is given by:

$$\bar{z} = \frac{1}{n} \cdot \sum_{i=1}^n z_i$$

3.1.17 measurand: The particular quantity subject to measurement.

3.1.18 multiphase flow: Flow of a composite fluid which includes natural gas, hydrocarbon liquids, water, and injected fluids, or any combination of these.

3.1.19 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.

3.1.20 random error: The error which deviates about the mean value of the measurement in an unpredictable, bipolar fashion.

3.1.21 reference meter: A flow meter used for the specific purpose of measuring the flow rates of one phase of the commingled stream, (e.g., the liquid hydrocarbon flow rate).

3.1.22 repeatability: The closeness of the agreement between results of successive measurements of the same measurand carried out under the same conditions of measurement.

3.1.23 reproducibility: The closeness of agreement of measurement results of the same measurand carried out under changed conditions of measurement, such as different location, time, reference standard, etc.

3.1.24 sample (experimental) standard deviation: An estimate of the standard deviation based on n samples of the random variable; the square root of the sample variance.

$$\sigma_z = \sqrt{\frac{1}{n-1} \cdot \sum_{i=1}^n (z_i - \bar{z})^2}$$

3.1.25 sample (experimental) variance: An estimate of the variance based on n samples of the random variable,

$$\sigma_z^2 = \frac{1}{n-1} \cdot \sum_{i=1}^n (z_i - \bar{z})^2$$

3.1.26 specified imbalance limit: A limit on System Balance which is established for the purpose of satisfying contractual obligations and/or regulatory requirements.

3.1.27 standard deviation: The square root of the variance of a random variable.

3.1.28 system imbalance (I): The difference between the measured Master Quantity (Q_z) and the sum of the Individual Theoretical Quantities ($\sum Q_i$), sometimes referred to as the System Balance.

3.1.29 systematic error: The difference between the mean value of a measurement and its true value, generally a constant or near-constant value.

3.1.30 true value: The underlying characteristic of the measurand which would be recorded if the measurement were perfect, (i.e., there were no random or systematic measurement errors).

3.1.31 uncertainty (of measurement): A parameter associated with the result of a measurement that characterizes the dispersion of the values that could be reasonably be attributed to the measurand, often expressed in terms of its variance or standard deviation.

3.1.32 uncertainty-based allocation: A method of hydrocarbon allocation in which the relative uncertainties of the measurements are taken into consideration, including measurements made by each of the allocation meters, by the reference meters, and by any other instrumentation, the readings from which affect hydrocarbon flow measurement.

3.1.33 uncertainty of allocation meter: The uncertainty of an Individual Theoretical Quantity relative to the flowing conditions experienced by the meter, which includes the uncertainty of the meter, any uncertainty in EOS application, and the uncertainties due to errors of ancillary devices such as pressure and temperature.

3.1.34 uncertainty of reference meter: The uncertainty of the Master Quantity relative to the flowing conditions experienced by the meter.

3.1.35 variance: The expected value of the square of the difference between the measurement and its mean value.

3.1.36 watercut (water-liquid ratio): The volumetric fraction of water in a liquid stream composed of water, liquid hydrocarbons, and perhaps other liquids.

3.1.37 water volume fraction: The volumetric percentage of water in a total fluid stream composed of water, liquid hydrocarbons, other liquids, and gas.

3.1.38 wet gas: A particular form of multiphase flow in which the dominant fluid is gas and in which there is a presence of free-flowing liquid.

Note: There are several ways of more precisely defining wet gas, as discussed in 1.1.

3.2 NOMENCLATURE AND SYMBOLS

Symbol	Meaning
α_i	Allocation Factor used for Assigning Imbalance to the i^{th} Meter
α_i	Fraction of Liquid Converted to Gas in Transport from Subsea to Platform
A_i	Individual Allocated Quantity
β_i	Fraction of Gas Converted to Liquid in Transport from Subsea to Platform
EOS	Equation(s) of State
GOR	Gas-Oil Ratio
GVF	Gas Volume Fraction
I	System Imbalance
IQ_i	Individual Quantity
LVF	Liquid Volume Fraction
M	Murdock Coefficient
m_g	Gas Mass
m_l	Liquid Mass
MW_g	Average Molecular Weight of a Gas Mixture
MW_l	Average Molecular Weight of a Liquid Mixture
MW_i	Molecular Weight of the i^{th} Component of a Mixture
n_g	Number of Moles in a Gas Mixture
n_l	Number of Moles in a Liquid Mixture
n_g^i	Number of Moles of the i^{th} Component of a Gas Mixture
$\dot{n}$	Total Molar Flow Rate (Gas Plus Liquid)
$\dot{n}_g$	Gas Molar Flow Rate
$\dot{n}_l$	Liquid Molar Flow Rate
P_p, T_p	(Platform) Pressure and Temperature
P_s, T_s	(Subsea) Pressure and Temperature
PVT	Pressure-Volume-Temperature
Q_i	Individual Theoretical Quantity
Q_g	Gas Mass Flow Rate
Q_{gi}	Indicated Gas Mass Flow Rate
Q_g^v	Gas Volume Flow Rate
Q_{gs}	(Subsea) Gas Mass Flow Rate
Q_{gp}	(Platform) Gas Mass Flow Rate
Q_l	Liquid Mass Flow Rate
Q_l^v	Liquid Volume Flow Rate
Q_{ls}	(Subsea) Liquid Mass Flow Rate
Q_{lp}	(Platform) Liquid Mass Flow Rate
Q_z	Master Quantity
ρ_g	Gas Density
ρ_l	Liquid Density
σ	Standard Deviation of a Random Variable
σ^2	Variance of a Random Variable
T_I	Imbalance Limit
X	Lockhart-Martinelli parameter

x	Gas Mass Fraction
x_g^i	Mole Fraction of the i^{th} Component of a Gas Mixture
x_l^i	Mole Fraction of the i^{th} Component of a Liquid Mixture

4 Subsea Meter Calibration and Testing

4.1 GENERAL

This section addresses testing and calibration of meters that is performed for the purpose of qualification, prior to installation for actual field operation.

The status of multiphase measurement for wet gas service is immature. Accepted calibration practice uses test and production separation techniques, which rely on separation and metering of each individual phase to known standards by traditional methods and metering equipment.

Further complicating the situation is the subsea location of these meters when in service. This means that not only are they unavailable for removal and verification of their performance, but that even routine test and inspection of sensors and other components is extremely difficult.

The following describes what reference loop testing is required prior to a meter's being declared qualified for subsea wet-gas service, what these reference facilities must possess in order to be certified as fit for the task, and what a successful calibration test should entail.

4.2 TESTING REQUIREMENTS

The nature of multiphase flows is complex. It is much more difficult to assure the reproducibility of fluid flow behavior at flow measurement sections—at different installation locations and through service life—than is the case for single phase flow. This results in a significantly higher degree of uncertainty in meter calibration for multiphase applications.

4.2.1 Meter Calibration Testing

Each flow meter design used for a specific wet gas application shall be qualified prior to use. A meter in an application may be exempted if it has already been qualified for the same application. Qualification testing should subject the actual meter design to the full range of conditions expected. This includes phase flow rates, pressures, temperatures, and fluid properties, using test fluids exhibiting similar properties and phase mass transfer behavior to the in-situ application process fluids. The meter under test shall be installed in a piping configuration similar to that of the intended service installation configuration, to demonstrate that it meets the uncertainty requirements over the range of flow conditions specified for the application. Reference meters used in this testing should meet the requirements of 4.3.1.

Some of the parameters which should be considered are the following.

4.2.1.1 Installation Pipework. Depending on the technique of multiphase flow measurement and the type of sensor technology used, the meter's response may be influenced by geometrical details of the surrounding pipework. To the maximum degree possible, the meter installation at the flow facility should be made to mimic that which will be implemented in the application.

4.2.1.2 Meter Size. Bulk flow rates requiring a previously unqualified meter size (both nominal diameter and meter opening) may necessitate testing of the specific proposed meter type of that size. Depending on the technique of multiphase flow measurement and the type of sensor technology used, meter response may be influenced by geometrical, dimensional and material specifications. The extent of the testing will be dependent on the meter's performance during testing as compared with previously qualified similar meters of a different size.

4.2.1.3 Fluid Properties. Meter response also depends on how sensors respond to changes in fluid properties such as salinity (conductivity), viscosity, density, etc. Consideration must be given to how closely the test facility can replicate the fluid properties expected. Furthermore, this and the pipework discussed above are the determining factors of flow regime. It must be demonstrated that the flow regimes tested are representative of those which are expected to be encountered in practice.

4.2.1.4 Operating Range. The proposed test facility should, to the maximum extent possible, operate over a similar range of phase flow rates, pressures, and temperatures to that expected in the application. It is recommended that testing be performed extending the operating range into anticipated transient start-up temperatures and pressures.

4.2.2 Meter Component Calibration Testing

Although the focus of this discussion has been the flow calibration testing of the wet gas meters themselves, it is of great importance to test individual components as well. Some of these tests are discussed below.

4.2.2.1 Sensor Testing. All sensors which are to be used in the meter shall be tested and calibrated under conditions which replicate the application environment as closely as possible. To the maximum extent possible, tests should replicate the anticipated production flow meter design for sensors and sense tubes, so as to increase the likelihood of identifying any unexpected or unintended affects.

4.2.2.2 Electronics Testing. Even though it is unlikely that electronics will be directly exposed to either subsea or well fluids, it is likely to experience thermal and possibly pressure stresses, therefore a test program to demonstrate its survival in the conditions of the application is mandatory.

4.2.2.3 Pressure Testing. All meter parts which are subject to either internal or external pressures, or both, as well as the complete meter itself, must be tested in as realistic a manner as is possible.

4.2.3 Factory Acceptance Testing (FAT)

It is recommended that at the factory of the supplier, or at another location agreed to by the parties, each meter, meter component, and the complete meter system be operationally tested.

Testing of individual meters or components should be conducted under as realistic conditions as possible over a reasonable range of input conditions, noting any deviations from specification.

In testing the complete metering system, it should be connected as it will be when installed subsea. This may or may not require an actual flow test, but should demonstrate the complete suite of functionality which will be employed when the metering system is in actual operation.

In this activity all aspects of the meters, meter components, and metering system operation should be simulated, and the response of the system observed. Any errors or anomalies should be noted, and either corrected or explained prior to the system's deployment.

4.3 FLOW TEST FACILITIES

Flow testing shall be carried out at a flow laboratory which is capable of matching the requirements of the application as detailed in 4.2.1. These flow test facilities may be specially built reference facilities, or may be part of a hydrocarbon production or transportation facility. The flow test facilities shall provide for witness testing, for traceability and calibration documentation, and for all pertinent facility and test data records. Test program management protocols shall assure the interests of all investing parties, and shall impose and enforce an agreed demarcation on what test data constitute calibration, validation and repeat test points respectively.

4.3.1 Reference Measurement

The quantities of each individual phase of the multiphase fluid to be tested shall be measured in a separated state on the test facility. Either closed-loop (circulating) or open-loop (pass-through) flow facilities may be used. Each single phase shall be measured as follows for use as the reference measurement in the meter calibration calculations.

4.3.1.1 Traceability. Flow test facilities shall employ reference measurement systems which have been calibrated against recognized traceable national standards. Where the practicalities of a particular test facility do not allow full traceability (e.g., producing oil or gas field), the reference measurements may be used where it can be demonstrated that

good flow process design and measurement practice have been applied.

4.3.1.2 Instrumentation. Reference measurement instruments shall be of a suitable type as used to determine the flow rate and quality of flow streams to high accuracy. The reference measurement uncertainty requirement shall be based on the uncertainty specification of the specific wet-gas meter under test. The reference measurement uncertainty shall be no more than 10% of the uncertainty specified for the meter under test, for each phase at application pressure and temperature.

4.3.1.3 Measurement Correction. The reference phase flow rate measurements shall be corrected to values corresponding to the process pressure and temperature at the meter under test for each test point condition. Industry-accepted EOS algorithms shall be applied using pressure and temperature measurements at the reference meter tubes and at the meter under test. An estimate of the uncertainties introduced by this conversion process shall be incorporated into the overall uncertainty analysis.

4.3.2 Test Facilities

The operation of the qualification test facility shall incorporate process efficiency monitoring measures and reporting. This shall identify and include all necessary instrumentation to assure flow process efficiency. Measures shall be taken to assure a minimum level of un-measured phase cross-contamination through the reference measurement systems. Typical examples of phase cross-contamination in reference measurement systems are the carry-over of liquid into the gas off-take, gas carry-under into the liquid leg, or water carry-over into the oil leg of phase separation measurement systems.

4.3.3 Test Period

Test period selection shall insure that the test data flow readings and computations are recorded only when the flow conditions—phase flow rates, pressures and temperatures—are stable (i.e., all transducer signals are statistically stationary). Computation of average flow quantities shall extend over time periods sufficient to render negligible any statistical uncertainty due to flow and signal fluctuations.

4.3.4 Test Fluids

The qualification test fluids shall exhibit properties, such as density, viscosity, surface and interfacial tension, conductivity, and dielectric constant, representative of the in-situ process fluids at the metering station during its service life. This shall account for the influence of injection chemicals to be used upstream of the measurement station during operations. The test fluids shall exhibit phase change mass transfer characteristics similar to the application fluid system, unless there is strong evidence from previous test and operation to show

that phase change through the multiphase meter measurement section has a negligible influence

4.4 CALIBRATION TEST PROGRAM

4.4.1 Test Matrix

The test matrix shall cover a range of the phase flow rates, pressures, temperatures, and fluid property conditions, which adequately represent the operating envelopes of the duty meter through its service life. In most cases, it is recommended to test beyond the operating range specified in the application, especially with respect to anticipated start-up conditions. It is recommended that the test envelope shall extend beyond this range to the extent necessary to permit the fitting of calibration algorithms. Extension of the test envelope, where possible, should insure that the calibration algorithm also covers operating conditions just outside the predicted range.

4.4.2 Extrapolation of Test Points

Where the practical limits of the fluid flow operating envelope of the qualification test facility cannot fully cover the fluid flow envelope of the application, calibration and performance validation may be determined by extrapolation. Any such extrapolation shall be supported by analysis of the fluid flow conditions and the impact of these on the calibration uncertainty for the meter under test within the extrapolation zone. This analysis shall account for the influence of fluid dynamic behavior and instrument response within the zone of extrapolation. It must be supported by other substantive recognized test and analytical or theoretical evidence.

4.4.3 Determination of Test Point Conditions

An analysis shall be made of the predominant influence factors of the meter under test to determine the major and minor variables influencing meter response, as well as the respective resolution and number of test points required for each variable. The selection of test point conditions shall also account for the relative operational impact of measurement uncertainty within the duty envelope and populate matrix data accordingly. This shall include as a minimum variation in pressure, gas flow rates, and liquid flow rates.

4.4.4 Test Execution

A description of the planned test with respect to parameters such as fluids to be used, pressure, temperature, etc. shall be prepared prior to the onset of testing. During the execution of the test all sensed parameters shall be acquired and recorded. Acquisition of data points should occur only after complete stabilization of all parameters.

The following types of test points shall be used throughout the test matrix. All are required for determining the calibration

tion parameters and evaluating the performance of the test meter and test facility.

4.4.4.1 Calibration. Test points where the reference phase measurements are used specifically to determine the calibration curve.

4.4.4.2 Validation. Test points where the output from the test meter is used (via the calibration curve) to predict the gas and liquid flows. These values are then compared to the reference phase measurements to determine test meter performance.

4.4.4.3 Repeat. Selected points covering the flow operating envelope should be subject to repeat testing. It is recommended that 20% – 40% of the test points in the calibration and validation matrix be repeated.

Distribution of calibration and validation points should be approximately 50:50. Outliers must be reported. A reasonable attempt to investigate and explain outlying measurements must be made.

4.4.5 Allowance for Spare Test Time

The test program should include spare capacity within the schedule to allow for unforeseen system faults such as:

- a. changes or additions to the number of test point conditions in order to adequately examine unforeseen phenomena or previously unidentified meter characteristics,
- b. troubleshooting of test facility or meter performance, or
- c. investigation of outliers, including repeat runs of these test points as necessary.

Test loop and test meter performance should be continuously evaluated during the test program to assure optimum operation and allow for matrix modifications if needed to improve the meter calibration.

4.4.6 Other Evidence

Published data and analyses concerning wet gas multiphase metering may be used to help determine the needs, scope and detail of the qualification test program. Such references may further be consulted during and after the completion of the test program to support analysis, results, conclusions and statements.

4.5 CALIBRATION DELIVERABLES

4.5.1 Meter Calibration

The qualification test and analysis program shall produce the calibration results of the meter under test, applicable to the range of fluid flow start-up and operating conditions, and the corresponding statement of uncertainty.

4.5.2 Uncertainty Analysis

The uncertainty analysis shall account for uncertainties added by changes made in hardware and software between the qualification test system and the installed application measurement and production reporting system. (This shall include but not be limited to, differences with respect to signal transmission fidelity, resolution, accuracy, repeatability and timing, data storage and flow rate computation and reporting accuracy and format).

For fiscal allocation, the full uncertainty chain, from national or international reference standards through field-installed calibrated measurement system to production reporting, shall be analyzed, by recognized metrological means of analysis, to estimate the overall measurement uncertainty.

5 Allocation Methodology

5.1 INTRODUCTION

Allocation methods involve the distribution of revenue. Central to the use of wet gas meters in the subsea environment is the allocation philosophy and methodology that accounts for differences in the relative measurement uncertainty of various meters within a given allocation system.

Allocation of the so-called *imbalance* between one set of high-accuracy meters and a set of lower-accuracy meters, the flows from which are commingled, is normally done in a pro-rata method using relative throughput as a basis. This is the method dictated in the API Standard for conventional allocation, API MPMS, Chapter 20, Section 1. An example of its use might be allocation of the readings of a sales gas meter back to meters located downstream of the separator vessels. While this is very effective for many measurement systems, it assumes equal uncertainty among all the lower-accuracy meters. This straightforward approach must be modified to accommodate systems where there may be wide variation in the accuracy of individual allocation meters, which is often the case with subsea measurement, or instances where the production through subsea meters is commingled with that flowing through topside meters. If no accommodation is made for this discrepancy, the allocation among producers is almost guaranteed to be unfair. The methodology which has been developed to address the equitable distribution of the system imbalance is called *Uncertainty-based Allocation*, and will be described in the paragraphs which follow.

5.2 PRINCIPLE

An allocation methodology must be used which incorporates the random uncertainty of each meter within the set of meters, relative to the uncertainty of the whole set. This will thereby effectively and fairly assign the system imbalance to those meters or processes most likely to have caused the difference.