

Testing Protocol for Multiphase Meter

Table of Contents (page numbers will be inserted after ballot)

Introduction

1. Scope

2. Normative References

3. Terms and Definitions

4. Field of Application

5. Parameters affecting Performance

Sub titles here

6. Testing (Mandatory Testing)

Sub titles here

7. Test Facility Requirements

8. Uncertainty

9. Test Report

Introduction

The following are objectives of this Testing Protocol:

- Provide documented performance characteristics and parameter sensitivity of the multiphase meter under controlled fluid properties and flowing conditions over a defined operating range with a standardized reporting format.
- Stating the assumptions of the operating and installation conditions for which the stated uncertainties apply.

Dynamic testing enables the evaluation of performance (and factors influencing performance) of an MPFM technology/type/model across a clearly defined operating range, under controlled conditions.

Performance testing of a multiphase flowmeter is a critical step in validation of the flow models and the fluid models which are used to measure multiphase flow. A multiphase meter will typically contain several of these models in order to address the challenge of measuring individual phase flowrates within a range of flow regimes, operating velocities and fluid types.

1 Scope

This testing protocol provides the minimum requirements for documenting performance testing of an inline multiphase flowmeter under controlled flowing conditions in a flow loop facility. Completion of the testing protocol is not a calibration and does not replace field testing and validation.

This testing protocol documents the method for testing the performance characteristics of multiphase flowmeters used in production allocation. The testing protocol includes a listing of parameters affecting the performance of the devices, a description of the tests required, requirements for the test facility, a data reporting format, and an uncertainty determination methodology.

2 Normative References

ISO Guide to the Expression of Uncertainty in Measurement (GUM)

API MPMS Ch 13 Statistical Aspects of Measuring and Sampling

ISO 8601 Date and Time Format

3 Terms and Definitions (terms and definitions will be added after work group ballot)

4 Field of Application

The field of application of this testing protocol is limited to inline multiphase meters used in the measurement of hydrocarbon fluids for production allocation.

5 Parameters Affecting MPFM Performance

The manufacturer shall specify parameters and conditions that influence the performance of the device such as those listed in 4 above and any other, for example:

1. fluid property: e.g., fluid density, viscosity.
2. flow regime and composition: e.g., slugging, annular, water cut, oil or water continuous, emulsion state, low or high GVF.
3. dynamic conditions: e.g., transitioning from oil-continuous to water-continuous and vice versa; transitioning from low-GVF to high-GVF and vice versa.
4. installation conditions: e.g., nature and location of upstream flow disturbances, flow conditioners, sensor installation orientation.
5. environmental conditions: e.g., ambient temperature, piping vibration.
6. process conditions: e.g., abrasive materials, hydrate formation/dissociation, wax, scale.
7. Any performance test with gas (i.e. not liquid only) shall evaluate the impact of pressure.

Where known, the manufacturer shall specify quantify the sensitivity of the parameters that influence performance.

The target performance at line conditions shall be defined for all output variables at all test points including:

1. Oil, gas, liquid and water volume and mass flow rates
2. Oil, gas, liquid and water daily and hourly totalized volume and mass
3. Water-liquid ratio when applicable
4. The range of conditions (i.e., WLR and GVF) over which uncertainties apply

6 Mandatory Tests

6.1 Device Configuration

The manufacturer shall calibrate and configure the MPFM prior to the start of the test using procedures consistent with their commissioning/operating guidelines. Any deviations shall be documented and reasons explained in the test report. The device configuration and calibration summary shall be documented in the report, including fixed values or assumptions included for the scope of the test that may not be relevant in a field installation.

The stakeholders (vendor, operator, flow facility, etc) may request sample(s) and/or composition(s) of single-phase test fluid(s) from the test facility. If requested and required, sample(s)/composition(s) shall be provided to the manufacturer so test fluid properties can be validated for field meter performance modeling.

Any anticipated configuration changes during the course of the test must be predefined (by the manufacturer) with clear instructions (to the stakeholders tasked with overseeing the test) regarding the conditions in which such a configuration change may be required. These subsequent configuration changes (if any) shall be consistent with device's field commissioning/operating guidelines.

6.2 Testing scope

Testing shall consist of the items described in this document. All assumptions shall be documented in the test report.

All stakeholders shall agree on an acceptable data-sampling frequency and test point duration for each test point in the test matrix.

All stakeholders shall agree on stability criteria to be met prior to the commencement of a test point.

All stakeholders shall agree on testing sequence (to optimize flow loop stability)

The operating range shall be clearly defined and used to frame the scope of testing including the range and value(s) of:

1. Pressure
2. Temperature
3. Flow rates
4. GVF
5. WLR
6. Gas composition
7. Oil type and density
8. Water salinity
9. Environmental conditions (e.g., ambient temperature)
10. Piping parameters (e.g., line size and rating)
11. Upstream/downstream piping and meter configuration and orientation
12. Gas densimetric Froude number
13. Lockhart-Martinelli number

6.3 Test Plan

The stakeholders shall review the test facility's proposal and confirm that they are fully satisfied with the following aspects of the test proposal prior to execution of the test.

- **Fluid properties**
- Proposed reference metering system (including relevant certifications)
- Calculation of fluid properties at line conditions
- Proposed methods for evaluation of meter performance
- Proposed sampling of test fluids, including analysis to be completed on any samples
- Proposed method for verification of fluid mixing in test section
- Uncertainty calculation method for test loop parameters over the test plan operating range
- Proposed method for validation of contamination of single phase fluids after separation (i.e. oil in water etc)

Any testing that is blind shall be documented. Blind testing refers to test matrix order fluid properties, and/or range that is hidden from the manufacturer.

Any audit of test loop reference metering or flow calculation parameters / procedures shall be completed prior to commissioning of the test, with any corrective actions implemented.

The test plan shall specify any operating parameters and/or ambient conditions which must be achieved (e.g. operating conditions in the separator or flow loop) prior to commencement of a test point.

The test plan shall specify and document agreed requirements for stability prior to commencement of a test point.

The test plan shall provide clear criteria for acceptance or rejection of an individual test point. These parameters shall be based entirely on data from the flow loop and shall not account for the performance of the manufacturer's equipment.

6.4 Test Fluids

The selection of appropriate test fluids is a critical step in the specification of a multiphase flowmeter test. The properties of a test fluid can significantly affect the performance of a multiphase flowmeter and flow regime modeling. The impact of using a surrogate fluid (e.g. hydrocarbon liquid including synthetic oil, Nitrogen, natural gas mixture, methane and/or Fresh Water) will depend on the sensor technology employed.

The flow test is not an assessment of the flow or phase model in real field conditions outside of the scope of the test.

The scope of testing shall identify the test fluid properties and process conditions, including:

- GVF
- L-M
- Frg
- WLR
- Densities and gas/liquid density ratios

Additional test fluid properties may include:

- Gas absorption and oil shrinkage

- Viscosities
- Interfacial tensions
- Gas entrainment in hydrocarbon liquid*
- Inversion region width, location relative to viscosity, temperature etc**
- Salt composition***
- Permittivity / Conductivity (where these variables form part of the measurement technology)
- Ability to form emulsions

*For example, nitrogen/air has higher density and lower gas-liquid mass transfer than methane/natural gas.

**The inversion region is the range of WLR across which the hydrocarbon liquid / water mixture varies from being oil-continuous to water-continuous.

***Water salinity and density, where appropriate may be controlled by adding salts.

6.5 Dynamic Test Matrix

Based on the measurement goals the test matrix shall span either the entire operating envelope of the MPFM or a specific range of operating conditions agreed by all stakeholders.

The test matrix shall strive to address the intended range of WLR, GVF and flowrates for the application(s) where possible.

The influence of pressure and temperature shall be considered, as it can affect gas/liquid density ratios which affect flow regime characteristics.

Extrapolation shall not be used to predict performance of the multiphase flowmeter across the inversion region of the fluid mixture (i.e. from oil-continuous liquid to water-continuous liquid).

An example test matrix is shown graphically below in terms of a flow map and a composition map (at a given pressure and temperature).

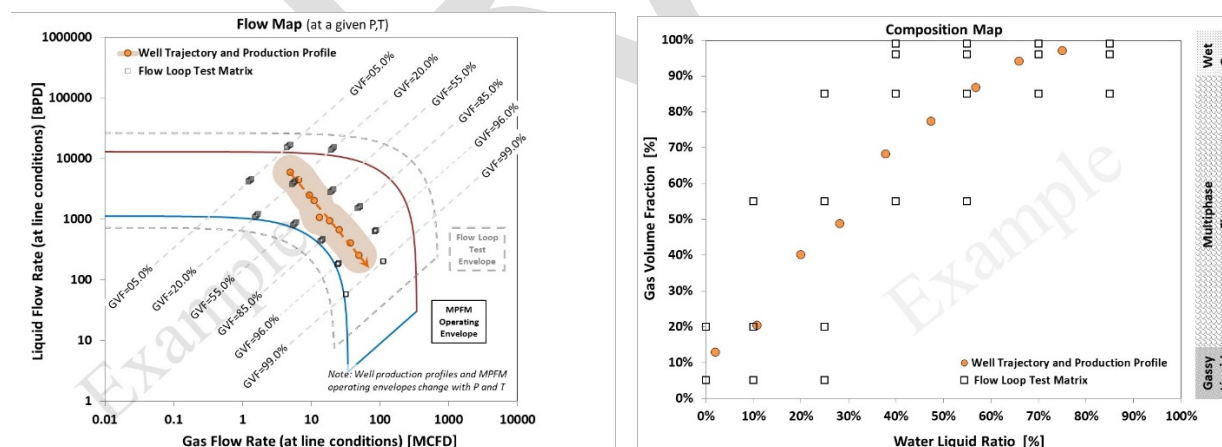


Figure 6.1: Example test matrix depicted with a flow map and a composition map

The test matrix may include single-phase (gas, water and/or oil) test points to verify the device baseline.

Based on the parameters affecting MPFM performance (section 5), the test matrix should include test points that vary these parameters to assess how they affect the performance of the device where possible.. Test points that mimic real-world applications should receive high priority.

The test matrix shall additionally include repeat points to assess repeatability and reproducibility of measurements.

6.6 Test Installation

The manufacturer shall provide installation requirements including meter orientation, upstream (and downstream) piping requirements, and flow conditioners (if any) consistent with the device's field commissioning/operating guidelines.

The manufacturer shall provide pressure-safety, wiring, hazardous location rating, storage and handling, and Safety Data Sheets.

The stakeholders shall agree and document the communication protocols used in the test...The test facility shall prepare a relevant detailed piping and instrumentation drawing for the test loop and isomeric drawing for MPFM installation, in line with the manufacturer's installation guidelines, for approval by the stakeholders.

The test facility shall perform the installation and wiring per the approved piping and instrumentation drawing and using manufacturer's guidelines.

6.7 Test procedure

The document shall describe in detail how the tests are to be conducted, including installation, flow loop operation, data acquisition, uncertainty calculations and decommissioning.

A test procedure shall be developed by the test facility and agreed by all parties prior to startup of the flow test.

As a minimum, the test procedure shall address:

1. Safety protocols required for execution of the test matrix
2. Stability criteria for execution of any individual test point, and document any exceptions
3. An agreed protocol for health monitoring of the flow loop and multiphase meter.
4. An agreed protocol for addressing warnings or alarms from the flow facility or from the multiphase meter.
5. An agreed protocol for sampling of fluids, including confirmation of analysis to be completed.
6. Criteria for successful completion of any individual test point.
7. Maintenance of a test log, including recording of any anomalies observed.

6.8 Test Results

The parameter(s) defining the performance of the single phase reference meters and the meter under test shall be recorded for each test point in the test matrix.

Time stamps shall be recorded in ISO 8601 format. unless agreed otherwise with all parties. If data is being recorded in multiple systems, all such systems must be time synchronized.

All variables shall be recorded in SI units or US customary units.

The test data shall not be changed or edited for the duration of the test.

The test facility shall measure and record each relevant variable including those listed in section 4 and those listed below (average and standard deviation as per the test plan) including intermediate variables used to calculate final results.

The following shall be reported at line conditions:

1. static pressure and temperature and location of measurements
2. single-phase mass accumulations and flow rates
3. single-phase volume accumulation and flowrates
4. WLR
5. GVF
6. Differential pressure where applicable
7. density and composition of gas
8. density and composition of liquid hydrocarbon
9. density and salinity of water
10. viscosity (dynamic or kinematic) of all fluids
11. isentropic exponent of compressible fluids
12. permanent pressure loss across the meter and location of measurements

The following shall be reported at standard condition and list phase change and compressibility assumptions and methods:

1. GOR
2. WC
3. single-phase volume accumulation and phase rate
4. single-phase mass accumulation and phase rate
5. density and composition of gas
6. density and composition of liquid hydrocarbon
7. density and salinity of water
8. viscosity (dynamic or kinematic) of all fluids
9. isentropic exponent of compressible fluids

The following should be supplied by the manufacturer and reported:

As found and as left MPFM configuration file

1. Diagnostic data where applicable
2. Fluid properties and sensor parameters selected
3. Alarms
4. Raw sensor data sufficient to enable accurate post processing of metered flow rates and quantities

The test facility shall maintain a log of abnormal events or deviations from the test plan as well as the corresponding actions taken during the test program.

Example of recorded data (not all variables presented).

This document is not an API Standard; it is under consideration within an API technical committee but has not received all approvals required to become an API Standard. It shall not be reproduced or circulated or quoted, in whole or in part, outside of API committee activities except with the approval of the Chairman of the committee having jurisdiction. Copyright API. All Rights reserved.

Test Point Number	Start Time	Stop Time	Test Section Static Pressure [bara]	Test Section Temperature [C]	Test Section Gas Flow Rate [m3/hr]	Test Section Oil Flow Rate [m3/hr]	Test Section Water Flow Rate [m3/hr]	Test Section Gas Density [kg/m3]	Test Section Liquid Density [kg/m3]	Test Section GVF [%]	Test Section WLR [%]	MPFM Static Pressure [bara]	MPFM Temperature [C]	MPFM Gas Flow Rate [m3/hr]	MPFM Oil Flow Rate [m3/hr]	MPFM Water Flow Rate [m3/hr]	→
ABC-1	2020-02-04 10:57:00	2020-02-04 11:01:58	96.2	28.4	28.54	12.13	12.13	72.50	919.60	70.2	59.0	97.1	28.3	28.17	11.89	12.72	→
ABC-2	2020-02-04 11:15:00	2020-02-04 11:19:58	96.3	29.4	49.95	20.15	20.15	72.40	990.90	71.3	89.0	96.7	29.5	51.30	19.67	19.59	→
ABC-3	2020-02-04 11:28:00	2020-02-04 11:32:58	96.7	29.3	42.82	28.52	28.52	72.90	795.30	60.2	10.5	97.5	29.0	43.85	28.83	27.75	→
ABC-4	2020-02-04 11:43:00	2020-02-04 11:47:58	97.5	29.7	24.47	15.95	15.95	74.40	895.50	61.0	49.9	98.0	29.4	24.05	16.28	16.21	→
ABC-5	2020-02-04 11:55:00	2020-02-04 11:59:58	97.0	29.9	29.56	22.37	22.37	73.10	972.80	57.1	81.8	97.5	29.9	29.00	22.44	23.42	→
ABC-6	2020-02-04 12:19:00	2020-02-04 12:23:58	97.0	29.7	18.35	15.28	15.28	74.20	807.30	55.1	14.6	97.3	29.8	18.74	14.88	15.51	→
ABC-7	2020-02-04 12:31:30	2020-02-04 12:36:28	96.5	29.8	12.23	10.14	10.14	72.30	860.80	54.8	36.0	96.7	29.7	12.55	9.89	10.43	→
↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	→

Figure 2 Example table of recorded data

7 Test Facility Requirements

The test facility shall describe the capabilities and limitations of the flow loop, including feasible test envelopes (ranges/limits) in terms of pressure, temperature, flow rates, fluid types/properties, water-liquid ratios, line sizes.

The test facility should provide information regarding which test condition variables it can independently control, e.g., changing the GVF while maintaining a constant liquid rate.

The test facility shall provide evidence of calibration of its sensors and flow meters and demonstrate traceability to reference standards. The test facility should also prescribe an instrument validation plan to continuously monitor test loop instrumentation throughout the test.

Instrument validation can be achieved by redundant measurements or a verification against other reference instruments in the facility.

The test facility shall collect samples and/or provide evidence of oil and water mixing performance at the test section (and provide uncertainty of WLR at the test section).

The test facility shall document contaminant level in each of the single phases throughout the test.

The test facility shall provide documentation that the tests are performed in accordance with this testing protocol, including deviations with reasoning.

This documentation shall be provided at the request of any user of the facility.

The stakeholders can request an audit of the laboratory or the testing facility to ensure the validity of the tests. The depth of the audit is determined by the user of the facility and shall be consistent with relevant national and/or international standards. The stakeholders may require the laboratory or testing facility to be traceable to national or international standards of weights and measures. The laboratory or testing facility shall provide documentation of how it estimates the uncertainty of its systems and procedures and how that uncertainty is maintained throughout the testing process under this protocol. Stakeholders wanting a detailed analysis of the performance of the lab/facility, may request to review its applicable procedures and processes.

Test facility measurement systems for mass, time, temperature, and pressure shall be traceable to National Institute of Standards and Technology (NIST) Primary Standards or an equivalent National or International Standard.

Record and document the traceability to a national standard (e.g. NIST).

8 Uncertainty Analysis and Calculation

The statistical methodology for calculating and assigning measurement uncertainties should comply with standard or accepted industry practice, such as the ISO Guide to the Expression of Uncertainty in Measurement (GUM), or API MPMS Ch 13.

1. The test facility shall provide expanded uncertainty estimates with 95% confidence interval for test facility variables – including pressure, temperature, fluid properties where applicable (for example phase densities, permittivity), phase flow rates, WLR, and GVF – at the test section where the MPFM is installed.
2. Uncertainty calculations shall be provided for each test point within the test matrix. Visualizing uncertainty values for each test point can be done using graphs, for example shown in Figure 3. The graphs are also important to quantitatively show the statistical variability of MPFM deviation from the reference measurement for different parameter ranges (ex. High or low GVF, WLR, phase rates.etc). Additionally accumulative error plots should be included.
3. Uncertainty calculations shall factor in each instrument's uncertainty sources, for example drift, response time, reproducibility, response to ambient conditions, and operating principle.
4. Uncertainty estimates shall factor in separator efficiency and gas-liquid mass transfer between the reference (single-phase meter and/or injection) location and the MPFM location, and facility induced transients where they exist, for example pump stability that could impact the test results not already addressed in instrument uncertainty above.
5. Uncertainty in individual reference phase flowrates shall be lower than the stated uncertainty of the meter being tested for all test points.
6. The flow test facility shall detail the methodology used for uncertainty analysis, preferably with examples and an explanation of the source terms such as the manufacturer-specified uncertainties of single-phase reference instruments and the uncertainty associated with the measurement of fluid properties.
7. In reporting uncertainty for a full test, individual test point differences between the mean of a measurand and the mean of the reference (an error mean statistic) over the duration of the test point, shall be recorded and reported.
8. For large data sets, a graphical representation of the individual test point errors should be depicted in a tiered graph, similar to that shown in Figure 4 and Figure 5. The performance tiers should be agreed with user, manufacturer and/or vendor in alignment with the performance testing objective. Definition of tier ranges should consider the same number of data points, or defined absolute performance limits. The methodology used for the tiers shall be defined and reported and represent statistically significant tiers. The tiered graphs shown in Figure 4 and Figure 5 show oil rate errors as an example. The same method of graphical representation should be used for other phase rates or fractions.

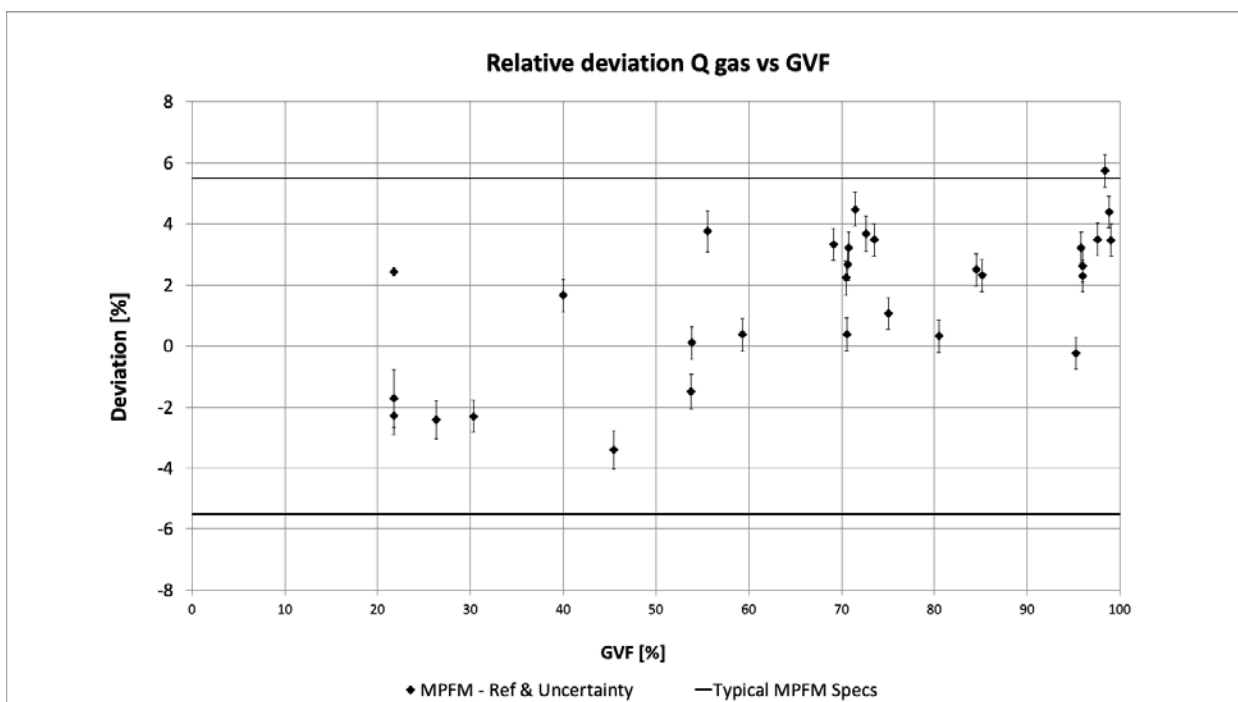


Figure 3 Example display of Qgas performance as a function of GVF.

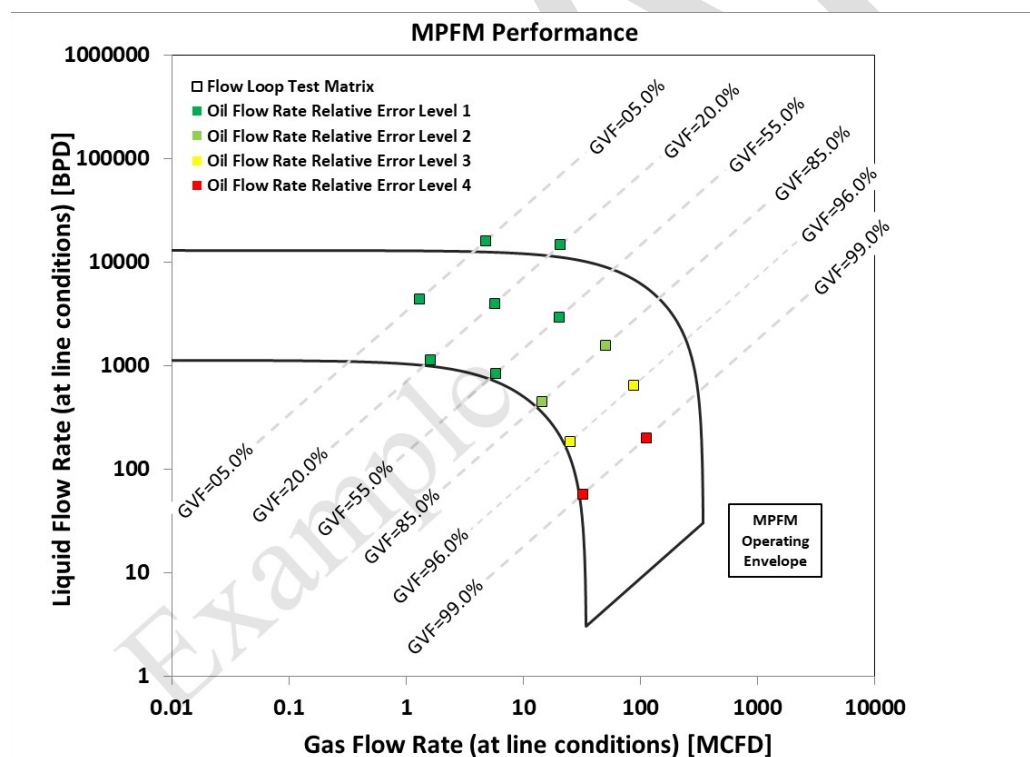


Figure 4 Example display of oil flow rate performance as a function of rates.

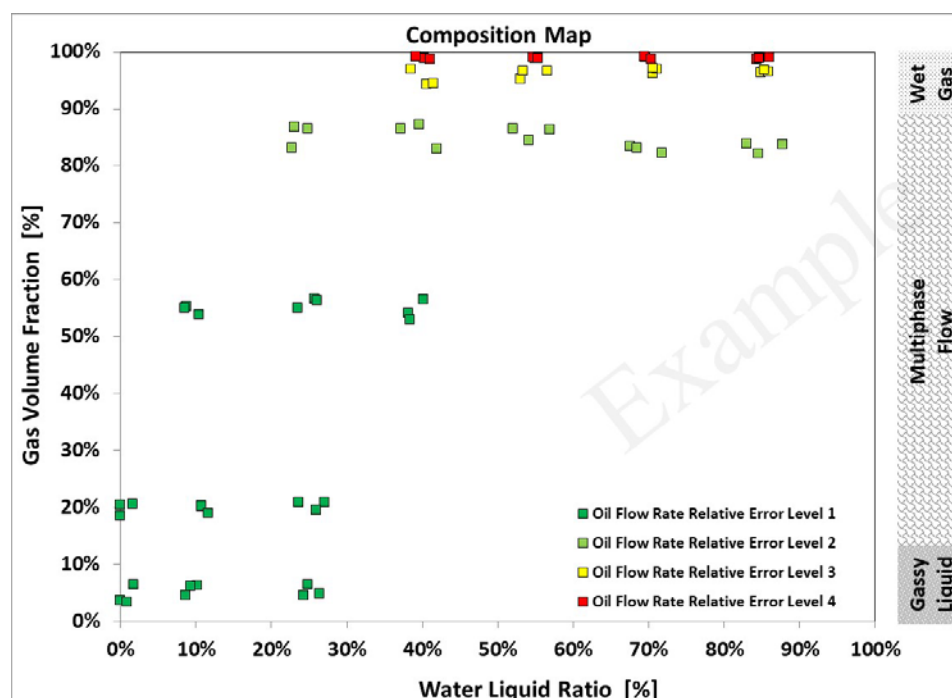


Figure 5 Example display of oil flow rate performance as a function of phase rate fractions.

9 Test report

The test facility shall generate a test report to ensure that the user is provided with a sufficient level of pertinent information on the testing that was performed. The format should be such that a side by side comparison of results can easily be made, regardless of where the tests were conducted. The report shall include date, time, location of test and author and approver of report.

As a minimum, the test report should contain the following sections:

1. Executive Summary
2. Testing scope
3. Description of device tested provided by the manufacturer
 - 3.1. Identification Information make and model, serial number, firmware version, line flow rate limits, general arrangement drawing, serial number etc.
4. Device configuration summary including as found and as left
5. Parameters Affecting Device Performance (including tolerance/limits if available)
6. Test facility details
 - 6.1. lab certification documents; traceability and calibration information on test equipment and calibration references.
7. Test conditions and matrix
 - 7.1. test setup drawings and/or descriptions
 - 7.2. dimensional drawings of pipework (if included as part of the test)
 - 7.3. detailed description of the complete test matrix
 - 7.4. environmental conditions during tests or other uncontrolled factors that may impact test results.
8. Test installation
9. Test procedure
10. Test results

- 10.1. All test results from 6.8 above shall be recorded and reported
 - 10.2. a comparison of measured results for each test point to reference values at the test section
 - 10.3. details of sample collection and analysis
 - 10.4. the statistical methodology for calculating and assigning measurement uncertainties
 - 10.5. uncertainty calculations for facility reference values at test section
 - 10.6. the test report shall include any calculated variables (e.g. GVF or rates at standard conditions), the equations and assumptions shall be included in the report for clarity and documentation purposes. The variables in the equations shall clearly reference the actual instruments used to measure these variables.
 - 10.7. details of any sample data, analysis data or reference measurement data of any kind provided to the manufacturer during the test, including the time point at which this information was provided.
 - 11. Uncertainty analysis and calculation
 - 12. Discussion of test results
 - 13. Conclusions
 - 14. Appendices
- Informative Annex: Additional informative and relevant information should be defined in the appendices of the document and provided by the manufacturer. Those may typically include descriptive literature, sales literature, specification sheets, installation and operation manuals, service manual, parts lists, photographs, and drawings/sketches. If used, published procedures or test protocols should also be provided in the appendices section of the report.