METHOD(S) FOR THE VALIDATION OF MULTIPHASE FLOW METERS IN ALLOCATION SERVICE GUIDANCE DOCUMENT – V1.0

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1 Introduction

With the continuous growth of subsea tiebacks to existing production platforms along with royalty rate and ownership differences, subsea and topside multiphase flow meters (MPFMs) are increasingly becoming a necessity for regulatory and commercial entities. In many applications, industry standards, regulatory bodies and commercial agreements require the operator to ensure that the meters are operating correctly in the field and to validate the accuracy of the meter outputs. The most common validation method has been limited to a volume comparison between the MPFM(s) and a reference system with single phase meter(s). Differing operational configurations and less than ideal flowing conditions have yielded results that are outside of set tolerances due to limitations of this validation method.

This document provides an overview of existing and alternative methods for in situ validation of MPFMs. Operational factors and realistic expectations will be considered for evaluating possible error sources and making informed corrections based on validation results.

The purpose of this document is solely for guidance on the validation of MPFMs, which is a comparison of the MPFM(s) to a reference system. This document is not intended to supersede regulatory requirements, commercial agreements or industry standards.

2 Validation

Compared to single phase meters, MPFMs are more challenging to ensure they are meeting performance expectations. Regular surveillance and validation are needed on these meters. System designs may restrict methods to validate these meters (e.g., subsea MPFMs can add an additional level of complexity); therefore, it is recommended to develop a plan based on each facility setup. The MPFM validation plan should include the validation method(s), performance criteria, frequency, surveillance activities, reporting, and steps to take if a validation falls outside of expected performance criteria. Key items to consider when developing a plan are:

- Regulatory requirements
- Commercial agreements
- Location of MPFM (topsides, subsea)
- Production process flow configuration
- Reference system devices
- Fluid characteristics/process conditions
- MPFM performance capability across full range of production life

Methods to consider in developing a MPFM validation plan include:

- Direct Validation to a Separator with Single Phase Meters
- By Difference Validation to a Separator with Single Phase Meters
- Comparison between two MPFM Devices
- System Material Balances

Prior to comparing a MPFM to any reference system, an expectation of the performance of the MPFM(s) and the reference system should be understood. Not understanding the performance of the MPFM(s) or reference system may make it technically difficult to justify a validation. A reference system can be a single meter, a group of meters, or another method to determine mass or volume. The MPFM(s),

reference system and associated components should be properly maintained in accordance with regulatory requirements, industry standards and manufacturer recommendations. If using a MPFM as a reference device, then the MPFM should be validated on similar fluids prior to using as a reference device.
To properly perform a validation, both the MPFM and the reference system should be operating at normal operating conditions (refer to API Ch. 20.5) and should be adjusted to compare values at similar conditions (e.g., standard conditions).

MPFM validations should follow the principles of API Ch. 20.5 (Recommended Practice for Application of Production Well Testing in Measurement and Allocation), API Ch. 20.2 (Production Allocation Measurement Using Single-phase Devices), API Ch. 20.3 (Measurement of Multiphase Flow), and API 17S (Recommended Practice for the Design, Testing, and Operation of Subsea Multiphase Flow Meters).

A. Methods:

1. Direct Validation to Separator with Single Phase Meters

This method may be used for one MPFM (or multiple MPFMs as referenced in the By Difference validation method) compared to a two or three phase production separator single phase meters.

A. **Mass**: Comparison of MPFM calculated mass vs Separator calculated mass

(1) Samples analysis. Comparison by mass requires a PVT analysis from a reservoir sample or recombination PVT analysis from separator samples for the inlet sources (MPFMs), and gas, oil and water samples from outlet sources of the separator to calculate mass. New samples are not required for every validation if representative samples are available. Representative sample means the conditions of flow rate, fluid properties (i.e. composition), and process parameters (i.e. temperature and pressure) that correspond to a production stream in a non-transient state.

(2) Determine flowing fluid density. These samples are analyzed to determine the flowing fluid density during the measurement cycle. A % water value and shrinkage / flash gas factor will be needed on the sample for the oil.

(3) Determine Mass for each measurement point. The fluid density is used to give a total calculated mass of each individual fluid phase for the MPFMs and the separator.

(4) Sum the Mass for each phase. All the measurement points on the separator outlets will then need to be summed for the mass of each phase for gas, oil and water. This may require (1) removing the amount of water in the oil and gas in the oil and adding it to the total water and gas and (2) removing recirculated oil and gas mass.

(5) Compare MPFM Mass to Separator Mass. Comparison by mass can then be made between process inlet source(s) (MPFMs) for each phase and separator outlet sources for each phase to determine if the MPFM(s) are within the allowed tolerance vs the separator mass per phase.

(6) Summation. If there are multiple inlet sources (MPFMs), they are summed following the above steps and compared to the separator mass per phase, to determine if the system is within the allowed tolerance.

B. **Volume**: Comparison of MPFM calculated volume vs Separator calculated volume

(1) Sample analysis. Comparison by volume requires a PVT sample analysis for the inlet sources (MPFMs) and gas, oil and water samples from outlet sources of the system to calculate volume. New samples are not required for every validation if representative samples are available.

(2) Determine fluid properties and correction factors. These samples are used to determine correction factors for; shrinkage, flash gas, S&W, compressibility, fluid density and average temperature and pressure for the test duration and corrected to standard conditions.
(3) Determine volume for each measurement point. Apply these correction factors to the measured Gas, Oil and Water volumes of the individual separator meters.
(4) Sum the Volume for each phase. All the measurement points on the separator will then need to be summed for the volume of each phase for gas, oil and water. This may require (1) removing the amount of water in the oil and adding it to the total water volume and (2) removing recirculated oil and gas volumes.
(5) Compare MPFM Volume to Process System Volume. Comparison by volume can then be made between process inlet source (MPFMs) and separator to determine if the MPFM(s) are within the allowed tolerance.
(6) Summation. If there are multiple inlet sources (MPFMs), they may be summed following the above steps and compared to the process system outlet sources to determine the overall balance of the system.

C. Things to look for (list may not be all inclusive):

- Ensure all inlet and outlet sources used in the validation are measured
- Fluid analyses are available for all measured sources used in the validation
- Meters on the reference system are properly maintained according to appropriate industry recommendations and regulatory requirements
- MPFM measurement components such as differential transmitters, temperature transmitter, pressure transmitters, gamma detectors, salinity probes are properly maintained
- Fluid property configuration input values are representative.

2. By Difference Validation to Separator with Single Phase Meters

This method has multiple MPFMs compared to a two or three phase production separator single phase meters. This method can be used for addition or subtraction of inlet sources.

A. **Mass**: Comparison of MPFM calculated mass vs separator calculated mass
(1) Follow the steps in Direct Validation as listed above in 1A.
(2) By difference. Once the steps are complete, repeat the steps with one of the inlet sources (MPFM) added / removed and subtract the results of the separate validations to determine if the added / removed inlet source (MPFM) was within allowed tolerance.

B. **Volume**: Comparison of MPFM calculated volume vs separator calculated volume
(1) Follow the steps in Direct Validation as listed above in 1B.
(2) By difference. Once the steps are complete, repeat the steps with one of the inlet sources (MPFM) added / removed and subtract the results of the separate validations to determine if the added / removed inlet source (MPFM) was within allowed tolerance.

C. **Things to look for (list may not be all inclusive)**:

- Ensure all inlet and outlet sources used in the validation are measured
- Fluid analyses are available for all measured sources used in the validation
- Meters on the reference system are properly maintained according to appropriate industry recommendations and regulatory requirements,
- MPFM measurement components such as differential transmitters, temperature transmitters, pressure transmitters, gamma detectors, salinity probes are properly maintained

- Fluid property configuration input values are representative
- By difference validation may impact the uncertainty of the results and this impact should be understood when using this method.

3. Direct Comparison Between Subsea MPFM(s) and a Topsides MPFM

This method may be used for one MPFM (or multiple MPFMs as referenced in the By Difference validation method) compared to a topsides MPFM.

A. **Mass**: This method is to validate a subsea MPFM to a topsides MPFM
   (1) Follow the steps in Direct Validation as listed above in 1A.

B. **Volume**: This method is to validate a subsea MPFM to a topsides MPFM
   (1) Follow the steps in Direct Validation as listed above in 1B.

4. By Difference Comparison between subsea MPFM(s) and a topsides MPFM

This method has multiple MPFMs compared to a topsides MPFM. This method can be used for addition or subtraction of inlet sources.

A. **Mass**: Comparison of subsea MPFMs calculated mass vs topsides MPFM calculated mass
   (1) Follow the steps in Direct Validation as listed above in 1A.
   (2) By difference. Once the steps are complete, repeat the steps with one of the inlet sources (MPFM) added / removed and subtract the results of the separate validations to determine if the added / removed inlet source (MPFM) was within allowed tolerance.

B. **Volume**: Comparison of subsea MPFMs calculated volume vs topsides MPFM calculated volume
   (1) Follow the steps in Direct Validation as listed above in 1B.
   (2) By difference. Once the steps are complete, repeat the steps with one of the inlet sources (MPFM) added / removed and subtract the results of the separate validations to determine if the added / removed inlet source (MPFM) was within allowed tolerance.

5. System Material Balance

A. **Mass**: Comparison of MPFM calculated mass vs Process System calculated mass
   (1) Follow the steps in 1A (1), 1A (2) and 1A (3).
   (2) Sum the Mass for each phase. All the measurement points on the Process System outlets will then need to be summed for the mass of each phase for gas, oil and water. This may require (1) removing the amount of water in the oil and adding it to the total water mass and (2) removing recirculated oil and gas mass.
   (3) Compare MPFM Mass to Process System Mass. Comparison by mass can then be made between process inlet source(s) (MPFMs) for each phase and vessel or process system outlet sources for each phase (individual separator or LACT, sales gas, overboard water, flare, vent, fuel gas, gas lift, etc.) to determine if the MPFM(s) are within the allowed tolerance as a balance against the process system mass.
   (4) Summation. If there are multiple inlet sources (MPFMs), they may be summed following the above steps and compared to the process system outlet sources to determine the overall balance of the system.

B. **Volume**: Comparison of MPFM volume vs Process System calculated volume
   (1) Follow the steps in 1B (1), 1B (2) and 1B (3).
   (2) Sum the Volume for each phase. All of the measurement points on the Process System outlets will then need to be summed for the volume of each phase for gas, oil and water. This may require (1) removing the amount water in the oil and adding it to the total water volume and (2) removing recirculated oil and gas volumes.
   (3) Compare MPFM Volume to Process System Volume. Comparison by volume can then be made between process inlet sources (MPFMs) and process outlet sources (individual

separator or LACT, sales gas, overboard water, flare, vent, fuel gas, gas lift, etc.) to determine if the MPFM(s) are within the allowed tolerance.

(4) Summation. If there are multiple inlet sources (MPFMs), they may be summed following the above steps and compared to the process system outlet sources to determine the overall balance of the system.

C. **Things to look for (list may not be all inclusive)**:

- Ensure all inlet and outlet sources used in the validation are measured
- Fluid analyses are available for all measured sources used in the validation
- Meters on the reference system are properly maintained according to appropriate industry recommendations and regulatory requirements,
- MPFM measurement components such as differential transmitters, temperature transmitters, pressure transmitters, gamma detectors, salinity probes are properly maintained
- Fluid property configuration input values are representative

B. Surveillance

A routine surveillance process should be incorporated into a MPFM validation plan. The following should be considered in setting up routine surveillance activities:

- Use of Diagnostics
- Use of Process Monitoring / System Balance
- Use of Fluid Sampling
- Use of Reservoir and Well Models

C. Assessing Results

1. Determine if the results of the MPFM validation, based on method used, are in acceptable tolerance as described in the MFPM validation plan.

A. If MPFM Validation fails acceptance criteria:

- If MPFM was the error, perform troubleshooting or calibrations as per manufacturer recommendations
- If MPFM was not the error, perform troubleshooting or calibration of components of the reference system and ensure PVT properties being used are representative and consistently derived.
- If MPFM repeatedly fails validation, reassess MPFM validation plan, including methods chosen.

B. If MPFM validations are consistently meeting acceptance criteria:

- With support of positive results from the surveillance process, the frequency in the MPFM validation plan may be adjusted. Commercial and regulatory requirements will need to be assessed prior to making any adjustments to the validation plan.

D. Worked Examples

- Direct Validation to Separator with Single Phase Meters (Volume) - One Well Direct Validation w/3 Phase Separator
- Direct Validation to Separator with Single Phase Meters (Volume) - Two Well Direct Validation w/3 Phase Separator
- By Difference Validation to Separator with Single Phase Meters (Volume) - Two Well By Difference Validation w/3 Phase Separator
- Direct Validation to Separator with Single Phase Meters (Mass) - One Well Direct Validation w/3 Phase Separator

- Direct Validation to Separator with Single Phase Meters (Mass) - Two Well Direct Validation w/3 Phase Separator

3 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):	10,000	9,000	: Separator Gas Outlet (MSCF)
A-1 MPFM Oil Vol (BBL):	15,000	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:	0.9800
Flash Factor (SCF/BBL):	45.0

Corrected Volumes to Standard Conditions

	MPFM (STD)	Separator (STD)	Balance	Acceptance Criteria
Gas Volume Corrected (MSCF):	10,000	9,682	3.3%	+/-X%
Oil Volume Corrected (BBL):	15,000	15,147	-1.0%	+/-X%
Water Volume Corrected (BBL):	825	854	-3.4%	+/-X%
Liquid Volume Corrected (BBL):	15,825	16,001	-1.1%	+/-X%
Calculated S&W (%):	5.2%	5.3%		
GOR (SCF/BBL):	667	639		

Start Time:	1/1/19 0:00
Finish Time:	1/1/19 6:00
Length of test (hrs.):	6.00

4 Method: Direct Validation to Separator with Single Phase Meters (Volume) Two Well Direct Validation w/3 Phase Separator

Well A-2 & A-4 MPFMs (Direct Combined)

Raw Data

	MPFM (STD)	Separator (LC)	
A-2 MPFM Gas Vol (MSCF):	2,000	4,450	: Separator Gas Outlet (MSCF)
A-2 MPFM Oil Vol (BBL):	5,000	10,750	: Separator Oil Outlet (BBL)
A-2 MPFM Water Vol (BBL):	500	50	: Separator Water Outlet (BBL)
A-2 MPFM Liquids Vol (BBL):	5,500	10,800	: Separator Total Liquids (BBL)
A-4 MPFM Gas Vol (MSCF):	3,000		
A-4 MPFM Oil Vol (BBL):	5,000		
A-4 MPFM Water Vol (BBL):	500		
A-4 MPFM Liquids Vol (BBL):	5,500		

Adjustment Factors for Reference Measurement

Oil S&W (%):	9%
Oil Shrinkage:	0.9800
Flash Factor (SCF/BBL):	45.0

Corrected Volumes to Standard Conditions

	MPFM (STD)	Separator (STD)	Balance	Acceptance Criteria
Sum Gas Corrected (MSCF):	5,000	4,881	2.4%	+/-X%
Sum Oil Corrected (BBL):	10,000	9,587	4.3%	+/-X%
Sum Water Corrected (BBL):	1,000	1,018	-1.7%	+/-X%
Sum Liquid Corrected (BBL):	11,000	10,604	3.7%	+/-X%
Calculated S&W (%):	9.1%	9.6%		
GOR (SCF/BBL):	500	509		

Start Time:	1/1/19 0:00
Finish Time:	1/1/19 6:00
Length of test (hrs.):	6.00

5 Method: By Difference Validation to Separator with Single Phase Meters (Volume) Two Well By Difference Validation w/3 Phase Separator

Well A-1 & A-5 MPFMs (Direct Combined)

Raw Data

	MPFM (STD)	Separator (LC)	
A-1 MPFM Gas Vol (MSCF):	10,000	9,875	: Separator Gas Outlet (MSCF)
A-1 MPFM Oil Vol (BBL):	15,000	19,400	: Separator Oil Outlet (BBL)
A-1 MPFM Water Vol (BBL):	825	175	: Separator Water Outlet (BBL)
A-1 MPFM Liquids Vol (BBL):	15,825	19,575	: Separator Total Liquids (BBL)
A-5 MPFM Gas Vol (MSCF):	1,500		
A-5 MPFM Oil Vol (BBL):	3,000		
A-5 MPFM Water Vol (BBL):	100		
A-5 MPFM Liquids Vol (BBL):	3,100		

Adjustment Factors for Reference Measurement

Oil S&W (%):	4%
Oil Shrinkage:	0.9800
Flash Factor (SCF/BBL):	75.0

Corrected Volumes to Standard Conditions

	MPFM (STD)	Separator (STD)	Balance	Acceptance Criteria
Sum Gas Corrected (MSCF):	11,500	11,244	2.3%	+/-X%
Sum Oil Corrected (BBL):	18,000	18,252	-1.4%	+/-X%
Sum Water Corrected (BBL):	925	951	-2.7%	+/-X%
Sum Liquid Corrected (BBL):	18,925	19,203	-1.4%	+/-X%
Calculated S&W (%):	4.9%	5.0%		
GOR (SCF/BBL):	639	616		

Start Time:	1/1/19 0:00
Finish Time:	1/1/19 6:00
Length of test (hrs.):	6.00

6 Method: By Difference Validation to Separator with Single Phase Meters (Volume)
Two Well By Difference Validation w/3 Phase Separator

Well A-1 (Direct Individual)

Raw Data

	MPFM (STD)	Test Sep (LC)	
MPFM Gas Vol (MSCF):	10,000	9,000	: Separator Gas Outlet (MSCF)
MPFM Oil Vol (BBL):	15,000	16,100	: Separator Oil Outlet (BBL)
MPFM Water Vol (BBL):	825	210	: Separator Water Outlet (BBL)
MPFM Liquids Vol (BBL):	15,825	16,310	: Separator Total Liquids (BBL)

Adjustment Factors for Reference Measurement

Oil S&W (%):	4%
Oil Shrinkage:	0.9800
Flash Factor (SCF/BBL):	45.0

Corrected Volumes to Standard Conditions

	MPFM (STD)	Separator (STD)	Balance	Acceptance Criteria
Gas Volume Corrected (MSCF):	10,000	9,682	3.3%	+/-X%
Oil Volume Corrected (BBL):	15,000	15,147	-1.0%	+/-X%
Water Volume Corrected (BBL):	825	854	-3.4%	+/-X%
Liquid Volume Corrected (BBL):	15,825	16,001	-1.1%	+/-X%
Calculated S&W (%):	5.2%	5.3%		
GOR (SCF/BBL):	667	639		

Start Time:	1/1/19 0:00
Finish Time:	1/1/19 6:00
Length of test (hrs.):	6.00

7 Method: By Difference Validation to Separator with Single Phase Meters (Volume) Two Well By Difference Validation w/3 Phase Separator

Well A-5 (By Difference)

Combined Well Data

	MPFM (STD)	Separator (STD)	
Gas Volume Corrected (MSCF):	11,500	11,244	: Separator Gas Outlet (MSCF)
Oil Volume Corrected (BBL):	18,000	18,252	: Separator Oil Outlet (BBL)
Water Volume Corrected (BBL):	925	951	: Separator Water Outlet (BBL)
Liquid Volume Corrected (BBL):	18,925	19,203	: Separator Total Liquids (BBL)

A-1 Well Data

	MPFM (STD)	Separator (STD)	
Gas Volume Corrected (MSCF):	10,000	9,682	: Separator Gas Outlet (MSCF)
Oil Volume Corrected (BBL):	15,000	15,147	: Separator Oil Outlet (BBL)
Water Volume Corrected (BBL):	825	854	: Separator Water Outlet (BBL)
Liquid Volume Corrected (BBL):	15,825	16,001	: Separator Total Liquids (BBL)

A-5 By Difference Data

			Balance	Acceptance Criteria
Gas Volume Corrected (MSCF):	1,500	1,562	-4.0%	+/-X%
Oil Volume Corrected (BBL):	3,000	3,105	-3.4%	+/-X%
Water Volume Corrected (BBL):	100	97	3.1%	+/-X%
Liquid Volume Corrected (BBL):	3,100	3,202	-3.2%	+/-X%
Calculated S&W (%):	3.2%	3.0%		
GOR (SCF/BBL):	500	503		

8 Method: Direct Validation to Separator with Single Phase Meters (Mass)
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 Mass (lbs):	500,000	11,000	: Separator Gas Outlet (MSCF)
A-1 MPFM Oil Mass (lbs):	1,425,000	5,000	: Separator Oil Outlet (BBL)
A-1 MPFM Water Mass (lbs):	90,000	50	: Separator Water Outlet (BBL)
A-1 MPFM Liquids Mass (lbs):	1,515,000	5,050	: Separator Total Liquids (BBL)

Adjustment Factors for Reference Measurement

Oil S&W (%):	4.0%
Oil Shrinkage:	0.9800
Flash Factor (SCF/BBL):	75.0
Gas Density (g/ml):	0.0007
Oil Density (g/ml):	0.8600
Water Density (g/ml):	0.9982

Corrected to Standard Conditions

	MPFM (STD)	Test Sep (STD)	Balance	Acceptance Criteria
Gas Mass Corrected (lbs):	500,000	496,112	0.8%	+/-X%
Oil Mass Corrected (lbs):	1,425,000	1,417,953	0.5%	+/-X%
Water Mass Corrected (lbs):	90,000	87,469	2.9%	+/-X%
Liquid Mass Corrected (lbs):	1,515,000	1,505,422	0.6%	+/-X%
Water Liquid Ratio (%):	5.9%	5.8%		
Gas Per 100 lbs Oil:	35.09	34.99		

Start Time :	1/1/19 0:00
Finish Time :	1/1/19 6:00
Length of test (hrs.) :	6.00

9 Method: Direct Validation to Separator with Single Phase Meters (Mass) Two Well Direct Validation w/3 Phase Separator

Well A-2 & A-4 MPFMs (Direct Combined)

Raw Data

	MPFM (STD)	Test Sep (LC)	
A-2 MPFM Gas Mass (lbs):	500,000	17,000	: Separator Gas Outlet (MSCF)
A-2 MPFM Oil Mass (lbs):	1,200,000	10,000	: Separator Oil Outlet (BBL)
A-2 MPFM Water Mass (lbs):	45,000	260	: Separator Water Outlet (BBL)
A-2 MPFM Liquids Mass (lbs):	1,245,000	10,260	: Separator Total Liquids (BBL)
A-4 MPFM Gas Mass (lbs):	250,000		
A-4 MPFM Oil Mass (lbs):	1,500,000		
A-4 MPFM Water Mass (lbs):	45,000		
A-4 MPFM Liquids Mass (lbs):	1,545,000		

Adjustment Factors for Reference Measurement

Oil S&W (%):	10.0%
Oil Shrinkage:	0.9800
Flash Factor (SCF/BBL):	50.0
Gas Density (g/ml):	0.0007
Oil Density (g/ml):	0.8600
Water Density (g/ml):	0.9982

Corrected to Standard Conditions

	MPFM (STD)	Test Sep (STD)	Balance	Acceptance Criteria
Sum Gas Mass Corrected (lbs):	750,000	762,163	-1.6%	+/-X%
Sum Oil Mass Corrected (lbs):	2,700,000	2,658,663	1.6%	+/-X%
Sum Water Mass Corrected (lbs):	90,000	89,309	0.8%	+/-X%
Sum Liquid Mass Corrected (lbs):	2,790,000	2,747,972	1.5%	+/-X%
Water Liquid Ratio (%):	3.2%	3.3%		
Gas Per 100 lbs Oil:	27.78	28.67		

Start Time :	1/1/19 0:00
Finish Time :	1/1/19 0:00
Length of test (hrs.) :	6.00

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