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Technical Paper

# Experience from Implementing a Metering Solution For Subsea and Topside Multiphase Flow Metering

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## 1 INTRODUCTION

The use of multiphase flow meters (MPFM) for allocation metering purposes has become more and more common on many installations in North Sea. By utilizing multiphase flow meters both subsea and topside allows for tie-in projects to existing processing platforms where field ownership of the tie-in field may be different from the original field having the processing capacity.

Statoil has more than 20 years of experience of installing and operating multiphase meter and have today approximately 230 meters in operation, both subsea and topside. Multiphase meters are used on single wells, templates as well as flow lines for both well and ownership allocation metering.

FMC Technologies has for many years collaborated with Statoil in developing common solutions for the multiphase metering systems. These solutions have over years developed into a common solution for use on both new and existing fields.

The main purpose of this paper will give some information on how to configure, install and operate a system with multiphase meters based on statutory requirements, partner requirements and the experience gained by more than 20 years of operation.

## 2 Statutory Requirements

From the presentation at the 2012 NSFW given by Steinar Fosse from the Norwegian Petroleum Directive about the Update of Norwegian Regulations for Fiscal Measurement [1], Chapter IV, section 13 gives a detailed list of requirements for using multiphase meters as a fiscal meter. These requirements are:

***Multiphase measurement***
*Multiphase measurement may be used if traditional single phase measurement of hydrocarbons is not possible for financial reasons. The multiphase meter can then be used as a fiscal meter.*

*The following elements shall be satisfactorily documented to allow use of a concept based on multiphase measurement, cf. Chapter VII and Section 18:*

- *The operator shall present a concept to the Norwegian Petroleum Directorate for comments and formal processing well before submitting the Plan for Development and Operation (PDO). An estimate of the expected measurement uncertainty shall be presented, combined with financial figures for the risk of loss between production licenses (cf. NORSOK I-105), Annex C).*
- *The main principles of the operations and maintenance philosophy shall be described.*
- *Possibility to calibrate meters against test separator or other reference.*
- *Redundancy in sensors and robustness in the design of the measurement concept.*
- *Relevant PVT (equation of state) model and representative sampling opportunity to be able to perform a sound PVT calculation.*
- *Design of inlet pipes to ensure similar conditions if multiple meters are used in parallel.*
- *Flexibility in the system for handling varying GVF (gas volume fraction).*
- *The planned method for condition monitoring and/or planned calibration interval shall be described.*
- *The planned method and interval for sampling and updating PVT data shall be described.*

*When the multiphase meters are part of the fiscal measurement system, they shall be treated as other fiscal measurement equipment and the administrative requirements which apply pursuant to these Regulations shall therefore be fulfilled.*

Other important sections that must be taken into consideration when designing a fiscal metering system using multiphase meters for the Norwegian sector are:

- Section 7 – Verification
- Section 8 – Allowable measurement uncertainty
- Section 18 – Application for consent
- Section 26 – Operating requirements for instrument part
- Section 27 – Operating requirements for computer part
- Section 29 – Documentation relating to the metering system in operation

## 3 BEST PRACTICE

Based on more than 20 years of experience with multiphase flow meters Statoil has developed a list of best practice recommendations:

- Integrate the multiphase meters into a Supervisory Metering Computer.
- Always try to have on-line verification by test separator/inlet separator/export metering.
- Use PVT calculations based on what type of oil you have
- Use HC mass for both allocation and verification.
- Always flow test the meter on the same conditions and on the same type of oil.
- For heavy oil its recommended to measure viscosity and make a calculation based on tested viscosity/water cut.

### 3.1 Integrate the MPFMs into a Metering Supervisory Computer

A Metering Supervisory Computer is optimized for collection, storing and reporting fiscal figures. The recommended solution is therefor to connect the multiphase flow meters to the Metering Supervisory Computer. In addition to the accounting tasks, the Metering Supervisory Computer should also handle any verification of the multiphase meters, either by performing a calibration against a test separator or continuously monitoring of hydrocarbon mass between subsea and topside meters.

### 3.2 On-line verification

Topside multiphase meters should always have the possibility to be verified against a test separator / inlet separator or export metering equipped with meters and instrumentation of fiscal standard. The flow from subsea multiphase meters should normally be continuously compared to topside meters. Typically the flow from one or more subsea flow meters flashed to standard conditions by the PVTpack is accumulated and compared to the total flashed flow accumulated by the topside meter(s), by hourly and/or daily values.

### 3.3 Use PVT Calculations

A PVT calculation should always be used in order to correct the flows from all meters to standard conditions. It is recommended to implement a PVT calculation model which is adjusted to the type of fluids in the reservoir / flow lines and the process model used to separate the fluids. A typical process model used for flashing a multiphase flow is shown in Figure 7.

### 3.4 Use HC mass for both allocation and verification

The total HC mass is recommended to be used both for allocation accounting and verification. This will secure that a uniform value is used for mass figures regardless of any weakness in the flash model when calculating PVT volumes.

Correction factors for meter volume flows should also be calculated during verification, but they are more of "academic" interest since all allocation figures shall be based on HC mass. As a result a calibration run against a test separator, a HC correction factor is also established.

### 3.5 Test Separator Configuration

The following items are some recommendations for a test separator installation used for verification/calibration of multiphase flow meters:

- To verify/calibrate multiphase meters against test separator, an assessment of any upgrades of the process and/or the test separator shall be performed to ensure verification and calibration of multiphase meters at highest operating flow rates.
- To reduce the uncertainty in the PVT composition it is recommended to install additional density meters on the gas and oil legs in the test separator.
- It should also measure water cut on the oil leg.
- It is recommend to use ultrasonic meters to measure gas, and compare calculated VOS against measured in order to secure the accuracy of the gas composition used.
- For oil it can be recommended to use Coriolis meters. These meters can give us the mass flow and densities.
- Sampling points for extraction of samples for PVT analysis must be included and designed after recognized standards.
- With parallel multiphase meters, it is required with piping arrangement upstream the meters to ensure symmetric flow (equal distribution of components) through the meters.
- Needed to ensure efficient separation conditions. This is particularly important for heavy oil applications. This shall apply needed mapping of the capacities and maximum flow rates to the inlet and test separators.

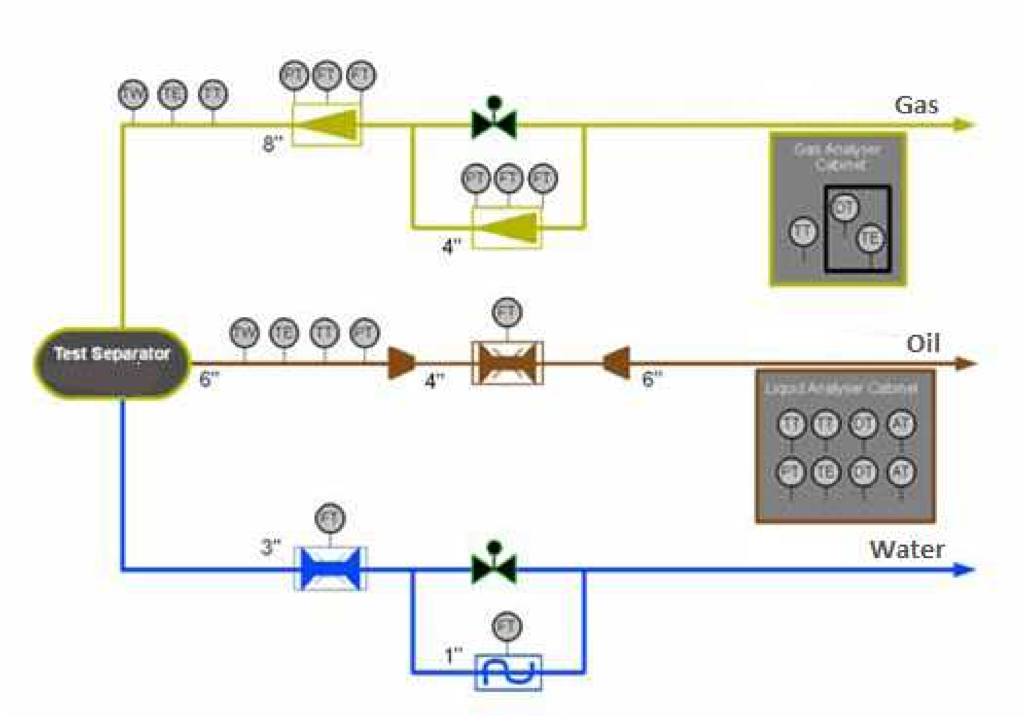


Figure 1 - Typical test separator configuration

## 4 TYPICAL TOPOLOGY DRAWING FOR THE COMPUTER SYSTEM

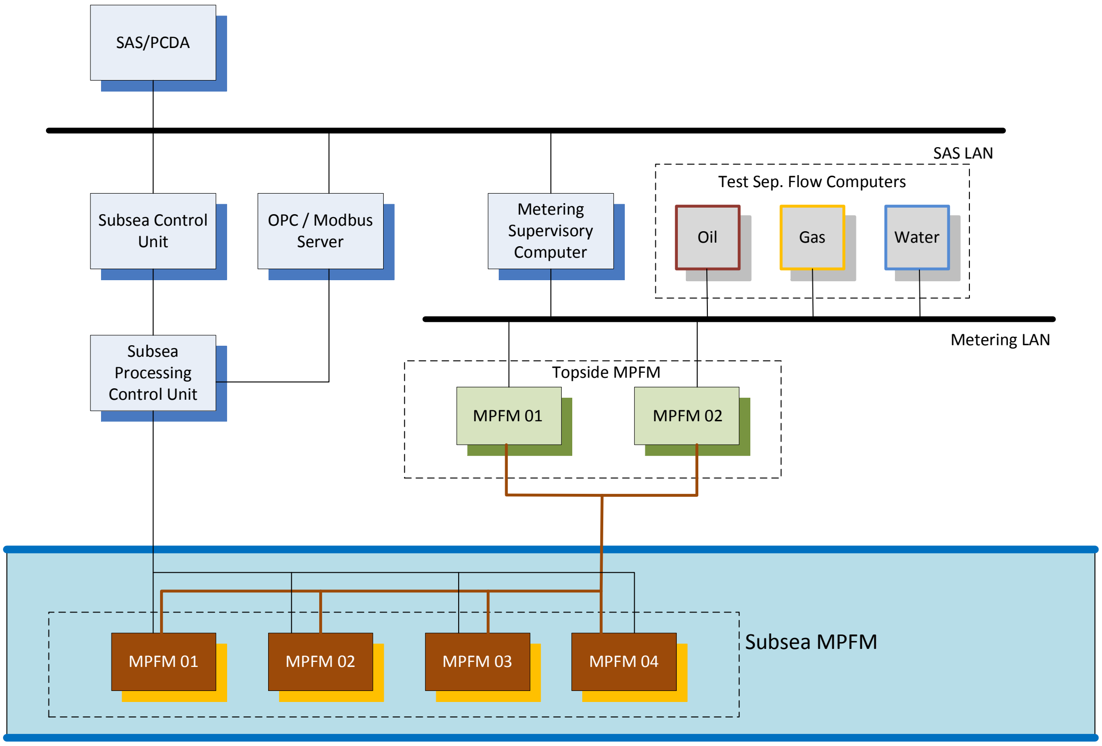


Figure 2 – Typical Topology Diagram

The above drawing illustrates a simplified typical topology drawing of a metering system with both subsea and topside multiphase meters and a test separator with measurement in accordance with fiscal standards using flow computers for all three phases.

The purpose of the drawing is to illustrate the different interfaces in a typical configuration where the topside multiphase meters are connected directly to the metering supervisory computers while the subsea meters are often connected via subsea and/or topside processing units belonging to the installation Safety and Automation system. The communication with the subsea meters were for many years a challenge due to limited data capacity in the subsea connection but today's use of fibre optical interfaces has improved this considerably.

In many projects it can still be a challenge to establish a high quality fast connection to the subsea multiphase meters. The reason is that the SAS vendor is very restrictive in allowing 3rd party equipment to talk with any controlling nodes in the network. The best solution is normally to have an OPC or Modbus TCP server connected to a less restrictive network such as the installation technical network. Use of slow serial connections should be avoided whenever possible.

It is also recommended to perform all interface testing prior to installation offshore. The interface test should include all interfaces involved in transmitting the data to and from the MPFM.

## 5 TOPSIDE AND SUBSEA MULTIPHASE METERS

The installation requirements for software functionality are slightly different between a topside multiphase metering installation and the subsea installation.

### 5.1 Topside Multiphase Meters

For the topside multiphase meters, changes in the PVT input data (composition) can continuously change due to the relative production from different well or reservoirs. In addition gas lift, gas injection and diluent injection contributes to changes to the fluid composition.

With known fluid composition of wells and/or reservoirs, model-based PVT-input to the topside PVT calculations is implemented. A set of flow weighted composition data based on all subsea well/reservoir compositions shall be calculated and presented as a possible composition to be used as input to the PVT calculations. A mode for continuously calculating a corrected fluid composition may also be available. See section 6.2 and Figure 5 for more details about mixing the composition from different sources.

Samples of produced gas and liquids should always be planned for.

### 5.1 Subsea Multiphase Meters

The subsea multiphase meters will primarily be used for well optimisation and flow monitoring. In addition they can be used as a backup meter for the topside multiphase meters.

Subsea multiphase meters should continuously be compared to the topside multiphase meters. The total HC mass rate measured by the topside meters should be close to the sum of the HC mass rate measured by the subsea multiphase meters. Optionally the HC mass for any riser-based gas lift must also be added to the total measured HC-mass before comparison.

If the template is equipped with a continuously arrangement for gas lift the gas lift HC mass must be measured and accounted for. In addition, the well composition must be updated with the gas lift composition for PVT input. The PVT calculation can then calculate new densities at meter conditions based on the updated well composition.

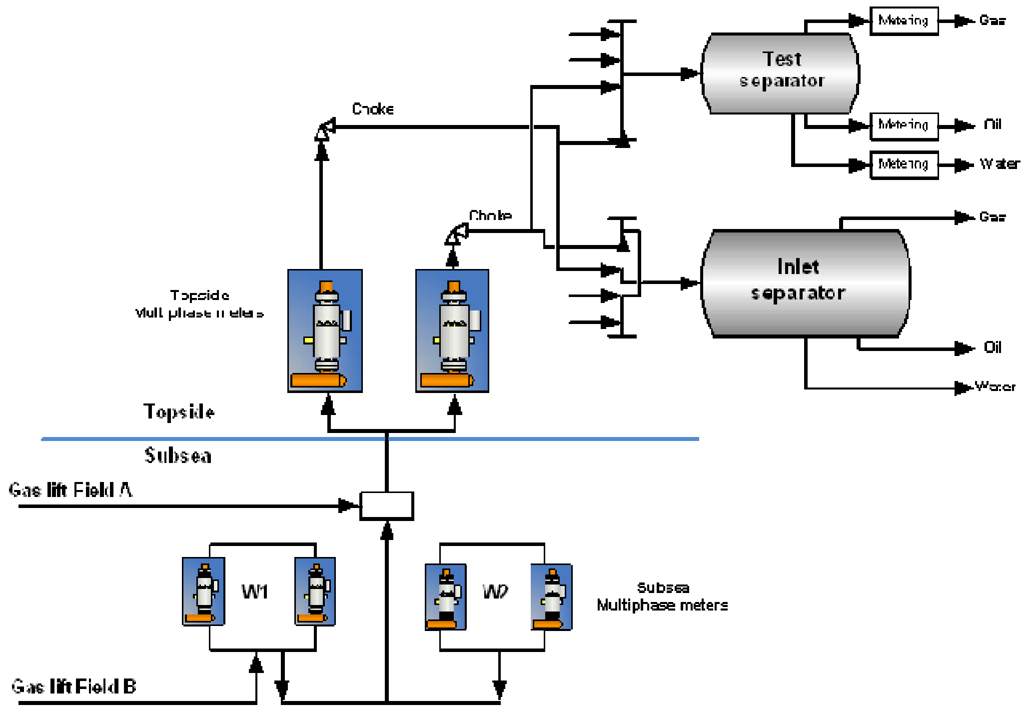


Figure 3 – Typical MPFM configuration with manifolds and separators

## 6 MAIN SOFTWARE FUNCTIONALITY

The Metering Supervisory Computer shall have as a minimum the following main functionality:

- PVT Calculation of all flow measurements and converting to standard conditions.
- If relevant, update the multiphase meters with PVT corrected densities for all three phases together with density temperatures and water salinity.
- On-line supervision of the deviation between subsea and topside metering.
- Verification of topside multiphase meters against test separator/production separator or export metering.
- Calculation (on-line mixing) of PVT composition input for the topside multiphase meter and test separator, based on flow weighted PVT composition from subsea meters.
- Generating reports for all verifications and parameters change (including the composition).
- Optionally adjust the well composition measured by subsea multiphase meters and composition for the topside multiphase meters to include any measured lift-gas by online composition mixing.
- Collect all relevant data and measurement values in a unified system and store them for future reporting and auditing purpose without any further conversion and corrections.

The above functionality gives the following benefits:

- Supervising the quality of the measurement.
- Audit benefits and traceability, supports NPD and partners auditing requirements.
- Simplifies the process of reallocation.
- Provides operating savings regarding daily reporting and allocation.

### 6.1 PVT Calculations

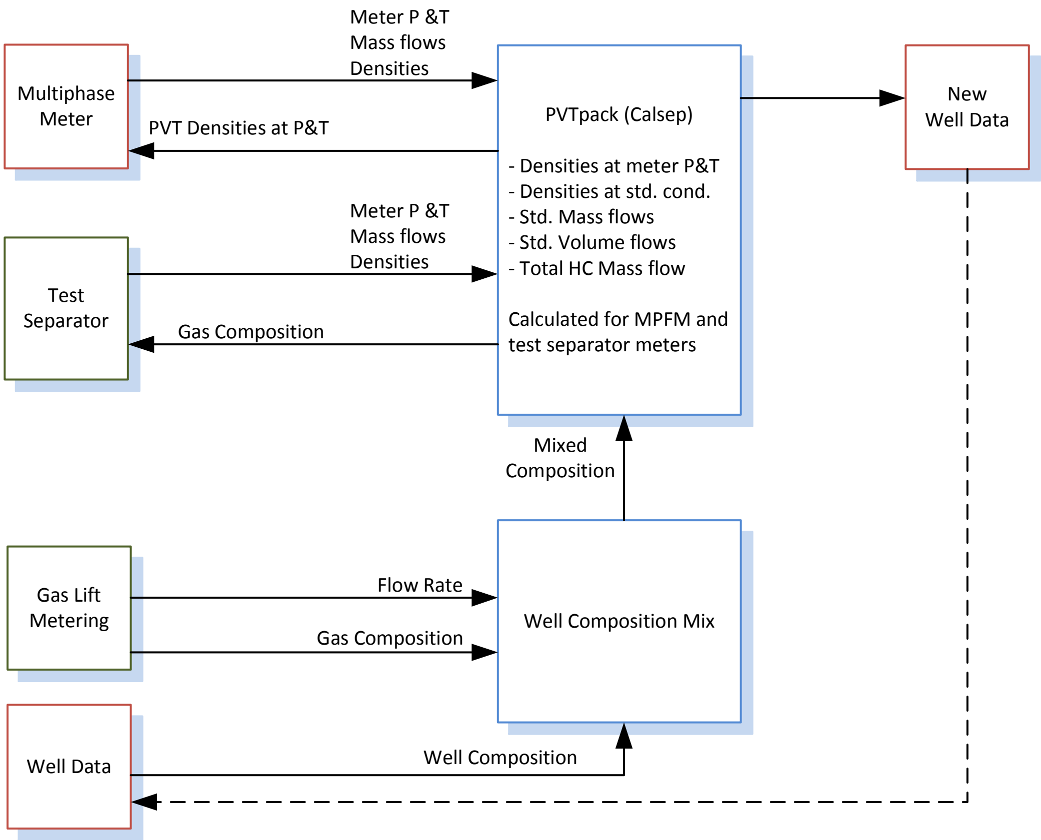


Figure 4 – PVT Calculations

A simplified of the data flow between meters and the PVTpack based on PVTsim from Calsep [3] including the Well Composition mixing routine is shown in Figure 4. The PVTpack continuously reads the flows for gas, oil and water from the multiphase meter together with the current densities, pressure and temperature. Based on the meter readings and the calculated mixed well composition, the PVTpack flashes each phase to standard conditions using a single- or multi-flash model. A new set of densities at for each flow is calculated at a given temperature and pressure together with new water salinity value.

The PVT calculated flows are accumulated and reported while the densities can be written back to the multiphase meters together with the corresponding density temperatures and pressures.

During a verification/calibration of a multiphase meter against a test separator or equal, the PVTpack can calculate a corrected gas composition for the gas leg of the test separator. The corrected gas composition can optionally be updated in the test separator gas flow computer(s).

After a verification/calibration run of a multiphase meter against a test separator, the PVTpack calculates a set of correction factors for each phase + a Total HC Mass correction factor. In addition the PVTpack calculates a new well composition which can be accepted as the well composition to be used in future calculations.

For more information about PVT calculations see reference [2].

### 6.2 Well composition mixing for topside multiphase meters

When multiple multiphase flow meters are connected to the same riser with one or more topside multiphase meters measuring the total flow from all wells it is strongly recommended to implement an on-line well composition mixing model based on the composition for each well and the flow rate from each subsea flow meter. The well composition mixing model must also be able to take into consideration any gas lift flow measurement used in the riser.

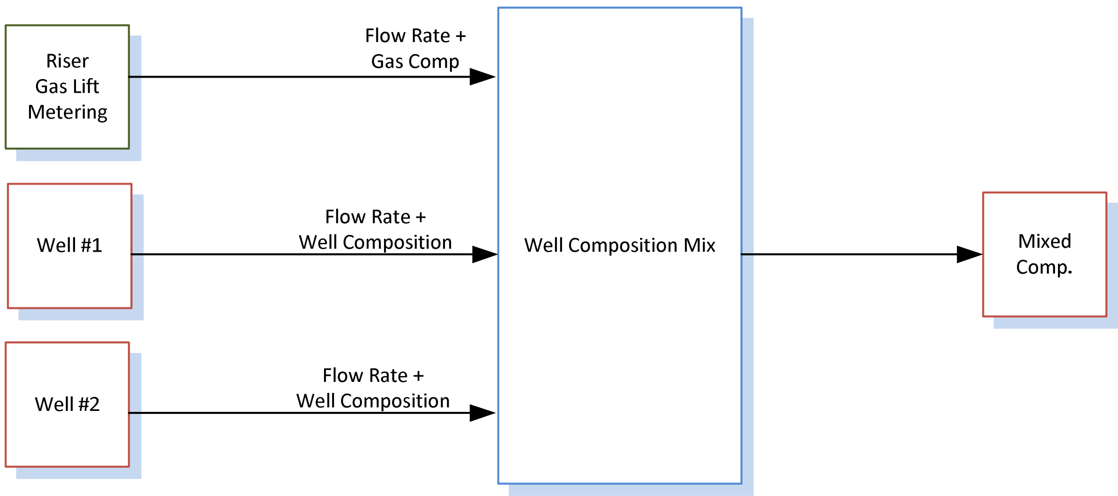


Figure 5 – Well Composition Mixing

### 6.3 Well composition mixing for subsea multiphase meters

As for topside multiphase meters there may be a requirement for adjusting the well composition with any gas lift quantities measured by the subsea multiphase meter. The mixed composition will be further used as input to the topside composition mixing model.

## 7 USING PVT CALCULATIONS FOR FLOW CALC AND CALIBRATION

In order to use multiphase meters for allocation purpose Statoil and FMC has together with Calsep developed a software package for handling the continues measured flow from the multiphase meters and calibration/verification of the meters when process conditions change. The main functionality found in the software package is described in the following sections. The functionality can be divided into the sub-functions:

- Continues accumulation the measured flow from the MPFM flashed/-corrected to standard conditions using a defined process model.
- Continues calculation of densities at meter conditions based on the defined composition for the meter, current pressure and temperature and the GOR.
- Calculation of test separator measured flows flashed to standard conditions using a defined process model.
- Calculation of a corrected gas composition which can be used as input to the AGA8 calculation used in the test separator gas leg.
- Calculation of a corrected composition for the test separator flow based on the original composition, test separator P &T and the test separator GOR.
- Determine correction factors for the observed MPFM flow connected to the test separator by comparing the flow for each phase flashed to standard conditions and "back-flashed" to MPFM conditions.
- Calculate a new composition Z for the MPFM based upon the results from the calibration.

## 7.1 Multiphase flow handling

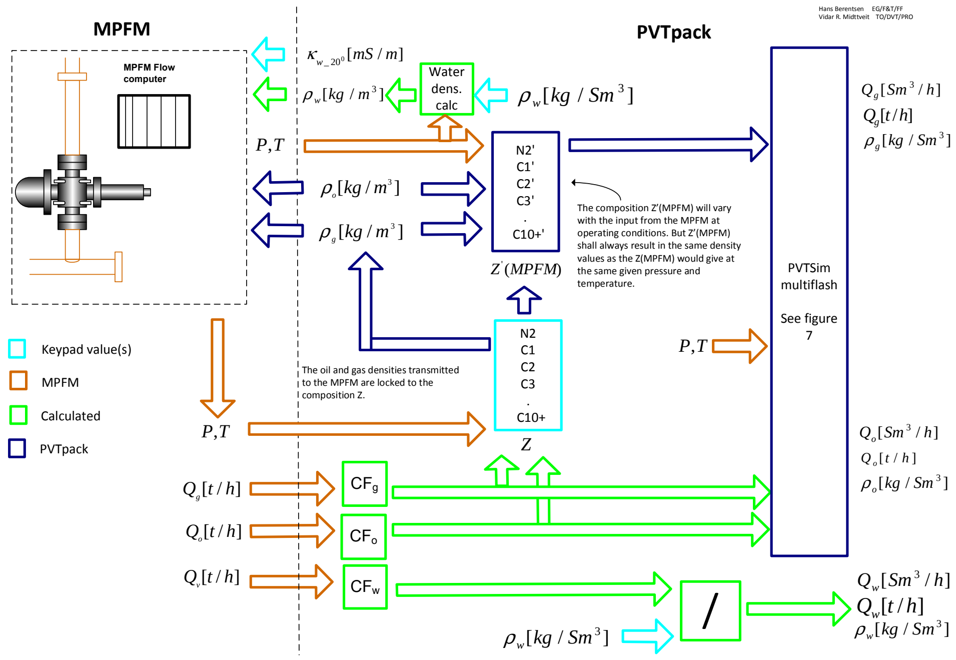


Figure 6 – Multiphase flow handling

The flows are read from the MPFM flow computer and corrected with a corresponding K-factor for each phase before they are passed on to the PVTpack together with the meters P & T and the composition Z. The PVTpack will flash the flow rates (or quantities) to standard conditions; calculate a corrected composition and densities for oil and gas. The corrected densities can be written back to the MPFM together with a corrected water density (calculated elsewhere). In addition, the water salinity should be updated by manual input on regular basis.

Experience has shown that a single flash algorithm is in many situations not the ideal solutions for converting the HC flow to standard conditions. Low density fluids may often require a multi-stage flash in order to give a high quality flow calculations suitable for use in allocation metering. The PVTpack package used on most Statoil installations with test separators and/or multiphase meters has implemented several process models including a single flash model.

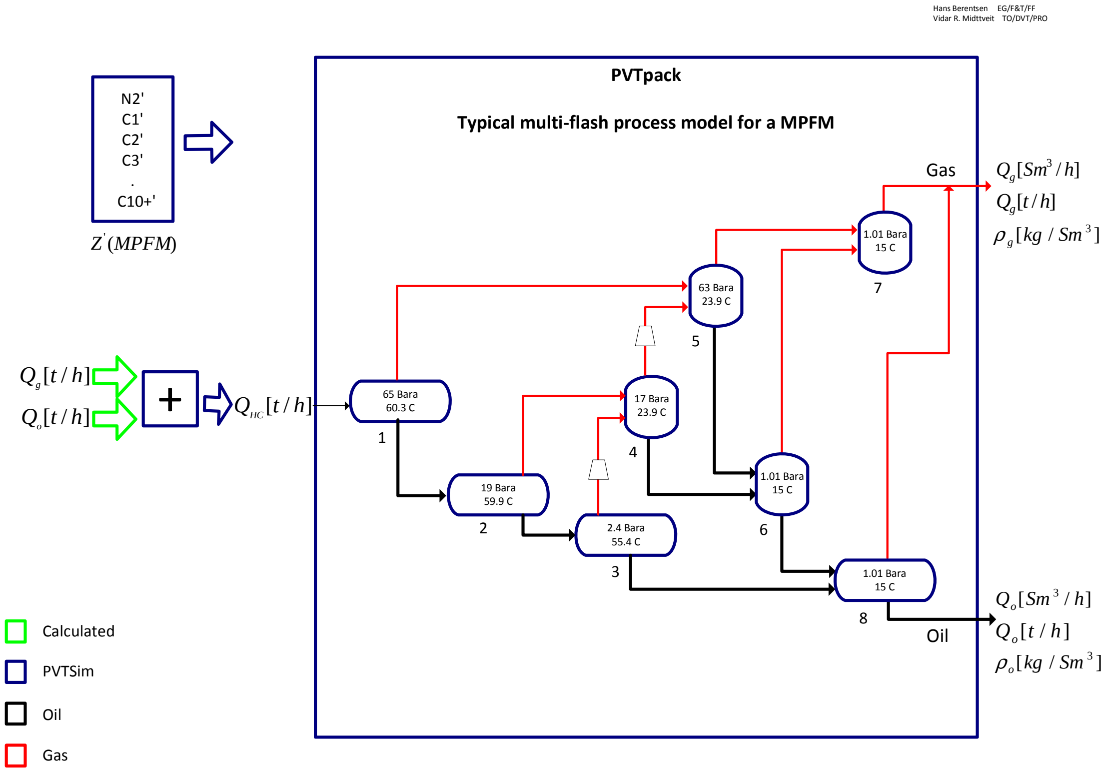


Figure 7 – Typical Multi-flash process model

Figure 7 illustrates a typical process model used on several Statoil installations for converting the MPFM HC mass flow rates to standard conditions. The input is the corrected HC flow rates read from the MPFM together with P&T and the defined composition corrected by PVTpack. The output from PVTpack is the flashed flow rates with corresponding densities at standard conditions.

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## 7.2 Test Separator handling

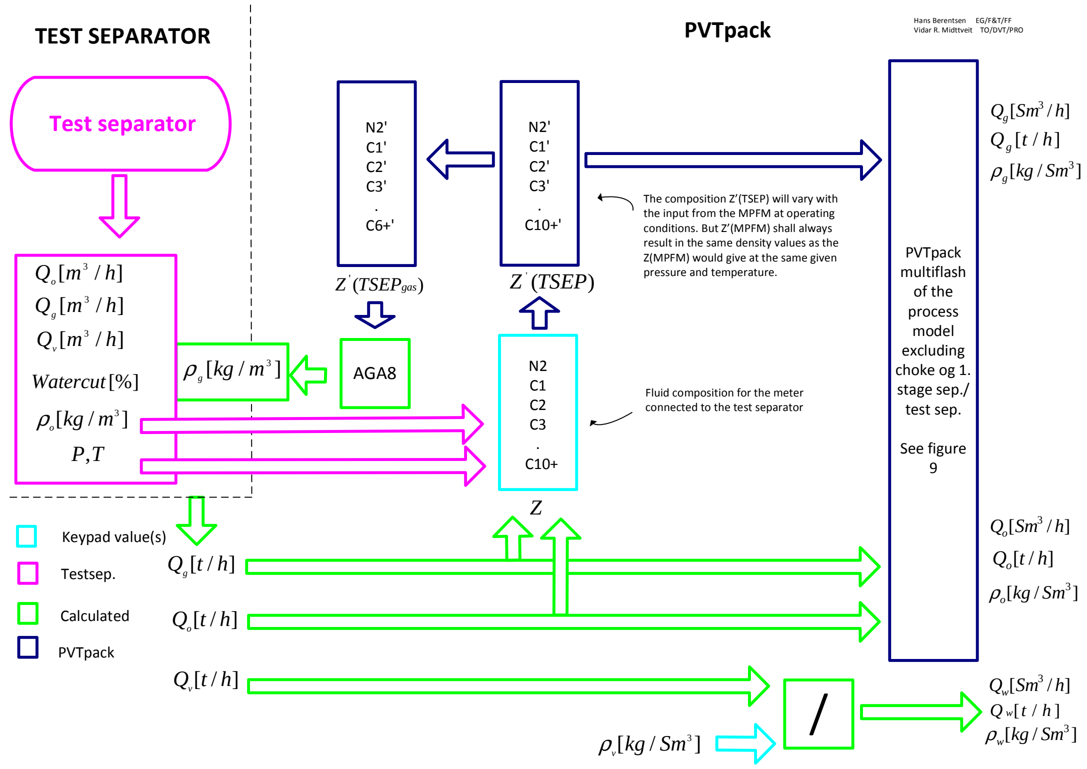


Figure 8 – Test Separator handling

The flows are calculated by the test separator flow computers and passed on to the PVTpack application together with the measured densities and the composition belonging to the MPFM currently connected to the test separator. The PVTpack calculates the flows to standard conditions, calculates a adjusted composition Z'(TSEP) and a gas composition Z'($TSEP_{gas}$) which optionally may be used in future gas calculations in the test separator (AGA 8 density).

The water flow is converted to standard conditions. Any remaining water in the oil leg from the test separator should be measured and accounted for in the total water flow (net calculations in accordance with API Chapter 20, Section I).

The typical process model used for a test separator is shown in Figure 9.

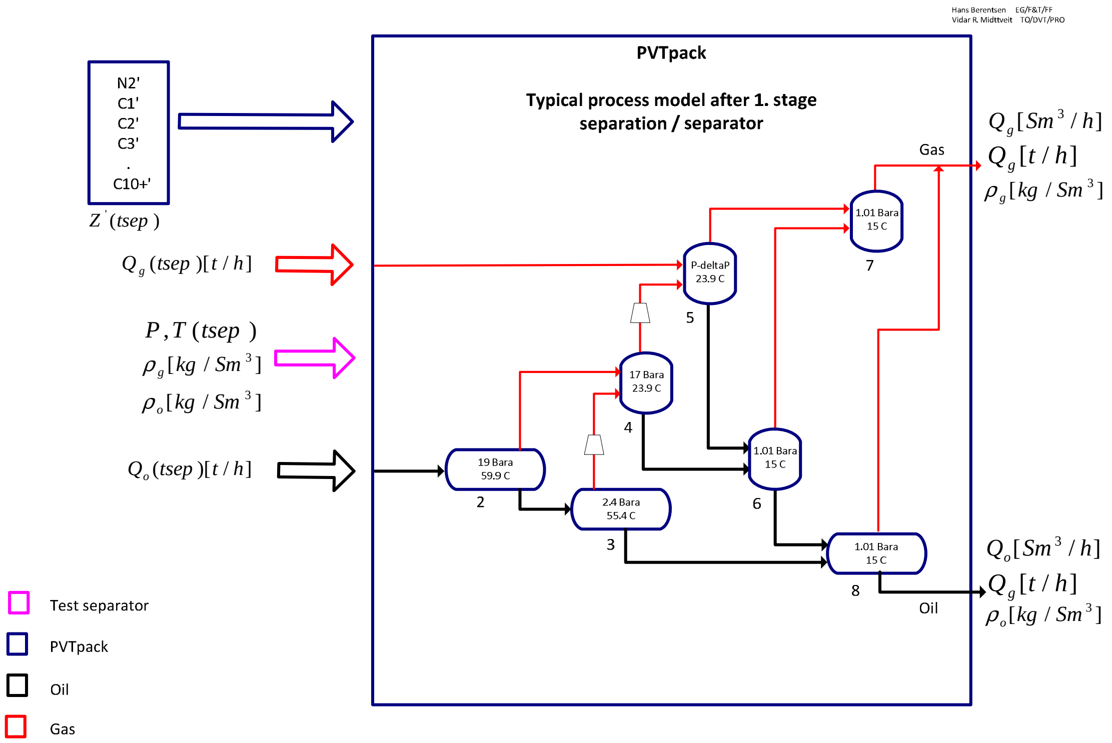


Figure 9 – Typical test separator process model

## 7.3 Calibration of MPFM against a Test Separator

The calibration of a MPFM against a test separator should be performed on a regular basis in order to secure that the flow accumulation based of the MPFM measured flow is as accurate as possible. The calibration is performed using a special calibration mode within the PVTpack application by averaging the flow over a period or, if available, by utilising synchronized batch functionality in the flow computers. In both cases there is a need for averaging the temperature, pressure and densities from both the MPFM and the test separator.

After ending the calibration run, the PVTpack is used to backflash the accumulated flow to the MPFM conditions and calculate the correction factors for each phase as follows:

$$K'_X = \frac{Q(tsep)_X[t/h]}{Q(mpfm)_X[t/h]} \qquad [1]$$

where X is either G(as), O(il), W(ater) or HC(total HC mass).

In addition to the new correction factors, the PVTpack calculates a new suggested composition $\overline{Z}'(TSEP)\_KAL$ for the MPFM. The quality of a recommended new composition for the multiphase flow meter is highly dependent on density measurement in the test separator gas and oil legs. The new suggested composition must be manually confirmed before taken into use in future calculations.

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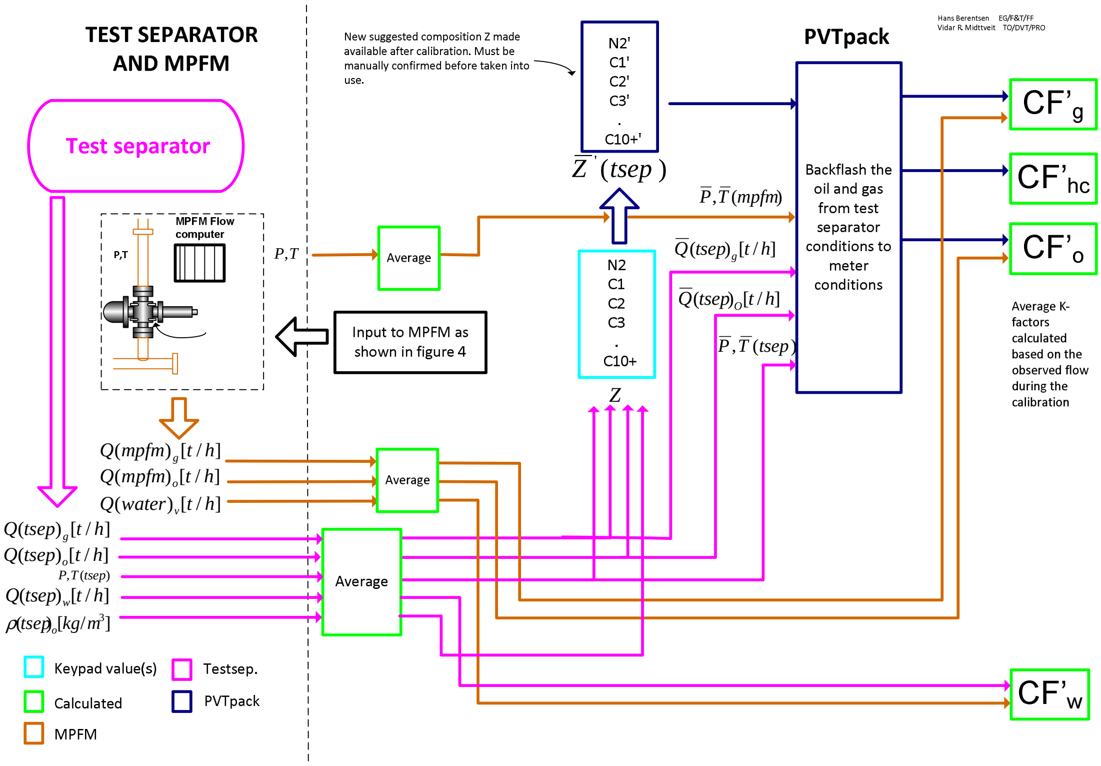


Figure 10 – Calibration of MPFM against a test separator

## 8 UNCERTAINTIES IN PVT CALCULATIONS

The estimates for uncertainties in the PVT calculation are based on Calsep's experience, and based on handling all types of fluids (gas, condensate, volatile and heavy oils). The requirements for these estimates are:

- A high quality updated analyse of the fluid composition
- A known GOR at test separator P&T
- Possibility to automatically tune the composition to match the measured GOR
- The composition mix far from its critical point (that is gas and oil phase differ considerably)
- The salinity is known by on-line measurement or analysis

Based on the above requirements Calsep gives a rough estimate for the uncertainties in the PVT calculations as follows:

- Phase amounts - 5%
- Oil density - 3%
- Gas density - 3%
- Water density - 2%
- Water + salt density - 2-3% (accumulated value)

## 9 TESTING AND VERIFICATION

By comparing continuous HC mass and water rates, measured by topside meters and subsea meters, including gas lift in riser base, any deviation between the topside measurements and subsea measurements should be revealed. With an averaged deviation >10 % (based on the combined uncertainties of the subsea and topside multiphase meters) of HC mass rate during one week between subsea and topside, more extensive testing by using the test separator is required in order to identify the source of deviation.

The calculation of the average deviation should be based on daily production with automatic weekly reporting. The metering computer should make daily, weekly and monthly reports. These reports should be filed along with other quality records and can later be used to document the performance of the metering system.

Well testing should be performed in order to identify the source of deviation. Proper flexibility of the topside meters is important in order to handle a wide range of flow rates. The advantage by this method is reduced testing time to control the subsea multiphase meters performance.

Only with abnormal operations with considerable deviations more extensive test programs may be required.

The test separator should be used for verification and calibration of the topside multiphase meters. It is recommended to perform a verification and calibration of the topside multiphase meters on a regular basis. The calibration frequency should be revised according to operational experiences and to be agreed between licensees.

### 9.1 Verification methods and uncertainty levels

Verification methods and uncertainty levels are based on different information sources for production or measurement data. The different information sources will have different uncertainties. Every method shall be verified against a method with lower uncertainty.

In the table below, the available direct one to one verification methods that shall be available during normal production is listed.

| Uncertainty Level | Production measurement method | To be verified against |
|---|---|---|
| 1 | Topside Test Separator Measurements | Normal maintenance procedures. |
| 2 | Topside Multiphase Meter | Topside Test Separator Measurements |
| 3 | Sub-sea Multiphase Meter | Topside Multiphase Meter |
| 4 | Topside Choke Setting | Sub-sea Multiphase Meter |
| 5 | Sub-sea Choke Setting | No available reference |

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## 10 NOTATION

Notation should be included at the end of your paper and, if space is at a premium, it may be presented in two columns as follows:

| | |
|---|---|
| $Q_g$ | Gas flow |
| $Q_o$ | Oil flow |
| $Q_w$ | Water flow |
| $Q_{HC}$ | Hydrocarbon flow |
| $\rho_g$ | Density of gas |
| $\rho_o$ | Density of oil |
| $\rho_w$ | Density of water |
| P | Pressure |
| T | Temperature |
| Z | Composition |
| $CF_g$ | Correction Factor Gas |
| $CF_o$ | Correction Factor Oil |
| $CF_w$ | Correction Factor Water |
| $CF_{hc}$ | Correction Factor Hydrocarbons |

## 11 REFERENCES


[1] STEINAR FOSSE. Update of Norwegian Regulations for Fiscal Measurement, 30th International North Sea Flow Measurement Workshop 23 – 26 October 2012.

[2] KRISTIAN KREJBJERG AND NIELS LINDELOFF, Calsep A/S, Gl. Lundtoftevej 1C, DK-2800 Kgs. Lyngby, Denmark HANS BERENTSEN AND VIDAR RUNE MIDTTVEIT STATOIL, N-4035 Stavanger, Norway. Conversion of multiphase meter flowrates, 19th International North Sea Flow Measurement Workshop, Kristiansand, Norway, 22-25 October 2001

[3] Calsep http://www.calsep.com/index.aspx


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