

Conversion of multiphase meter flowrates

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Abstract

This paper outlines the principles behind conversion of multiphase meter flowrates from meter conditions to standard conditions. It is described how the configuration of the topside separation process should be taken into account in the calculations. It is furthermore discussed how compositional variations due to fluctuations in GOR can be accounted for. This technology can also be used for online calibration of the meter.

Introduction

Multiphase metering (MPM) has become technically feasible and in widespread use. The volumetric flow rates are usually required, not at the pressure and temperature conditions at the meter, but at standard conditions. Mass transfer will take place between the phases on their way through the topside separation process, and the phase densities will change as a result of pressure and temperature changes. For the purpose of fiscal reporting and allocation, it is essential that the measured flow rates can be converted accurately to standard conditions.

Simple correlations and conversion factors are insufficient, as the meter pressure and temperature in many cases vary significantly. Furthermore the overall composition of the mixture let to the meter may also fluctuate, which further complicates the problem. A combination of a reliable calculation model and access to online data is required in order to properly convert the MPM measurements.

Fluid densities and fluid phase behavior are in the petroleum industry most often calculated using the thermodynamic models referred to as equations of state (EoS). Combined with a set of mass balances generally known as flash equations, the EoS models may be used to calculate phase densities and distribution of hydrocarbons, water and production chemicals between the phases present. The required input for these calculations is pressure, temperature and chemical composition of the overall mixture. The approaches discussed in the paper are based on this technology.

Flash calculation and recombination

The flash calculation distributes the components between the different phases given the overall composition \mathbf{z} , pressure and temperature:

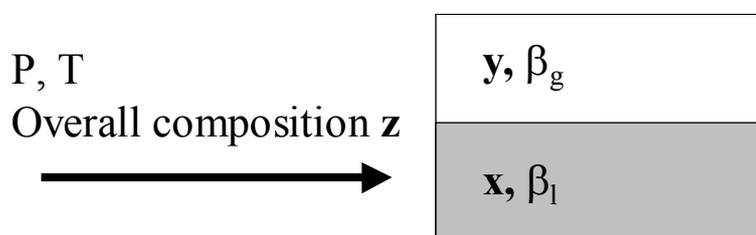


Figure 1 Input and output from a two-phase flash calculation

The output from the calculation is the molar phase amounts β_g and β_l and the phase compositions \mathbf{y} and \mathbf{x} . For each component i , in an N component mixture, the mass balance must be fulfilled:

$$z_i = y_i \beta_g + x_i \beta_l \quad i = 1, N \quad (1)$$

The phase densities may also be calculated using an EoS permitting the volumetric GOR to be calculated

$$GOR = \frac{\beta_g M_g \rho_l}{\beta_l M_l \rho_g} \quad (2)$$

where M_g and M_l are the average molecular weights of the gas and liquid phases and ρ_g and ρ_l the phase densities. The calculated GOR may not correspond to the GOR measured, but this may be taken care of by adjusting the relative amounts of gas and liquid in Figure 1. If the phase compositions are maintained, the system will still be in equilibrium. This means that the phase amounts can be changed to match a given GOR, as long as the phase compositions are the same as in Figure 1.

Consider Figure 2 below, where the original flash result is the molar phase amounts β_g and β_l . If the measured GOR is smaller than the one calculated, one can readily tune the overall composition to match this GOR by adding more of the liquid phase, with the same composition as the original liquid composition from the flash calculation. The new phase mole fractions are:

$$\beta_g = \frac{GOR_{measured} M_l \rho_g}{M_g \rho_l + GOR_{measured} M_l \rho_g} \quad \text{and} \quad \beta_l = 1 - \beta_g \quad (3)$$

and the new overall composition can be calculated from equation 1.

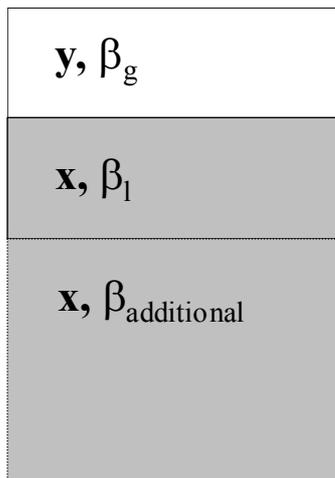


Figure 2 Addition of liquid phase to match GOR

The flash calculation and recombination for a given GOR is the very basis of carrying out conversion of flow rates to standard conditions. Recombination to a measured GOR gives the correct overall composition, which is used as input to a sequence of flash calculations describing the topside separation process. Figure 3 shows two possible sequences of flash calculations to standard conditions. One is a single stage flash and the second one a six stage separator train. For both separations the problem is to determine the volumetric flow rates of oil and gas at standard conditions with the flowrates at meter conditions as input. In Figure 3 the volumetric flow rates of oil at meter conditions is named \dot{V}_O^{MC} and the volumetric flow rate of oil at standard conditions is called \dot{V}_O^{SC} .

Classical table conversion approach

The classical way of handling the description of mass transfer between phases is the black oil nomenclature as it is applied for reservoir engineering purposes. Three components are considered:

- oil: May exist in the oil and the gas phases
- gas: May exist in the gas and the oil phases
- water: May exist only in the water phase

For this purpose the following black oil parameters are needed. Two sets of pressure and temperature conditions are considered, the Meter Conditions (MC) and Standard Conditions (SC)

$$B_o : \text{Oil volume factor} \quad B_o = \frac{V_o^{MC}}{V_o^{SC}} \quad (4)$$

$$R_s : \text{Gas in oil solubility factor} \quad R_s = \frac{V_{GinO}^{SC}}{V_o^{MC}} \quad (5)$$

$$B_g : \text{Gas volume factor} \quad B_g = \frac{V_g^{MC}}{V_g^{SC}} \quad (6)$$

$$R_v : \text{Oil in gas solubility factor} \quad R_v = \frac{V_{OinG}^{SC}}{V_g^{MC}} \quad (7)$$

$$B_w : \text{Water volume factor} \quad B_w = \frac{V_w^{MC}}{V_w^{SC}} \quad (8)$$

The volumes used in these definitions are calculated internally in the software based on the fluid composition and the specified temperatures and pressures. Conversion of volumetric flowrates from MC to SC makes use of these coefficients in the following way:

$$\text{Gas volume flow rate at SC:} \quad \dot{V}_G^{SC} = \dot{V}_O^{MC} * R_s + \frac{\dot{V}_G^{MC}}{B_g} \quad (9)$$

$$\text{Oil volume flow rate at SC:} \quad \dot{V}_O^{SC} = \frac{\dot{V}_O^{MC}}{B_o} + \dot{V}_G^{MC} * R_v \quad (10)$$

$$\text{Water volume flow rate at SC:} \quad \dot{V}_W^{SC} = \frac{\dot{V}_W^{MC}}{B_w} \quad (11)$$

Exactly how the black oil conversion factors should be generated, depends on the design of the facility in which the multiphase meter is installed. The conversion factors will reflect the separation efficiency of the topside separation train, and for that reason conversion factors obtained by a single stage flash from meter conditions to standard conditions may differ significantly from factors obtained from a simulation of a series of flash drums.

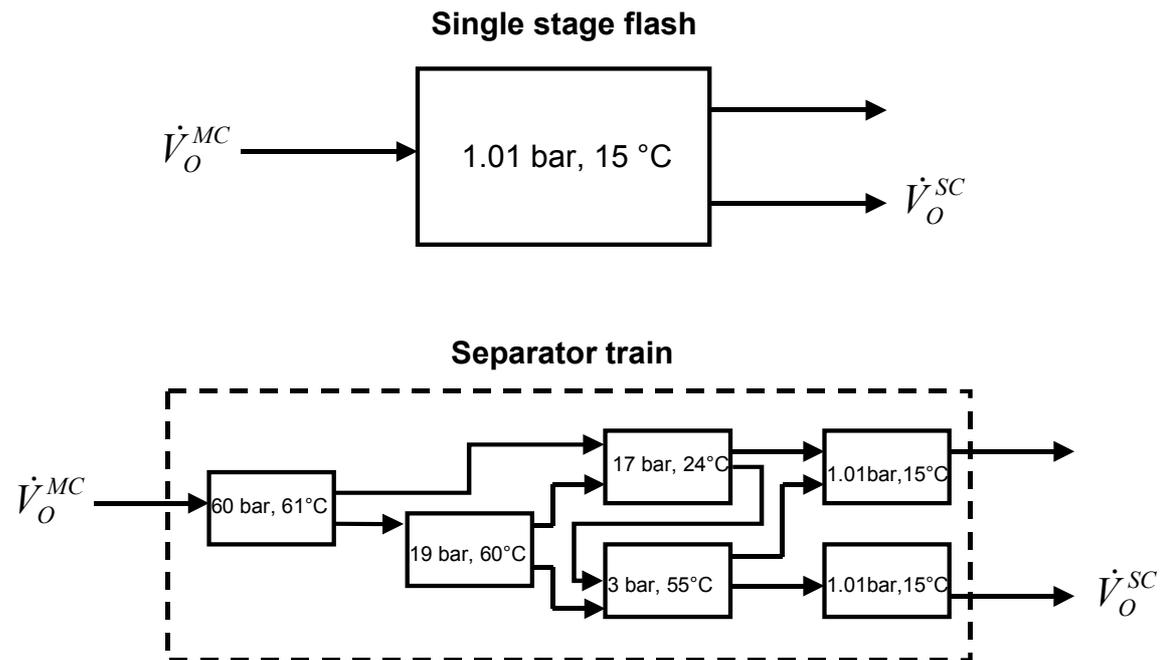


Figure 3 Single stage versus multistage separation

In spite of the added complexity, the separator train may be thought of as a box in which a single oil stream enters and an oil and a gas stream exit, similar to the single stage flash. This is illustrated by the dotted line in Figure 3. In both cases, a formation volume factor, B_O , may be calculated using Equation (4). Consider a typical volatile oil phase from a well stream entering a multiphase meter at 100 bar and 100°C. Calculating a B_O factor for this fluid, taking either the single stage flash route or the separator train, very different B_O values are obtained. The separator train keeps more components in the liquid phase, and a single stage flash may have a B_O factor that is as much as twice the one from the separator train.

When using the table approach, the conversion factors are usually made available to the meter as tables in a file, where the different conversion factors are calculated in a given PT grid for MPM conditions. The meter software may use the tables to interpolate to arrive at values representative of the pressure and temperature at the meter conditions that prevail in that instance. Having chosen a reference fluid composition to work with, it is very important to note that such a table in principle only is representative for one overall fluid composition, or, one GOR, since one GOR corresponds to exactly one overall composition. If the meter experiences large fluctuations in the fluid mixture or the GOR, one table is needed for each overall composition to get a correct description of the flow rates. In this case it may be more appropriate to use an online approach as outlined the next section.

The customized Gullfaks MPM conversion procedure

The Gullfaks field is located in the northern part of the Norwegian North Sea. A number of satellite fields have been developed with subsea wells remotely controlled from the Gullfaks platforms. For continuous metering of the oil/gas/water production from the Gullfaks satellites, multiphase meters have been installed topside at the Gullfaks A platform. 6 meters are installed for this purpose, each of which is measuring the production rates from the following subsea production frames :

1. Gullfaks Sør/Brent
2. Gullveig
3. Rimfaks/Statfjord
4. Gullfaks Sør/Statfjord B
5. Rimfaks/Brent
6. Gullfaks Sør/Statfjord A

The total oil production from the ‘Gullfaks satellite’ is approximately 11000 Sm³/d. The mass flow rates reported from the multiphase meters at meter conditions are transferred to a FMC KOS central metering computer. This computer also handles the mass flow rates from the Gullfaks A test separator. A Calsep PVT software package installed on the computer makes it possible to calibrate a multiphase meter against the test separator during a well test of the corresponding production frame. The test separator mass flow rates are converted to multiphase meter conditions so that a comparison can be made for calculation of multiphase meter correction factors.

The PVT software package initially also included a single stage flash routine for the conversion of mass flow rates at multiphase meter/test separator conditions to standard conditions. At quite an early stage it was, however, found that this routine did not give correct oil shrinkage factors compared to offline quality check simulations. As a result the well test software, running on a second computer, was changed so that the single flashed test separator standard flow rates from the FMC KOS metering computer are not being used. Instead, offline calculated oil shrinkage factors have been incorporated. The standard flow rates from the multiphase meters were, somewhat unfairly, still reported using the single stage PVT routine. Hence, a “successful” calibration of a multiphase meter against the test separator did not necessarily give acceptable results when looking at flow rates at standard conditions. To cope with this it was decided to replace the single stage flash routine with a multistage one established based on process simulations.

The PVT software used at the Gullfaks A platform will be used as an example of an advanced online PVT package for calibrating multiphase meters and for converting meter flow rates to standard conditions. The PVT package is tied in with the Gullfaks process model and metering system software and it is therefore possible to feed information into the package and adjust the conversion calculations to match measured data, such as a separator GOR. The PVT software includes a simplified

representation of the actual platform separation process. The setup furthermore allows the input compositions used for the conversion calculations to be adjusted on the fly to account for variations in the GOR at the meter due to slugging. The meters are tested against the test separator on a regular basis and calibrated online based on these test separator data.

Verification of the simplified topside process

It was investigated how well the designed topside separation process described the conversion of volumes from meter conditions to standard conditions by comparing obtained B_O values from the Gullfaks algorithm with B_O values obtained by simulating the whole topside processing plant in PRO/II. The simplified plan is similar to the lower one in Figure 3. Input for the PRO/II simulations were compositional files generated with PVTsim from CALSEP A/S. The objective was to predict B_O values within 2% deviation from the PRO/II calculations. In Table 1 below are given results for 11 different fluids for B_O values calculated from PRO/II, and the conversion algorithm using either a single stage flash or a simplified process description.

Fluid No	PRO/II (m^3/sm^3)	Single stage flash (m^3/sm^3)	Topside Process (m^3/sm^3)
1	1.132	1.133	1.123
2	1.300	1.488	1.320
3	1.178	1.214	1.167
4	1.198	1.241	1.186
5	1.133	1.132	1.123
6	1.283	1.535	1.282
7	1.100	1.087	1.093
8	1.172	1.199	1.162
9	1.145	1.396	1.122
10	1.153	1.160	1.141
11	1.168	1.186	1.158

Table 1 B_O factors for various fluids with different conversion methods to standard conditions

It is seen from Table 1, that considering the multistage separator train heavily improves the B_O values, particularly for the condensates with high B_O values. All the B_O values are now predicted within a deviation of 2%.

The well described topside separation process could also be used in the calculation of a black oil table as discussed above, but the online application can adjust the composition to a measured GOR continuously.

Calibration of the multiphase meter

If measured GOR data are available from a test separator, it is possible to calculate calibration factors for the multiphase meter. The reference composition \mathbf{z} is used as starting point for the calculation. After adjusting to the measured separator GOR by means of recombination as described above, the true overall composition \mathbf{z}_{true} is calculated from Equation (1).

Using \mathbf{z}_{true} the true flow rates of the phases at meter conditions can be calculated given the pressure and temperature at meter conditions. Comparing the true mass flow rates at meter conditions \dot{m} with the ones measured gives the opportunity to calculate correction factors for the multiphase meter:

$$CFAC_{gas} = \frac{\dot{m}_{gas,true}}{\dot{m}_{gas,measured}} \quad (12)$$

$$CFAC_{liq} = \frac{\dot{m}_{liq,true}}{\dot{m}_{liq,measured}} \quad (13)$$

This method is assuming the error in the measurement of the flowrates at meter conditions is proportional to the flowrate itself. The correction factors are used to correct measured meter flow rates, until next calibration.

Online calculations

Once the correction factors are known for each phase for the multiphase meter, they are used to convert the measured flow rates at meter conditions to true flow rates:

$$\dot{m}_{gas,true} = CFAC_{gas} \times \dot{m}_{gas,measured} \quad (14)$$

$$\dot{m}_{liq,true} = CFAC_{liq} \times \dot{m}_{liq,measured} \quad (15)$$

The true flow rates give the GOR at meter conditions, and recombination can take place from the overall starting composition \mathbf{z} to give the true composition \mathbf{z}_{true} . The true composition is then used to calculate flow rates at standard conditions considering the topside separation process.

Calibration of measured separator densities

Being able to predict phase densities at elevated pressure and temperature is essential for the conversion between mass and volume flow rates. The B_O values in Table 1 are calculated from Equation (4), showing that the conversion factors are directly dependent on densities at meter conditions. The phase densities calculated from the EoS are output from the flash calculation, and depend on pressure, volume and composition. Liquid densities will depend on a good compositional description of the heavy end of the fluid, but given the difficulties above in describing the true overall composition \mathbf{z}_{true} to be used in the flash calculation, the separator densities may be difficult to predict accurately.

An accurate prediction of the density of the separator liquid requires a correct liquid composition as well as an accurate model. The EoS contains an empirical correction term usually referred to as a volume shift parameter. If measured densities are available for the separator liquid the volume shift parameter can be selected to match this density. If this requires an unrealistic volume shift parameter, it is seen as an indication that the assumed liquid composition deviates considerably from the actual one and a composition tuning is performed. It essentially consists in shifting the ratio between heavier and lighter components.

In Table 2 the first column gives the oil density at separator conditions using the original composition and the standard EoS parameters. The flash result also gives a gas density, which is kept constant, while adjusting the liquid density. Columns 3 and 4 give the lowest and highest possible liquid densities with the tuning algorithm. The result from the tuning is an overall composition \mathbf{z} , which at the given temperature and pressure splits into a gas and liquid phase in equilibrium with the desired densities.

Fluid No	Calculated density (kg/m ³)	Lowest possible density (kg/m ³)	Highest possible density (kg/m ³)
1	791.1	~710	~870
2	667.5	~600	~780
3	760.4	~660	~860
4	759.0	~650	~870
5	795.6	~710	~870
6	661.7	~610	~740
7	827.0	~730	~920
8	762.9	~660	~880
9	709.4	~650	~790
10	792.7	~690	~910
11	756.4	~670	~860

Table 2 Density of oil at separator conditions (63 °C and 65 bara)

The customized conversion of flowrates from meter conditions to standard conditions, can be summarized as follows:

1. Initial reference composition from user.
2. Separator test with GOR and density adjustment gives new reference composition.
3. Flowrates at MPM conditions calculated from test separator flowrates.
4. MPM calibration factors calculated from flowrates from 3. and MPM flowrates.
5. Calibration factors used to adjust measured MPM flowrates until next separator test.
6. GOR adjustment to calibrated MPM measurement carried out continuously.
7. Flowrates at standard conditions from GOR adjusted MPM composition. Flash to standard conditions through Gullfaks process plant.

Conclusion

Flow rates of a well defined composition measured at meter conditions can accurately be converted to standard conditions. It is important to take into consideration the complexity of the topside process plant. Variations in GOR e.g. due to slugging may be accounted for by modifying the total composition to match the GOR. Composition variations with time in the produced liquid can be dealt with by adjusting the composition of the separator liquid to match a measured density.

Notation

B	<i>Formation volume factor</i>
$CFAC$	<i>Correction factor for MPM flow rates</i>
GOR	<i>Gas-oil ratio</i>
\dot{m}	<i>Mass flow rate</i>
N	<i>Number of components</i>
P	<i>Pressure</i>
R_S	<i>Gas in oil solubility factor</i>
R_V	<i>Oil in gas solubility factor</i>
T	<i>Temperature</i>
V	<i>Volume</i>
\dot{V}	<i>Volumetric flow rate</i>
x_i	<i>mole fraction of component i in liquid phase</i>
\mathbf{x}	<i>liquid composition</i>
y_i	<i>mole fraction of component i in gas phase</i>
\mathbf{y}	<i>gas composition</i>
z_i	<i>mole fraction of component i in total composition</i>
\mathbf{z}	<i>total composition</i>
β	<i>phase mole fraction</i>
ρ	<i>density</i>

Subscripts

g	<i>gas</i>
i	<i>component i</i>
l	<i>liquid</i>
o	<i>oil</i>
w	<i>water</i>

Superscripts

MC	<i>Meter conditions</i>
SC	<i>Standard conditions</i>

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.