

# **Experiences with the multiphase meter system used for allocation of Visund South tie-in to Gullfaks C**

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## **1. Abstract**

Visund South field is a subsea tie-in to Gullfaks C in the North Sea. Visund South is developed with one 4-slots subsea template with 4 producing wells. One 10" flow line is used for transport of Visund South production to Gullfaks C for processing and export.

Due to different owner structures between Gullfaks C and Visund South, multiphase metering is used for ownership allocation. Subsea multiphase meters (5") are installed on each individual well and one topside multiphase meter (10") is installed upstream the topside choke. In addition Live PVT (software) to handle changes in the PVT is implemented [1]. As part of the Visund South project, one test separator at Gullfaks C was upgraded with additional instrumentation according to NPD Measurement Regulations.

In this paper, the measurement philosophy for the Visund South subsea tie-in is presented. This includes the location of multiphase meters, PVT data handling and verification of the multiphase meters. Experiences during the project, commissioning and operational phases are described. Test results from K-lab, comparisons of measurements from subsea meters and topside meter, and finally, verifications of multiphase meters against test separator are presented.

The first Visund South producer was started up in November 2012. The field experiences so far show that the build-in redundancy has been necessary due to the redesign of the topside meter. Deviations in HC mass rates between subsea multiphase meters, topside multiphase meter and test separator measurements are within a range of +/-1%-5% during the first 2.5 years of production.

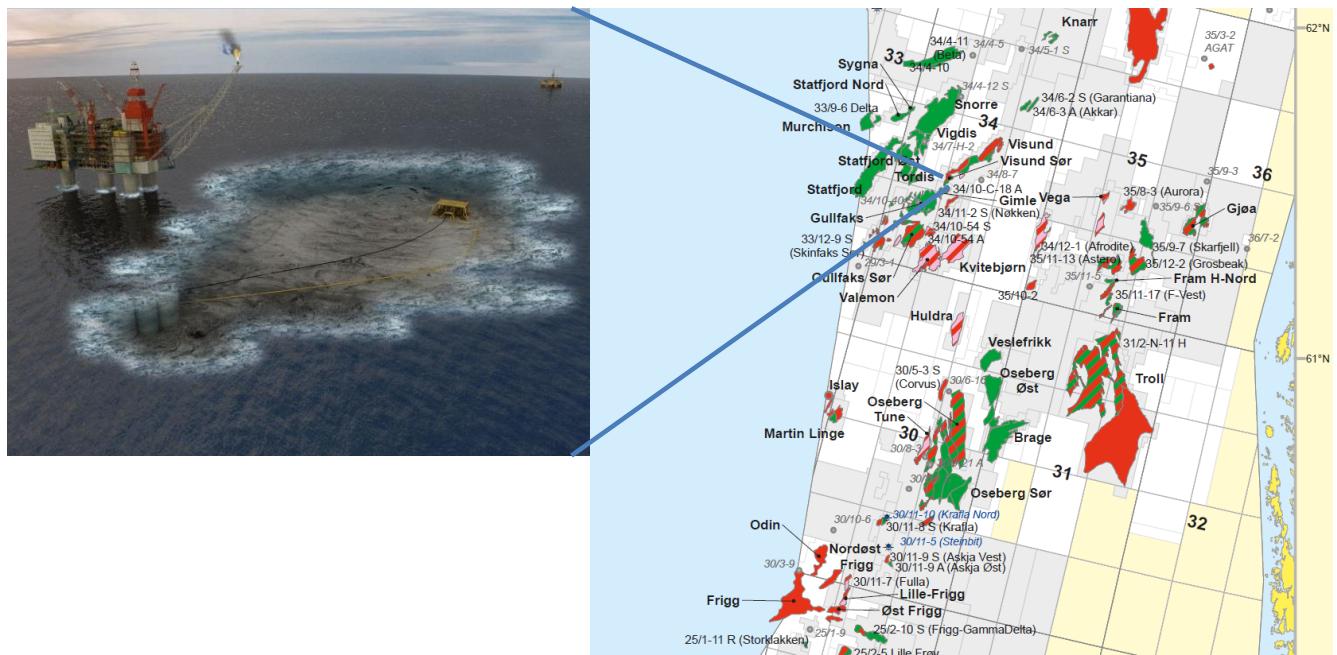
The multiphase metering system has met our requirements in terms of measurement uncertainties.

## **2. Introduction**

Statoil has about 250 multiphase and wet gas meters in operations, where several subsea tie-in fields have been developed with multiphase meters for ownership allocation. Visund South subsea field is such a field, developed as subsea productions system (SPS) where unprocessed multiphase flows are transported to Gullfaks C (GFC) process platform through one pipeline.

The Visund South (Pan/Pandora structures) was discovered in 2008 and the field started to produce in 2012. Visund South was the first Fast Track project in Statoil. Fast track is a method that will cut development times in half (from about 5 years to just 2.5 years) for uncomplicated fields on the Norwegian continental shelf. Due to standardization half development time has created profitability in small fields where commerciality has previously been an issue.

In this paper the ownership allocation metering for Visund South is presented. It is based on multiphase metering of the Visund South flow line production installed at GFC. Subsea multiphase meters are installed on each of the 4 subsea producing wells.



**Figure 2-1. Gullfaks C in North Sea.**

### Facts about Visund South

Here are some facts for Visund South [2]:

- Discovered: 2008/2009
- Production start-up: November 2012
- Location: In the North Sea between the Visund and Gullfaks fields
- Reservoir: Two structures, Pan and Pandora, with reservoir pressure of roughly 340 bar
- Volumes: 67 mboe (1/4 oil and 3/4 gas)
- Depth: 290 metres and 2900 metres below seabed
- Estimated lifetime: More than 15 years
- Visund South is located 10 kilometres southwest of the Visund platform and approximately 10 kilometres northeast of GFC. The water depth in the area is about 290 metres. Visund South is developed with a subsea template tied to GFC.
- The reservoirs lie at a depth of 2 800 - 2 900 metres and contain oil and gas in Middle Jurassic sandstones in the Brent Group.
- Visund South is produced by pressure depletion.
- The wellstream is routed to GFC for processing and export.

Company name	Nation code	Company share [%]
Statoil Petroleum AS	NO	53.200000
Petoro AS	NO	30.000000
ConocoPhillips Skandinavia AS	NO	9.100000
Total E&P Norge AS	NO	7.700000

Table 2-1. Licensees – Visund South current

Company name	Nation code	Company share [%]
Statoil Petroleum AS	NO	51.000000
Petoro AS	NO	30.000000
OMV (Norge) AS	NO	19.000000

Table 2-2. Licensees – Gullfaks current

### 3. Visund South allocation metering

The Visund South field was planned developed with three production wells in a four slot template. A 4th well was decided drilled after start-up of the field. Each well is equipped with a subsea multiphase flow meter installed in a retrievable flow control module.

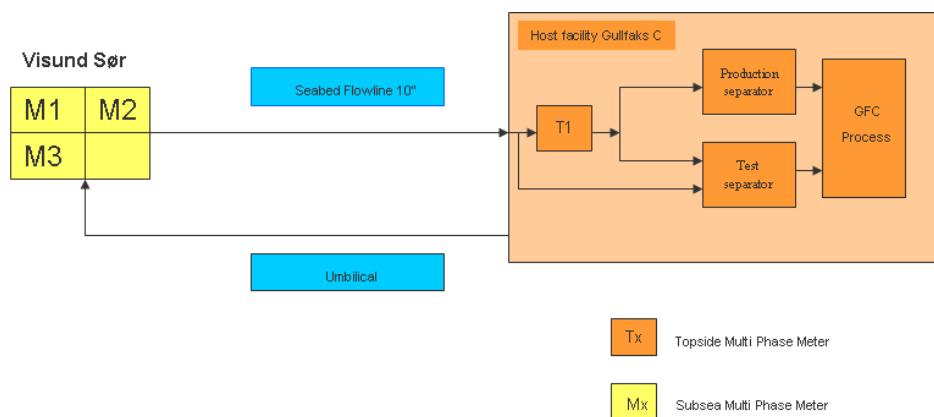


Figure 3-1. Visund South metering concept.

Production from Visund South is commingled with the production from GFC. Visund South and GFC are separate licenses with different ownership; hence ownership allocation of the Visund South production is required. The commingled Visund South production is routed directly to the GFC Platform. At GFC one multiphase flow meter (MPFM) with 100% total capacity is used as primary multiphase meter for the Visund

South allocation. The subsea multiphase flow meters are used as backup for the ownership allocation. In addition the subsea multiphase meters are essential for well allocation and production optimization.

The production from GFC is determined as the difference between the single phase export measurements and the allocation measurement of Visund South. Hence, any mismeasurement of Visund South will influence the allocated HC mass to GFC.

The flow through the topside MPFM can be routed either to the production header or the test separator for verification.

The initial production profiles showed that the individual wells covered large GVF spans, from about 40% to 99%. As a consequence it was required to select a multiphase flow meter technology which automatically covered both multiphase and wet gas conditions and had a good measurement performance in both domains.

In addition, measurements of salinity and formation water detection were important to ensure a robust flow assurance, which minimizes potential hydrate and scaling risks.

### ***3.1. Ownership allocation and metering philosophy***

Due to space and weight restrictions at GFC, it was not regarded feasible to install an inlet separator with single phase instruments for the Visund South production. In addition, it was not economically feasible. Instead, it was decided to use multiphase metering for ownership allocation of Visund South.

Subsea multiphase flow meters were introduced as backup flow meters which reduced the verification frequency of the topside multiphase meter to a minimum.

### ***3.2. Measurement uncertainty requirements of MPFM***

In Table 3-1 the uncertainty estimation of HC mass rate for Visund South is given. For subsea MPFM, the estimation is given for all four meters in total.

Level	Method	Estimated HC mass rate uncertainty
1	Test separator	1%
2	Topside MPFM	5%
3	Subsea MPFM	7%

Table 3-1. The estimated HC mass rate uncertainty levels

The project specific measurement uncertainty requirements are given in Table 3-2. The requirements have been given separately for the multiphase and wet gas domain and are valid for subsea and topside meters:

Parameter		Multiphase (GVF < 95%)	Wet Gas (GVF > 95%)
	WLR	Uncertainty	Uncertainty
Hydrocarbon mass rate	0 - 100 %	4 %	4 %
Gas volume flow rate	0 - 100 %	5 %	5 %
Condensate volume flow rate	0 - 50 % 50 - 75 % 75 - 85 %	7 % 10 % 15 %	
Water Liquid Ratio (WLR)	0 - 100 %	2 %	
Water Volume Fraction (WVF)	0 - 100 %		0.05 %
Salinity (wt% abs)	0 - 100 %	1 %	1 %

Table 3-2. Project specified measurement uncertainty requirements (95% confidence level).

### 3.2.1 Test separator upgrade

As part of the Visund South project, the test separator instrumentation was upgraded. Two single phase flow meters were installed at the oil leg; one 4" 5-path ultrasonic meter and one 4" turbine meter in series. Further a clamp-on gamma densitometer and a 4" water-in-oil meter were installed. For the gas phase it was installed one 8" 4-path ultrasonic meter with a densitometer installed in a bypass loop.

### 3.3. Subsea multiphase flow meters

Based on the production profiles 5" subsea multiphase flow meters were selected. The subsea multiphase flow meters were installed upstream the production choke and the continuous chemical injection point. The meters were installed vertically in the flow control module with the flow direction upwards through the meters.

Communication between the subsea meters and topside is bi-directional by optical fiber. This allows for running diagnostic communication in addition to obtaining frequent measurements and PVT data are updated frequently.

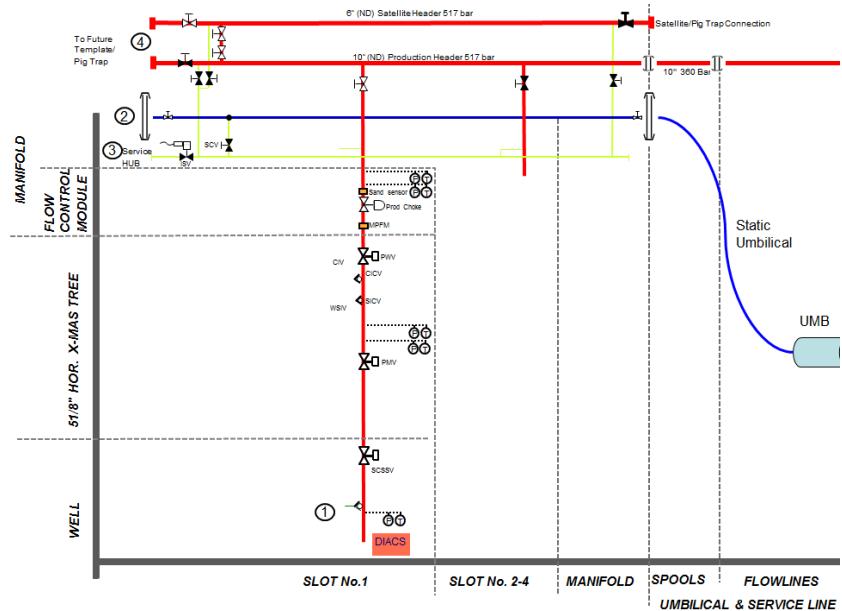


Figure 3-2. Visund South subsea schematics

### 3.4. Topside multiphase flow meter

One 10" multiphase flow meter covering full capacity of Visund South production was installed on GFC. This solution was preferred due to space constraint at GFC, instead of two smaller topside meters in parallel [1].

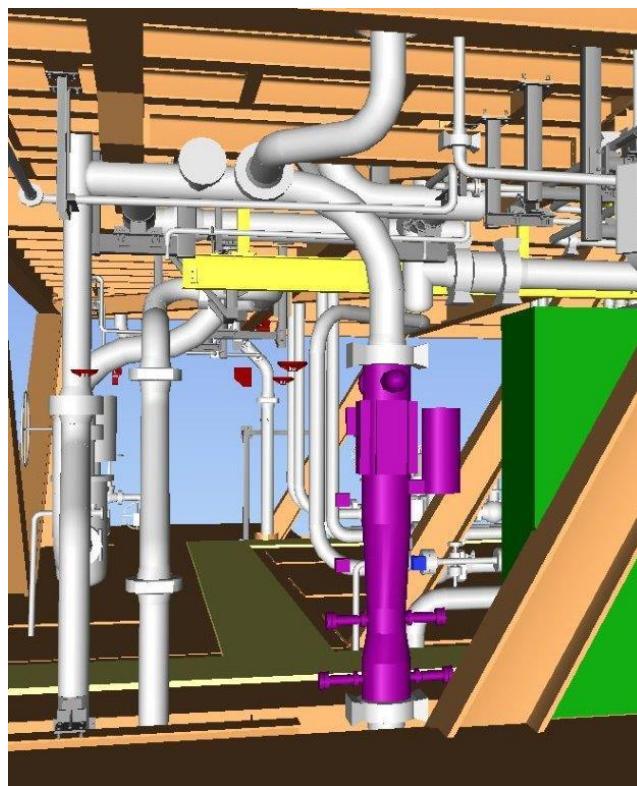


Figure 3-3. Model of Visund South 10" topside MPFM

### ***3.5. Method of Visund South MPFM verification***

The subsea multiphase flow meters are redundant measurement to the topside multiphase meter. As long as deviation between the total subsea measurement and topside measurement are within certain limits, initially set to +/-10%, verification of the subsea multiphase meter towards the test separator may be waived. The verification of the topside meter against test separator can be limited to cases where there are discrepancies between the sum of subsea meters and the topside meter.

Because of long stabilization time due to the length between subsea and topside meters, verification and comparison is only performed when the production is stable. During start-up of new wells, the production is routed to test separator thus the actual subsea meter are compared to test separator measurements.

### ***3.6. System implementation and supervisory metering system***

All measurements from the multiphase flow meters are in actual condition, and all measurements are transmitted to the supervisory metering system and control system.

Upgrading of the GFC supervisory metering system was required in order to facilitate:

- PVT calculation of MPFM rate measurements and densities in actual condition to standard condition
- PVT calculations of required composition for MPFM input data
- PVT calculations on the test separator measurements for comparison of MPFMs
- Software for calibration of k-factor for topside multiphase meter

Flow weighted PVT data to topside MPFM is implemented, thus the metering system calculate the overall PVT data based on the individual measured flow rates. Updated PVT data (densities) are downloaded to the topside MPFM regularly. This is known as LivePVT [1].

The subsea multiphase flow meters receive the calculated densities based on PVT data by automatic download from the supervisory metering system.

Secured remote access to the multiphase meters and the metering system is implemented. This gives fast diagnostics and service on the metering system from the vendor which requires less travelling to the field by service personnel.

### ***3.7. Topside MPFM technical challenge***

During FAT testing of the topside multiphase flow meter it was detected a small leakage in one of the microwave probes during hydrostatic testing. After the FAT the meter was scheduled for flow loop test at K-lab.

As the time was critical with respect to start-up, it was decided to continue with the K-lab test. Subsequent risk analysis called for a redesign of the probe seal arrangement and it was decided to manufacture a new topside flow meter, thus the original flow meter was rejected.

Due to the probe redesign it was decided to test the new flow meter at K-lab. However, it was not possible to have the new flow meter installed and ready for use at start-up of the field.

## 4. Full scale flow loop test of MPFM

It is a Statoil requirement to perform a flow test of multiphase flow meters before installation, by executing a flow test of minimum one flow meter in a batch of identical meters.

In this case identical subsea multiphase flow meters were also used in several fast track projects running in parallel; hence a combined flow test of the subsea flow meter was performed covering a total of 159 test points from four different projects.

In total three K-lab flow tests were performed for Visund South:

1. Subsea multiphase flowmeter (August 2011)
2. Topsides multiphase flowmeter (original – June 2012)
3. Topsides multiphase flowmeter (redesigned – May 2013)

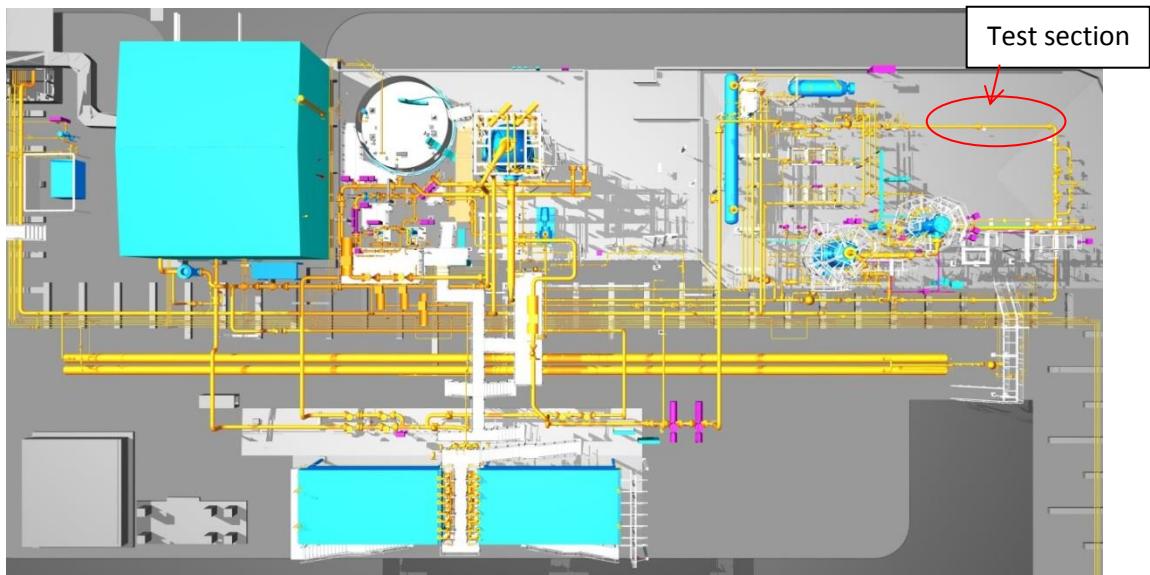
### 4.1. K-lab

The K-Lab test facility is located at the Kårstø gas plant in Norway. Kårstø is a nodal point for natural gas being produced in the North Sea, treating the gas before its being exported to Europe.

The K-lab facility is especially made for testing of wet gas and multiphase flow meters, as well as pumps, separators, etc, at realistic conditions. The test site uses gas, condensate and water (salt and fresh), and operates at pressure up to 130 bars, and temperature up to 60 degC.

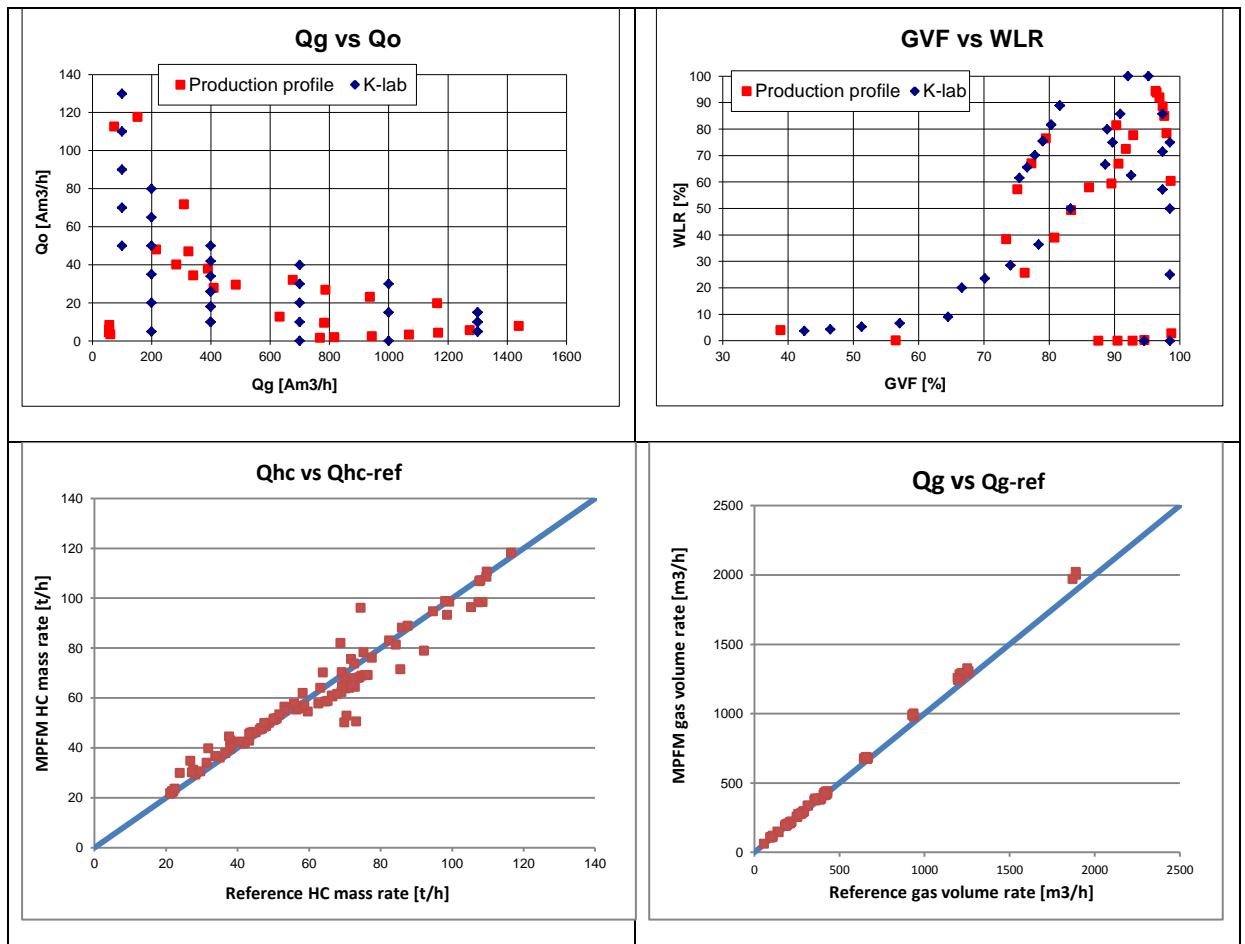
K-lab capacity	Unit	Range
Pressure	Barg	30 - 130
Temperature	degC	30 - 60
GVF	%	30 - 100
WLR	%	0 - 100
Liquid flow rate	Am <sup>3</sup> /h	0.01 - 150
Gas flow rate	Am <sup>3</sup> /h	40 - 2000

Table 4-1. K-lab capacities



**Figure 4-1.** K-lab schematics.

#### 4.2. *K-lab test of subsea flow meter*



**Figure 4-2.** Test matrix and test results of subsea MPFM.

The test points follow the production profiles as close as possible. Test results of the subsea MPFM demonstrate acceptable performance, where 90% of the test points were within the acceptance criteria. It is noted a bit more spread in the data, at HC mass rate about 70 t/h, which corresponds to a WLR near 50% or oil-water continuous transition point.

The test was conducted for 60 bar and 120 bar with temperature at 55C for both pressures.

### 4.3. K-lab test of topside flow meter

For the topside meter, the original topside MPFM was tested at two pressures, 50 bar and 130 bar. The temperature was 60C for both pressure. The test results of gas volume flow and HC mass rate are within acceptance criteria, as shown in Figure 4-3.

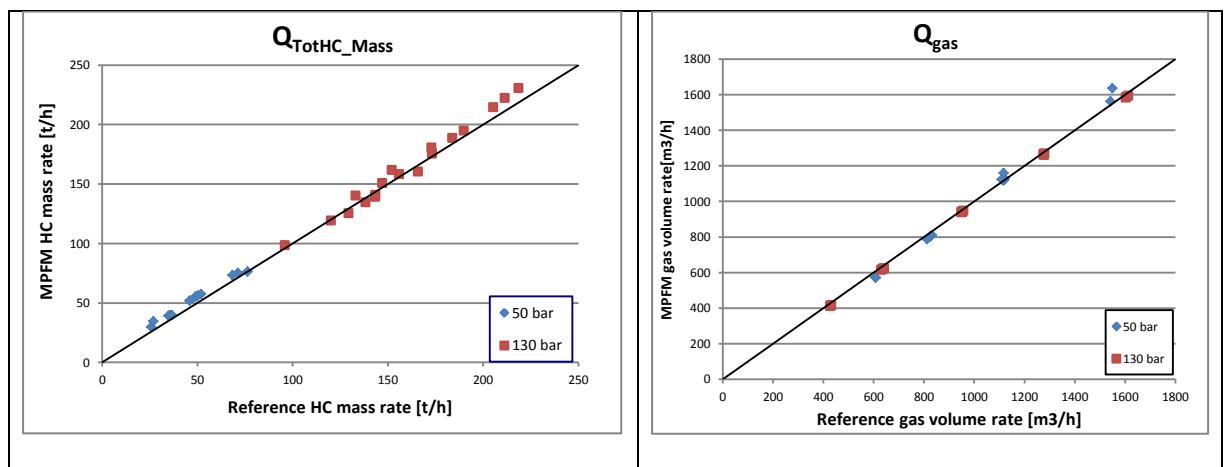


Figure 4-3. Test results of original topside MPFM.

### 4.4. K-lab test of redesigned topside MPFM

For the redesigned topside meter, the test matrix was similar as for the original topside MPFM and tested at two pressures, 50 bar and 130 bar, and one temperature, 60C. Also for this test, the results of gas volume flow and HC mass rate are within acceptance criteria.

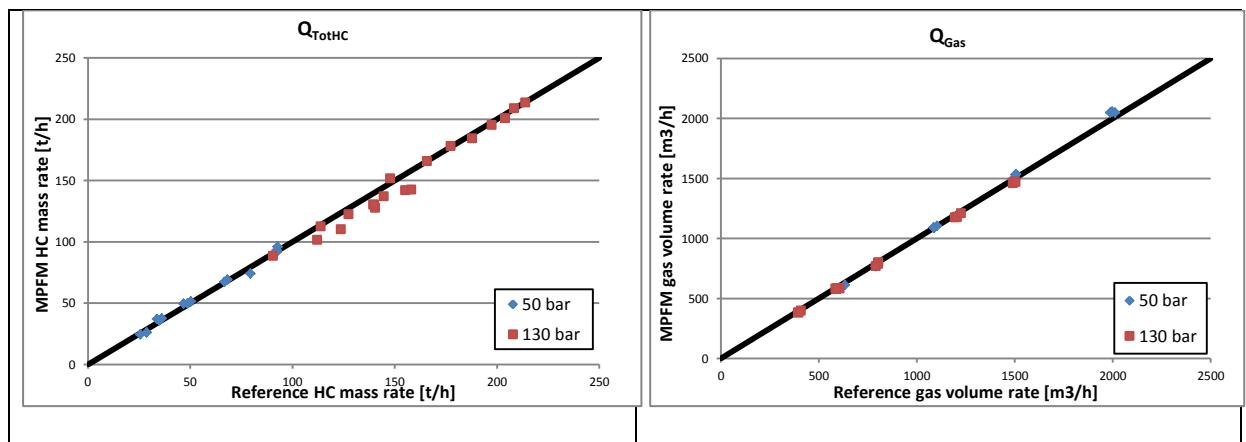


Figure 4-4. Test results of redesigned topside MPFM.

## **5. Field experiences**

An extensive test program against the test separator at GFC has been performed in order to verify the multiphase metering system. Verifications of subsea multiphase meters against test separator are done frequently. There are different combinations of wells that are produced during three major test campaigns performed with approximately one year, namely autumn 2012, autumn 2013 and autumn/winter 2014. Different combinations of single well testing and testing of multiple wells are available. The data used in this paper are taken from monthly production reports and logs for Visund South.

Due to different conditions (P,T) for the subsea MPFM and topside MPFM, it is in principle two possible methods to perform the comparison; by volume rates in standard condition or in HC mass rates. By using HC mass rate instead of oil and gas in standard volume flow rates, PVT issues due to differences in pressure and temperature topside and subsea conditions are expected to be minimized, as discussed in [3]. In addition, the ownership allocation for Visund South is based on the HC mass rates.

It is not possible to present all data available, but the intention here is to give a brief overview of the results achieved for Visund South multiphase metering system.

### ***5.1. Well V-4H during start-up in 2012***

The start-up date for Visund South was 22nd November 2012, when the well V-4H was started.

Due to the lack of topside meter in the first months of production, the V-4H subsea meter was used as primary input to the ownership allocation. The sequenced start-up wells from Visund South gave valuable verification of individual subsea meters against the test separator.

The first data from the MPFM at Visund South is presented in Figure 5-1. Only well V-4H was producing, thus the comparison of subsea multiphase meter against test separator was for one well. As shown in Figure 5-1, there are only minor differences between the daily production of HC mass rate measured by the subsea MPFM and the test separator. The difference in the figure is in a range between -1.6% to -1.9% during 24hrs HC mass rates the first week of production. Due to the small amount of water produced, only the oil leg of test separator was used to measure the liquid flow rates. The water-in-oil analysis showed water content in oil between 0.02% and 0.07% the first days of production.

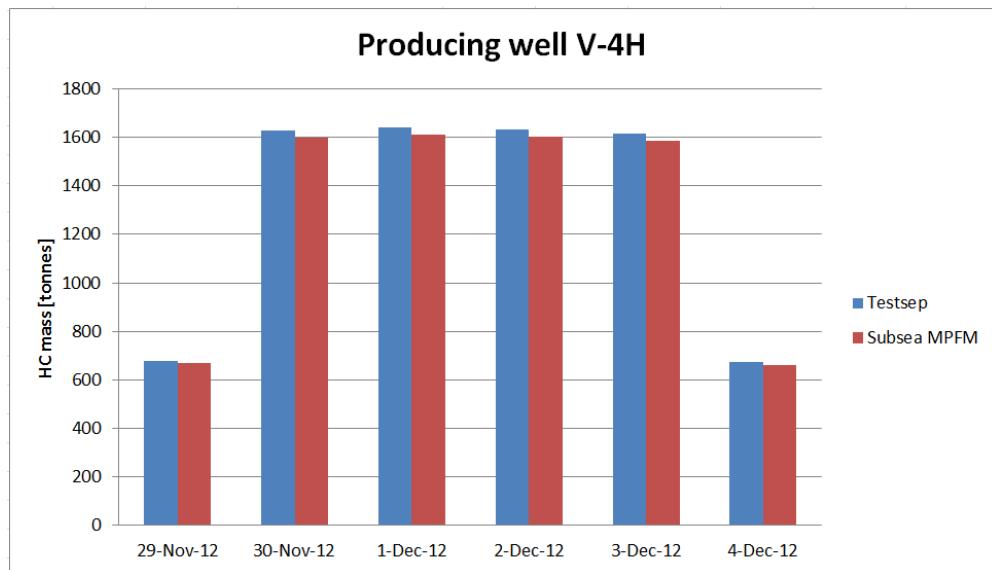


Figure 5-1. HC mass rate measured with subsea MPFM at V-4H compared against GFC test separator outlet during the test campaign 29. Nov - 4. Dec 2012. Each column represents 24hrs production.

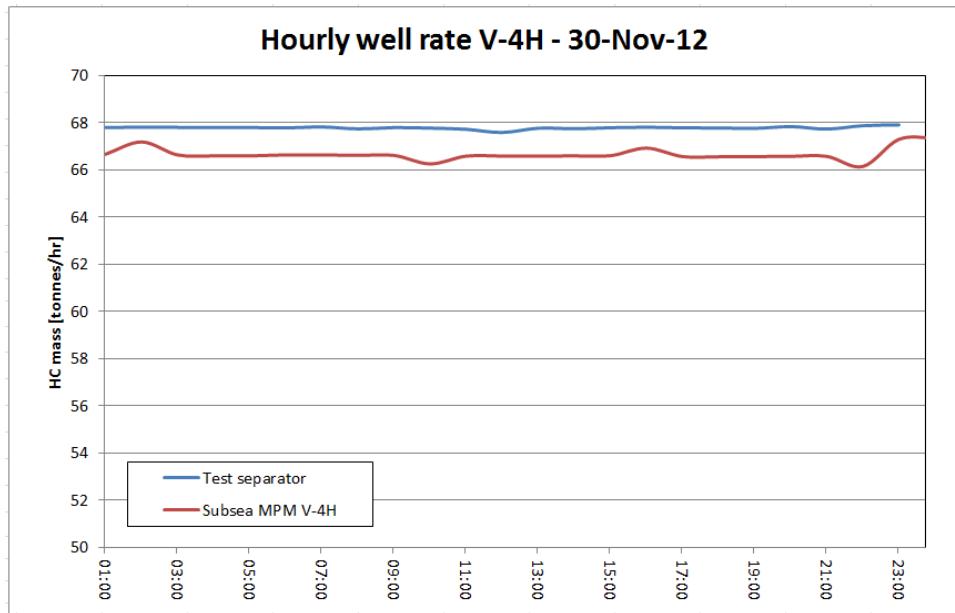


Figure 5-2. Hourly HC mass rate measured with subsea MPFM at V-4H compared against GFC test separator outlet during a 24 hrs test campaign 30. Nov 2012.

As shown in Figure 5-2, hourly production HC rates presented for 30. November 2012 have a rather constant offset of about 1 tonnes/hr between the subsea meter and the test separator measurements. Similar deviations were observed for the other days during this test campaign. In relative terms, this means a deviation of 1.5%. This is within the limit, but in order to further reduce the deviation, more detailed analysis is required.

## 5.2. Single well - start-up of V-3H in 2013

In Figure 5-3, hourly production rates from well V-3H are presented. Only the well V-3H was producing and routed to test separator at GFC. Due to the small amount of water produced, only the oil leg of test separator was used to measure the liquid flow rates.

This means that water mass rates are included in oil mass rates measurements for the test separator measurements. The water mass rates are in a range of 0.6 tons/hr measured by the subsea V-3H meter, which means a water mass fraction about 1.2 %.

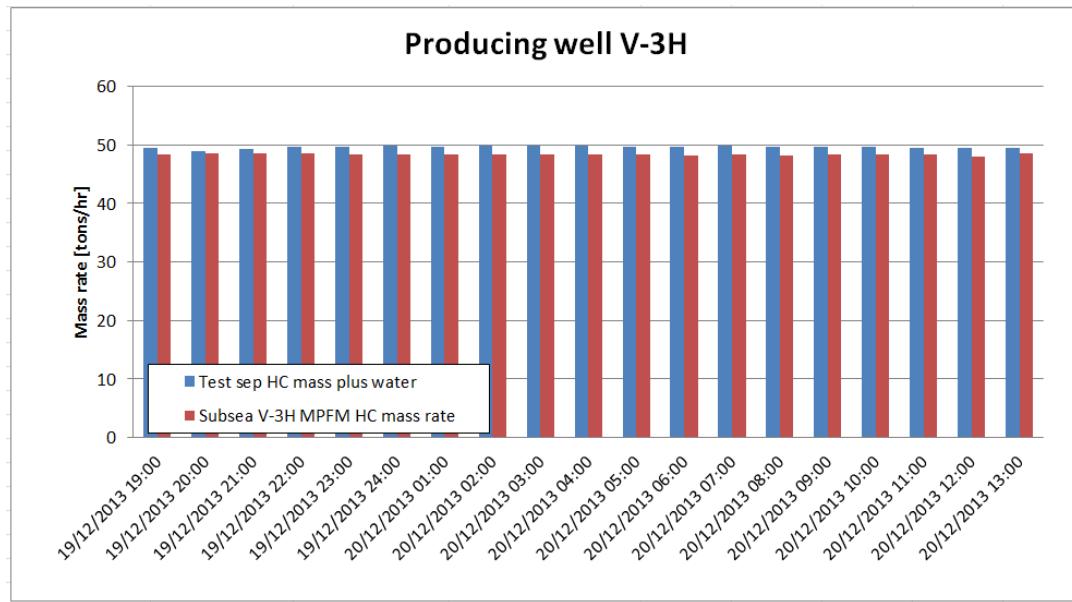


Figure 5-3. HC mass rate measured with subsea MPFM at V-3H compared with GFC test separator outlet during a 24 hrs test campaign 19-20. Dec 2013.

By subtracting the water mass rates measured by V-3H subsea meter from the test separator liquid measurements, comparison of the HC mass rates measured by the subsea meter at V-3H and test separator shows that the ratio between test separator measurements and the subsea meter at V-3H are less than 2%, as indicated in Figure 5-4.

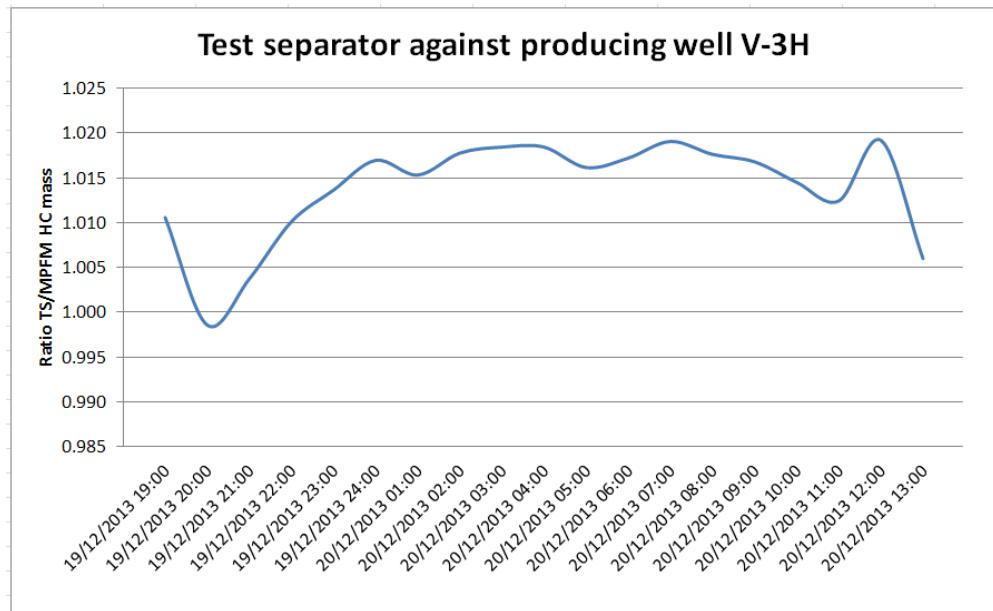


Figure 5-4. Ratio in HC mass rate measured with GFC test separator and subsea MPFM at V-3H during a 24 hrs test campaign 19-20. Dec 2013.

### 5.3. Multiple wells – V-3H and V-4H

Figure 5-5 shows the hourly production of well V-4H in addition to the production from well V-3H. The topside MPFM and test separator measurements represent therefore the sum of the two wells. For the topside meter, the HC mass rate is determined on an averaged 24 hrs production. The three independent measurements show a very good correlation with minor spread in the data.

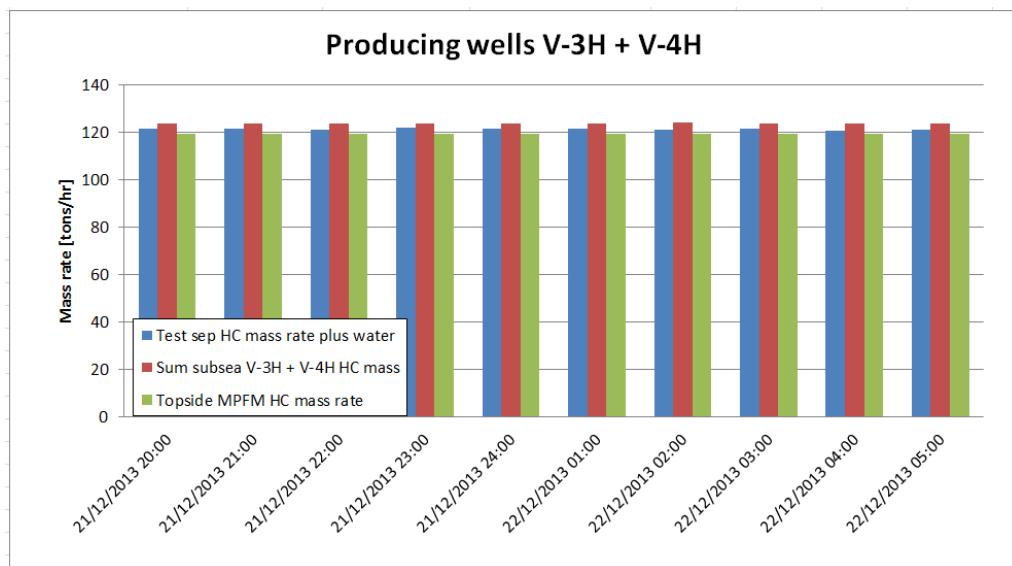


Figure 5-5. HC mass rate measured with GFC test separator, sum of subsea MPFMs and topside MPFM with production from V-3H and V-4H during a test campaign 21-22. Dec 2013.

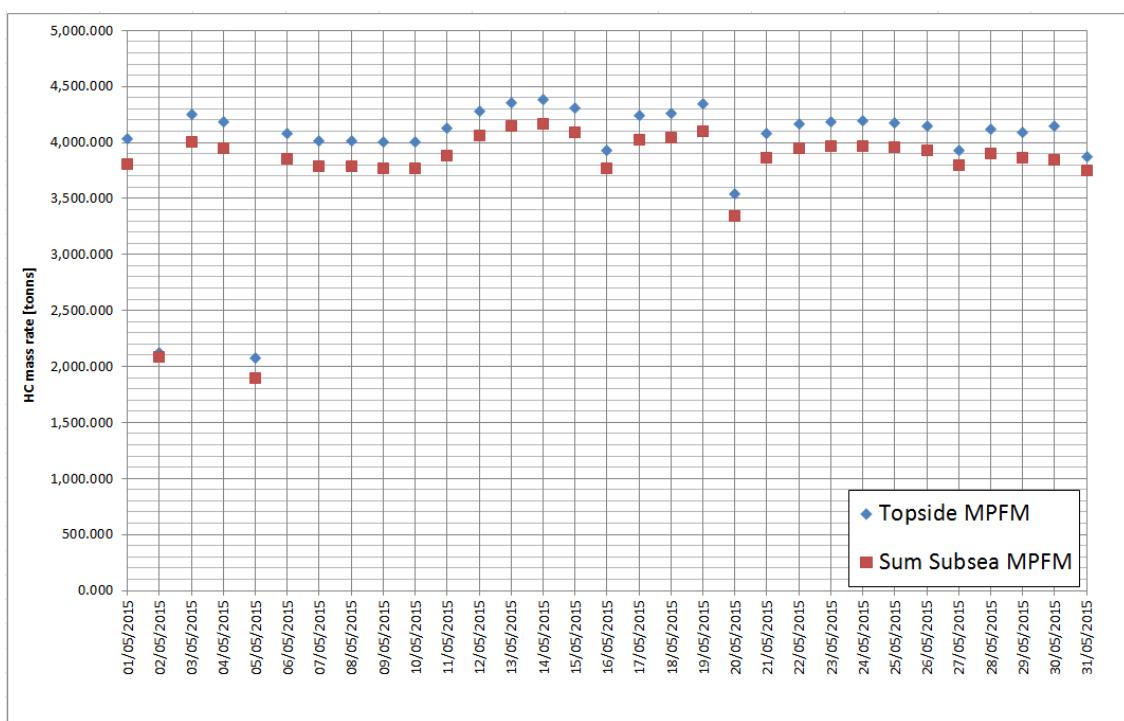
When only V-3H well is producing, the deviation is an offset about 1%. The offset is about -2% when V-3H and V-4H wells are producing. This means a shift in the offset which may be a result of changes in the commingled PVT composition.

The subsea multiphase meters indicate a water mass rate of 0.6 tons/hr and 6 tons/hr for the V-3H well and V-4H well, respectively. Only the oil leg of test separator is used to measure the liquid flow rates. The water-in-oil measurements show no water content in the oil leg.

#### **5.4. Comparison of subsea and topside multiphase meters**

On a daily basis the mass balance between HC flow rates subsea and topside is the first stage to verify that the measurement system is working according to the +/-10% limit . If comparison of the topside meter and the sum of subsea meters are within +/- 10%, this is a good indication that both the topside meter and subsea meters are working well.

Total mass flow rates will also include water, thus comparison of total mass flow subsea and topside will provide useful information about the water rate measurements, but so far the water production at Visund South in this phase has been limited.

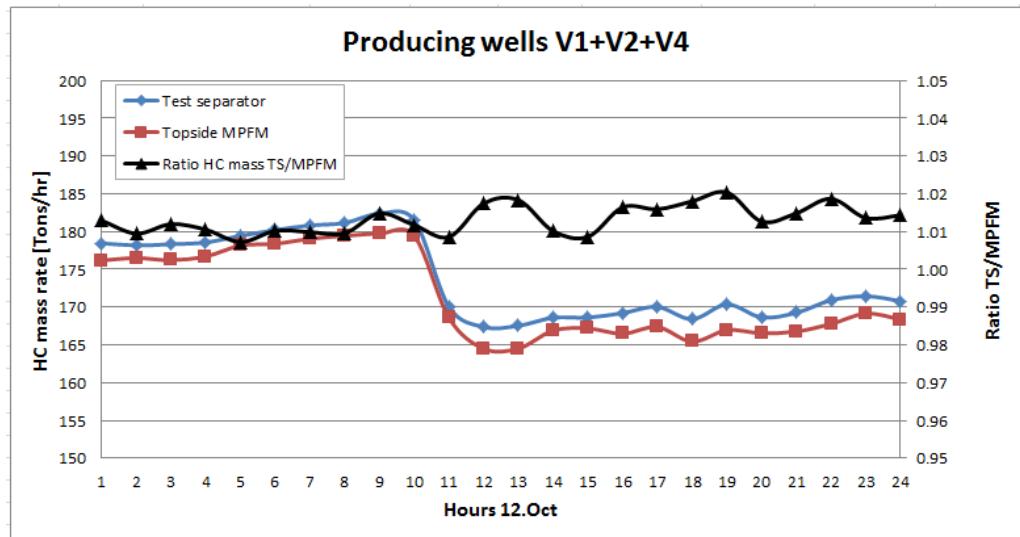


**Figure 5-6.** Daily reported HC mass measured with topside MPFM and sum of subsea MPFMs with production from V-1H, V-2H and V-4H during May 2015.

In Figure 5-6 it is seen a relatively good correlation, despite an offset, between the sum of subsea meters (V-1H, V-2H and V-4H) and the topside meter. The average deviation of HC mass rate is 5.6% for the whole period (1.May – 31.May 2015). The average water volume pr day measured by the topside MPFM during May 2015 is about 720 Sm3/d, representing an overall water cut of 39% in average.

## 5.5. Comparison of topside multiphase meter against test separator

Different combinations of producing wells are routed to test separator, which enable comparisons between test separator, topside multiphase meters and different combinations of subsea multiphase meters. With different compositions from each well, the commingled production will have a varying and changing composition. When measuring the commingled production with the topside MPFM, it is required to have correct PVT input (oil density, gas density) for the topside MPFM to work properly. By implementing flow weighted PVT calculations, based on individual production from each well, the commingled composition is calculated using a flow weighed average in composition. Updated PVT input (oil density, gas density) is then downloaded to the topside MPFM.



**Figure 5-7.** HC mass rate measured by topside multiphase meter for Visund South compared to test separator at GFC and relative difference between test separator and topside multiphase meter for a 24 hrs test campaign 12. Oct 2014.

Due to the transport time between subsea wells and topside, comparison of subsea MPFM during multi rate testing against topside MPFM and/or test separator is rather challenging, and we have not identified appropriate data to present. However, in Figure 13 HC mass rates of topside MPFM and the test separator is shown during a 24hr test 12.Oct 2012. The figure shows that when all three wells (V1+V2+V4) are producing, there is negligible deviation between the HC mass rates measured by the topside MPFM and the test separator, even if there are some changes in production. The HC mass ratio between the test separator and topside MPFM is seen to be within 1-2 % during the multi rate test.

As shown in Figure 5-7, the comparison in measured HC mass rates shows a good performance of the topside MPFM against test separator, even after a change in production. Due to differences in the PVT compositions from each individual well, changes in flow rates from one or several wells will result in changes in the commingled composition. Therefore changes in production could result in measurement errors due changes in flow rates from one or several wells, if not flow weighted based PVT input are utilized.

## **6. Conclusions**

Visund South was the first fast track project, with start-up in 2012. The concept is a subsea development with unprocessed flow to a processing unit. Ownership allocation was required between Visund South and GFC production. The only economical feasible metering system for ownership allocation for Visund South, was implementing a cost effective multiphase metering concept, which has shown encouraging results over time.

The results presented here are typically achievements for Visund South from start-up and today. Some deviations are observed, but deviations are well within the deviation limits of +/-10% HC mass rate that trigger corrective actions. The water production has so far been limited, thus more multiphase metering challenges with higher water cuts are expected to come within the next few years.

## **7. Acknowledgment**

The authors thank the Visund South license to allow publishing some of the measurement data of the Visund South production.

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