Paper 25

Phase Watcher VX Multiphase Flowmeter Heidrun Experience and Analysis

Dr. Paul Ove Moksnes, Framo Engineering, Norway,
Knut Skaardalsmo, Statoil ASA, Norway

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Knut Skårdalsmo, Statoil and Dr. Paul Ove Moksnes, Framo Engineering

1 ABSTRACT

Three PhaseWatcher Vx multiphase flowmeters have been installed on the Heidrun platform. It is shown how the Vx multiphase flowmeters are placed into the pipework and integrated into the measurement system on the platform. Much effort has been devoted to explain the influence of uncertainties in PVT data on the metrological multiphase flowmeter performance. Finally, some early test results are compared with corresponding test separator data. The conclusion is that the multiphase flowmeters function as intended, however, lack of PVT data has delayed the final set-up of the multiphase flowmeter.

2 INTRODUCTION

The measurement of multiphase flow is driven by the needs of reservoir and production engineers and by custody transfer between various legal entities or fiscal authorities for tax accounting. Depending of the application, the level of accuracy differs significantly. Whereas a reservoir engineer might be satisfied with a liquid rate measurement accuracy of ±10%, fiscal authorities may require that oil and gas rates are measured within ±0.5% accuracy. The equipment needed to meet these requirements might be very different, ranging from novel orifice plates to a full metering facility with separation of oil, gas and water with the purpose to meter individual phases with the required accuracy. The applications presented in this paper are continuous well monitoring and back allocation using a dual-energy spectral gamma ray / venturi multiphase flowmeter. The multiphase flowmeter measures the unprocessed well stream without separation of the phases and reports the oil, water and gas flowrates.

Multiphase flow meter technology has come so far that the industry has gained faith in these products. Consequently, more and more multiphase flowmeters are put into service and thus offering an alternative to test separators. On the Heidrun platform Statoil has installed three Vx multiphase flowmeters, each dedicated one well for permanent monitoring. In this paper is presented justifications for using a multiphase flowmeter and how the multiphase meter is integrated into the overall system measurement. The work required to setup the meters are presented. The influence of uncertainties in input data on the multiphase flowmeter accuracy is addressed and some early comparisons with the test separator are discussed.

3 MULTIPHASE FLOW METER BENEFITS

Using a multiphase flowmeter on a flow line connected to a single well or a cluster of wells adds valuable information to the production engineer. By using multiphase meters the following elements may individually or in combinations contribute to improve the overall project economics:

- Accelerated oil production due to:
  - Producing low pressure wells through the test separator

- Improved process capacity utilization
- Improved accuracy of daily rate monitoring

- Increased oil recovery due to:
  - Extension of the production life for low pressure wells by utilization of the test separator as an additional production separator
  - Better-scheduled and more successful well interventions based on improved history matching of the reservoir simulator
  - Early detection of performance deviations and initiation of remedial actions
  - Better predictions and long-term production planning
- Lower investment and operational cost due to:
  - Elimination of the need for additional test line and inlet separator at the host platform
  - Continuous measurement of water rates allows the chemical injection rates to be timed correctly and injection rates to be optimized

Previous experiences with multiphase flowmeters have shown that:

- Choke settings are continuously varied to obtain optimal production from each well with regards to gas coning and total production compared to injection rates. Without multiphase flowmeters on each well it would be very difficult to control the rates from each well in a cluster sharing the same flowline. Single well testing on the common flowline is a bad and expensive solution since this will not be representative for flow rates and pressures during normal production.
- Monitoring of GOR is important since the production on Heidrun is limited by the gas treatment capacity. To maintain maximum production it is necessary to trend the GOR development for each well.
- Water breakthrough has been detected much earlier than what has been possible with test separator testing.
- On a cluster of wells sharing the same flow line, the production information from each well is vital, and at one occasion it was early detected that one well had died due to unfortunate production conditions.

Based on these justifications and previous experiences it was decided to install three topside Vx multiphase flowmeters dedicated one well each on the Heidrun platform.

4 MULTIPHASE FLOWMETER INSTALLATION AND INTEGRATION

Three wells on the Heidrun platform have each been equipped with a PhaseWatcher Vx multiphase flowmeter. The multiphase flowmeters are placed topside and the well stream can either be routed to production or to test. The test line is equipped with a traditional three-phase separator with new coriolis meters on the water and oil leg and a v-cone on the gas outlet.

The characteristic nature of the three wells made them suitable candidates for permanent monitoring using multiphase flowmeters. The multiphase flowmeter is placed into the pipe work as shown in Figure 1.

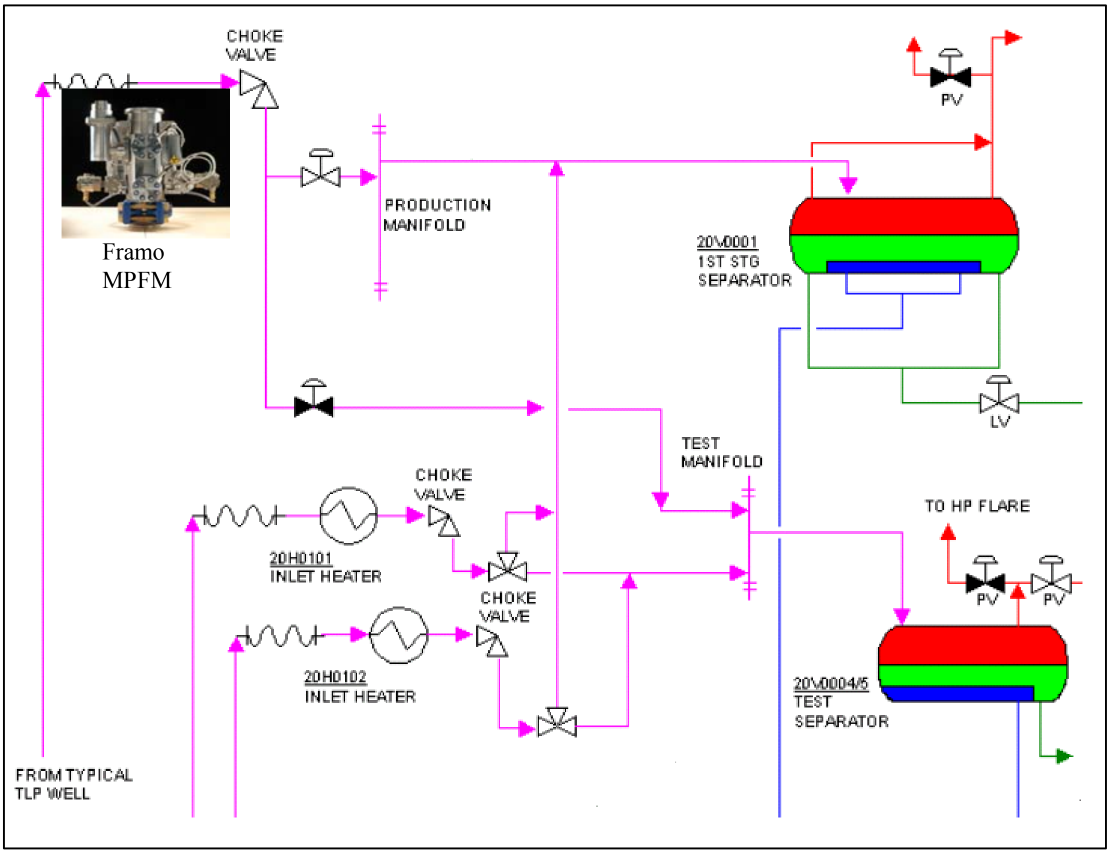

Figure 1 Process flow diagram in the vincinity of the Vx multiphase flowmeter.

The multiphase flowmeter facilitates two communication lines; one is connected to the control system, DCSS, and the other to a dedicated service computer. The DCSS system and the computer can read data from the multiphase flowmeter simultaneously. The control system acquires data into the measurement system as for any measurement device, whereas the computer is provided for diagnostics and service. Schematic of the signal hook-up is shown in Figure 2. Using a dedicated line for service and diagnostics means that the control system can acquire data un-interrupted while service and diagnostics are performed on the other line. The service computer is hooked up into the internal LAN system meaning that resources onshore can connect using appropriate software and control the computer from onshore. In practice, one can upload and download data from the service computer and also perform diagnostic services from land. This remote feature also enables service activities as upgrade of multiphase flowmeter software and multiphase flowmeter configuration parameters. The multiphase vendor can, if required, also be allowed access through the Soil network or from a Statoil office.

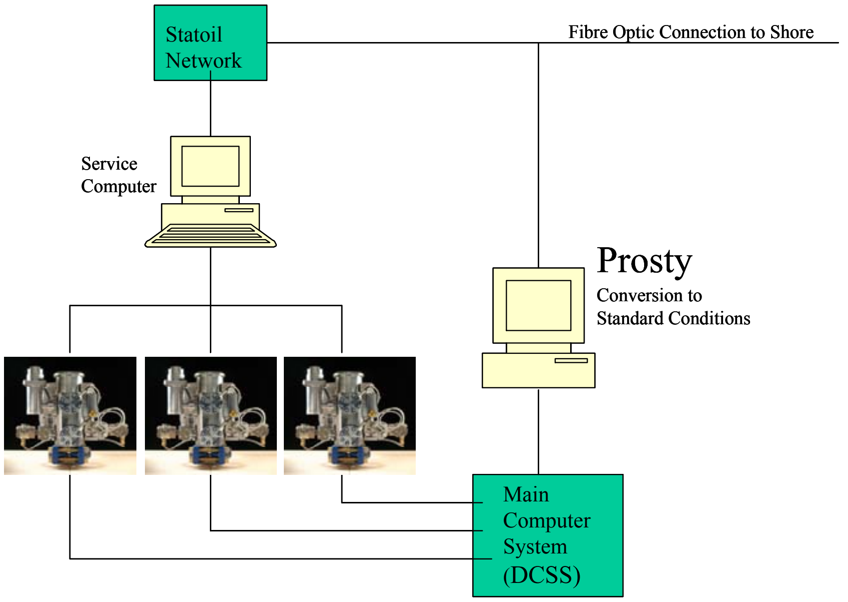

Figure 2 Signal hook-up schematics.

5 PhaseWatcher Vx WORKING PRINCIPLES

To prepare for a discussion about the PhaseWatcher setup and the influence of PVT parameters on the PhaseWatcher performance a brief introduction of the working principles are provided. In Figure 3 is shown cutaway schematics of the multiphase flowmeter.

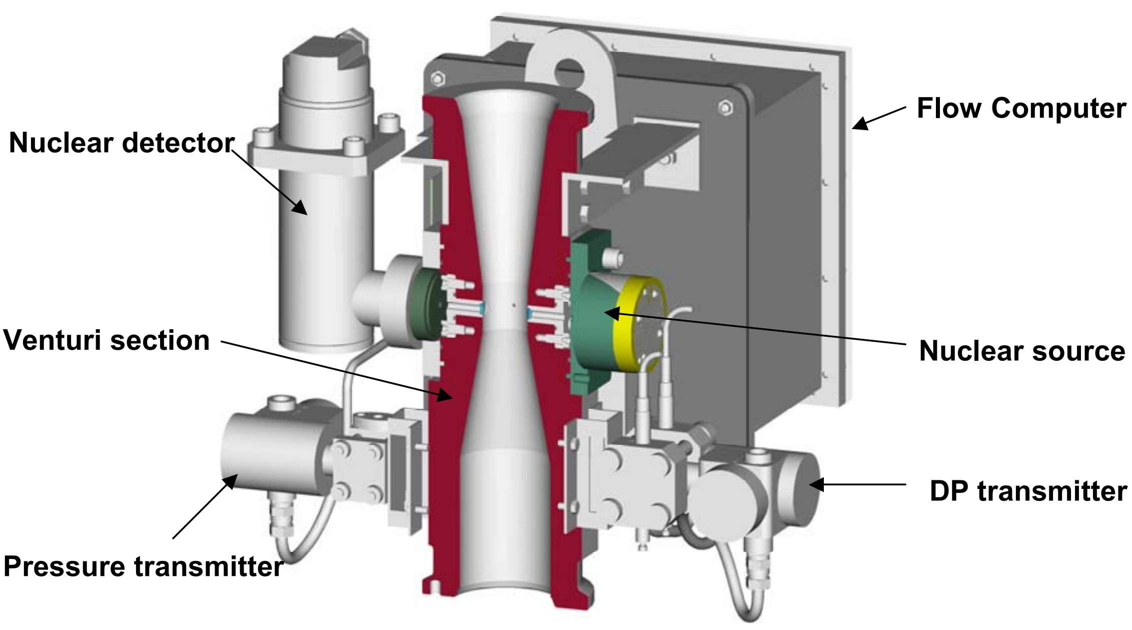

Figure 3 Cutaway schematics of the PhaseWatcher multiphase flowmeter.

The multiphase flowmeter is a dual energy spectral gamma ray – venturi multiphase flow meter. This means that the flowmeter contains a nucleonic source, which is used to measure the phase fractions and a venturi, which measures the total mass flow.

Five transmitter readings; pressure, temperature, differential pressure, low energy count rates and high energy count rates are utilized to finally arrive at the individual oil, water and gas flow rates. Knowing the measured fractions from the nuclear system and measured total flow rate from the venturi, one can calculate the individual phase flow rates. The equations used to solve for the fractions are based on the following physical relations:

$$\begin{aligned} N_{LE} &= N_{0LE} e^{-(\rho_o \mu_{oLE} h_o + \rho_w \mu_{wLE} h_w + \rho_g \mu_{gLE} h_g) D} \\ N_{HE} &= N_{0HE} e^{-(\rho_o \mu_{oHE} h_o + \rho_w \mu_{wHE} h_w + \rho_g \mu_{gHE} h_g) D} \\ h_o + h_w + h_g &= 1 \end{aligned} \tag{1}$$

Where:

ρ_o is the oil density
ρ_w is the water density
ρ_g is the gas density
μ_{oLE} is the oil low energy mass attenuation
μ_{wLE} is the water low energy mass attenuation
μ_{gLE} is the gas low energy mass attenuation
μ_{oHE} is the oil high energy mass attenuation
μ_{wHE} is the water low energy mass attenuation
μ_{gHE} is the gas high energy mass attenuation
h_o oil holdup fraction
h_w water holdup fraction
h_g gas holdup fraction
N_{LE} is the low energy count rates
N_{HE} is the high energy count rates
N_{0LE} is the low energy empty pipe count rates
N_{0HE} is the high energy empty pipe count rates
D is distance the gamma beam travels for measuring the fractions

The three equations contain three unknowns, the holdup fractions of oil, water and gas, which are solved for in the flow computer shown in Figure 3. Once the holdup fractions are known one can calculate the total flow according to the equation below.

$$\begin{aligned} \rho_{mix} &= h_o \rho_o + h_w \rho_w + h_g \rho_g \\ Q_T &= f(...) \sqrt{dP / \rho_{mix}} \end{aligned} \tag{2}$$

Where:

ρ_{mix} is the homogenous mixture density
dP is the venturi differential pressure
Q_T is the total flow rate
$f(...)$ is a function which accounts for the multiphase flow in the venturi

Then based on the knowledge of the holdup fractions and the total flow one can calculate the individual flow rates:

$$
\begin{aligned}
Q_o &= Q_T h_o \\
Q_w &= Q_T h_w \\
Q_g &= f_2(...) Q_T h_g
\end{aligned}
\qquad (3)
$$

Where
Q_o is the oil volumetric flow rate
Q_w is the water volumetric flow rate
Q_g is the gas volumetric flow rate
$f_2(...)$ is a function which accounts for the gas liquid slip

In fact, this is all there is to it to calculate the individual phase flow rates through the venturi. One should note that the functions $f(...)$ and $f_2(...)$ are non-trivial and have required a significant numbers of man-years of research to arrive at their present form. Given the equations above one can be convinced that the parameters needed to set-up the multiphase flowmeter are:
ρ_o, ρ_w, ρ_g which are the phase densities
μ_{oLE}, μ_{wLE}, μ_{gLE}, μ_{oLE}, μ_{wLE}, μ_{gLE} which are the mass attenuation coefficients
N_{0LE}, N_{0HE} which are the empty pipe reference count rates

The influence on the multiphase flowmeter performance from each of these parameters will be treated in turns.

6 PVT PROPERTIES AND MULTIPHASE FLOWMETER SETUP

Regardless of multiphase flow meter make, PVT parameters need to be known. Every multiphase flow meter measures flow rates at line conditions. However, the end-user usually wants the flow rates at standard conditions. This means that the knowledge of PVT properties is inevitable. The PhaseWatcher Vx flow computer reports both line and standard conditions flow rates based on PVT input parameters.

6.1 PVT parameters

There are two choices for setting up the multiphase flowmeter with the correct phase densities. One can either use a black oil model, which is developed and provided by the vendor, or data from a PVT analysis. The required input data for the black oil model are:

Oil density and oil viscosity at ambient pressure and some temperature

Gas specific gravity and gas composition up to C_9+ including CO_2, N_2 and H_2S
Water density at ambient pressure and some temperature

For heavy oils, which resemble black oil behavior, the use of the black oil model makes it very easy to setup the multiphase flowmeter and the results are good, often within the quoted accuracy for the multiphase flowmeter. The obtained accuracy is often sufficient for production engineers using the multiphase flowmeter for permanent well monitoring. To achieve the best possible accuracy, one will often resort to using PVT data based on a PVT analysis. Typically, one does flash calculations to the expected operating pressure and temperature for the multiphase flowmeter and the results are often presented in a matrix form with pressure and temperature as indices and density as the look-up value. Usually, the vendor needs to be supplied with this information, as this is information not readily available to him. The use of PVT properties based on PVT analysis in this manner is justified for applications where the multiphase flowmeter is used for back-allocation or revenue splitting where there are several partners in a field. Due to lack of PVT data all the multiphase flowmeters on Heidrun have been set-up with the black oil PVT model.

The sensitivity on errors in input data is readily investigated due to the fact that the measurement principles are based on physics, that is, the flowmeter is not trained or calibrated in flowing conditions in any way. That is, given the temperature, pressure, count rates and differential pressure the flow-rates can be recalculated utilizing a different set of PVT data and thus assess the sensitivity. For two of the multiphase flowmeters on Heidrun, data for a selected period have been acquired and than the oil density at standard conditions has been reduced with 3%. The acquired data were then re-processed to calculate the flow-rates. The purpose with this exercise is to demonstrate that the multiphase flowmeter accuracy is dependent on operating conditions and that results using a general black oil model have a potential for being improved. The results from this exercise are a prerequisite to make a good assessment of the comparison between the multiphase flowmeter and the test separator in the next section. The two selected wells are good candidates for this exercise since the operating pressures varies from 16 to 114 bara, the temperature from 50 to 68 °C and the WLR from 1 to 85%.

This is by no means a full sensitivity analysis, although it is easily performed, it is merely a demonstration of the importance of PVT data, which should be kept in mind when the data is assessed. The effects of PVT data on the metrological performance is not unique to the PhaseWatcher flowmeter, these effects will in principle be valid to every make of multiphase flowmeter. The results from reducing the standard conditions oil density with 3% is summarized in Table 1 and illustrated graphically in Figure 4.

		Orig.data	Proc.data	diff %
QO average	actm3/h	5.6	5.8	2.5%
QW average	actm3/h	33.71	33.75	0.1%
QG average	actm3/h	46.4	46.1	-0.5%
ROO line	kg/m3	854.6	827.2	-3.2%
ROW line	kg/m3	1013.5	1013.5	0.0%
ROG line	kg/m3	11.9	11.9	0.0%
QT average	actm3/h	85.7	85.7	-0.1%
GVF average	%	54.1%	53.8%	-0.3%
WLR average	%	85.6%	85.4%	-0.3%
ROOstd	kg/m3	895.419	868.496	-3.0%
Paver	bara	16.4		
Taver	C	67.2		

Table 1 Influence of a 3% reduction in standard conditions oil density summarized, Vx 1.

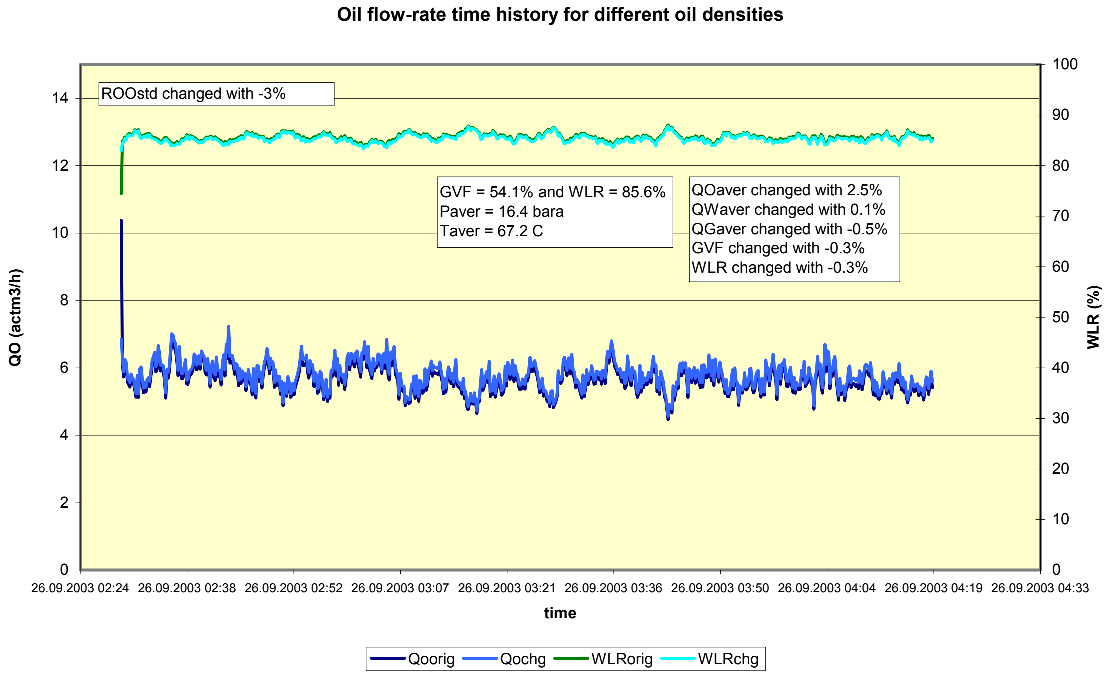

Figure 4 Influence of a 3% reduction in standard conditions oil density illustrated, Vx 1.

The results shown in Table 1 do not exhibit any dramatic changes as is also illustrated in Figure 4, as the curves almost overlap. One should note from Table 1 that the oil density at line conditions is reduced with 3.2% and that although the oil flow rate is increased with 2.5% the WLR is only changed with –0.3% and the GVF with –0.3%. The total flow rate is only changed with –0.1%.

The results presented above were for the multiphase flowmeter operated at a relatively low pressure, 16.4 bara. The second multiphase flowmeter is operated at a significantly different pressure, 114.2 bara. The results is summarized in Table 2 and illustrated graphically in Figure 5.

		Orig.data	Proc.data	diff %
QO average	actm3/h	26.7	28.7	7.6%
QW average	actm3/h	0.47	0.46	-1.8%
QG average	actm3/h	41.3	39.2	-5.1%
ROO line	kg/m3	795.2	751.6	-5.5%
ROW line	kg/m3	1026.2	1026.2	0.0%
ROG line	kg/m3	139.9	139.9	0.0%
QTaverage	actm3/h	68.4	68.3	-0.1%
GVF average	%	60.4%	57.4%	-3.0%
WLR average	%	1.7%	1.6%	-0.1%
ROOstd	**kg/m3**	879.812	853.396	-3.0%
Paver	**bara**	114.2		
Taver	**C**	49.7		

Table 2 Influence of a 3% reduction in standard conditions oil density summarized, Vx 2.

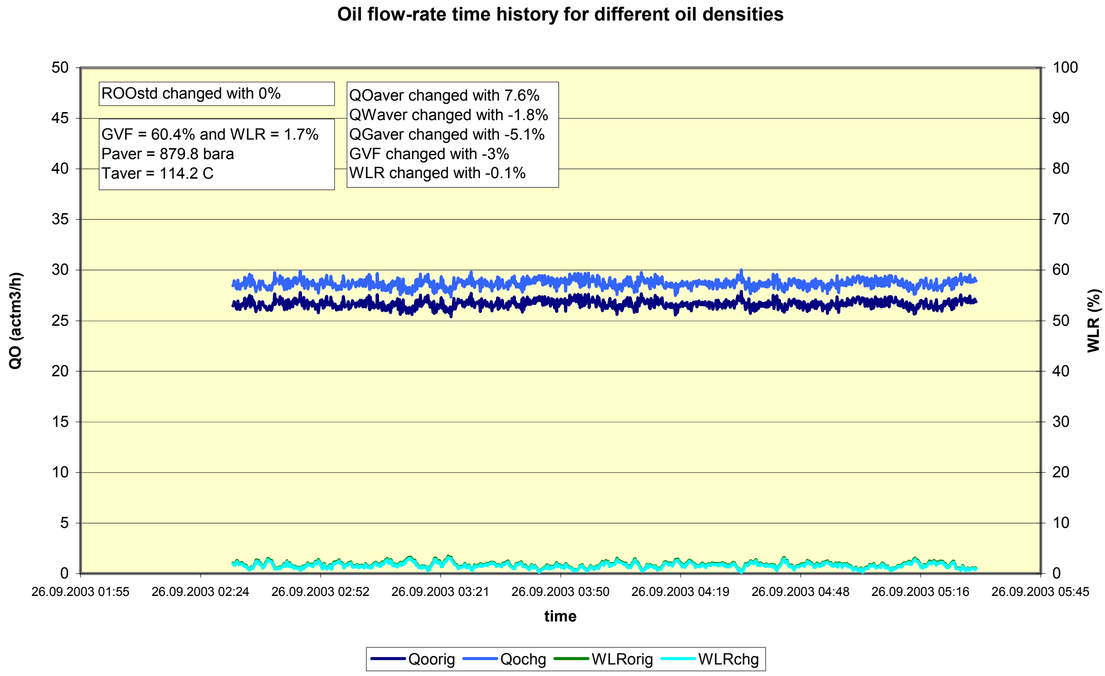

Figure 5 Influence of a 3% reduction in standard conditions oil density illustrated, flowmeter 2.

For Vx two, the 3% reduction in standard conditions oil density lead to a 5.5% reduction in oil density at line conditions and a corresponding 7.6% increase in the oil flow rate at line conditions. Again the WLR is not altered significantly, only by -0.1%. As for Vx one, also for Vx two the total flow-rate can be considered constant, it has only changed –0.1%.

The conclusions from this exercise is that

- The impact of an inaccuracy in the standard conditions oil density is dependent on operating conditions, and more significant for operating pressures and temperatures far from the standard conditions.
- The total flow-rate is not affected much by the oil density change, neither is the WLR.

- One should bear in mind the inherent characteristic of a general black oil model when the operating conditions are significantly different from standard conditions.

The results above can be improved by utilizing the client specific PVT model option in the multiphase flowmeter where PVT data has been generated for the multiphase flowmeter operating conditions. Whether this is an option or not depend on the availability of PVT data and the purpose of the multiphase flowmeter. On Heidrun the client specific PVT model will be implemented when sufficient PVT data are available.

6.2 Mass attenuation values

In addition to PVT data, the mass attenuation coefficient for each fluid is needed. Mass attenuation coefficients are needed as input for all multiphase flow meters utilizing a nuclear measurement system. The mass attenuation coefficient for a substance is a measure for how much the gamma photons are attenuated when they travel through that substance. Gamma photons are emitted at different energy levels from the nucleonic source and for each energy level there is a corresponding mass attenuation coefficient. There are three different ways the mass attenuation coefficient can be input to the PhaseWatcher.

1. Based on compositional data at line pressure and temperature one can calculate the mass attenuation coefficients from published tables.
2. By measuring a physical sample, this is called in-situ measurement. That is, a tool is inserted into the venturi throat to bring oil or water samples at ambient conditions into the gamma beam and by using the acquired gamma count rates, the mass attenuation coefficient for the sample can be calculated.
3. From the same input data as for the black oil model. There is a model in the flow computer, which can calculate the attenuation coefficients.

Method 1) is the most general way of obtaining mass attenuation data. It does not require physical samples or that the pipe work is opened as is required for an in-situ measurement. Method 2) requires physical samples for the oil and water. The pipe work is opened and a special tool is inserted into the venturi throat in front of the gamma beam. The physical sample is poured into the tool and one can actually measure the sample mass attenuation. In some cases the in-situ measurement is not representative for what is flowing through the venturi at line conditions. This could be the case for a condensate well, and one would have to use method 1) to find the mass attenuation coefficients. Method 3) is used when one is certain to have black oil or the available PVT data is limited. On Heidrun, method 2) has been employed. However, since the line pressure is 114 bara for the well stream flowing through flowmeter 2, the in-situ measured mass attenuation coefficients will be cross checked with compositional data when they become available.

Typical considerations regarding mass attenuation coefficients are:

- How much do the mass attenuation coefficients change with composition, how often is it needed to update the mass attenuation coefficients?
- Does changing salinity affect the mass attenuation values and finally the flow rates?

A sensitivity study has been done to assess the influence of the mass attenuation coefficients on the metrological performance. The gas mass attenuation coefficients have been omitted from this exercise, as they do not affect the performance nearly as much as the oil and water mass attenuation coefficients. The reason is that it is the product of μ and ρ for the fluid as shown in Equation (1), which determines the influence of the fluid on the solution of the equation. The mass attenuation for gas is of the same order as the mass attenuation for oil, however, the gas density is for normal operating pressure much lower than for oil and thus the product of μ and ρ is much smaller. Two cases have been considered:

- The oil composition has been changed significantly and the corresponding mass attenuation coefficients calculated. The same data as in the previous section has been re-processed and compared to the original data.
- The salinity has been changed and the corresponding mass attenuation coefficients calculated. The coefficients have been used in re-processing the data from the previous section.

6.2.1 Oil mass attenuation coefficients sensitivity

Since the compositional data have not been used on Heidrun to set up the Vx, a relative change to a given composition was calculated. The relative change was then applied to the current oil mass attenuation coefficients used in the Vx. The compositions considered are shown in Table 3.

Base composition	
Formulae	**Weight frac**
N2	0.000000
H2S	0.000000
CO2	0.000000
CH4	0.000022
C2H6	0.000629
C3H8	0.006585
C4H10	0.032929
C5H12	0.033981
C6H14	0.041009
C7H16	0.083826
C8H18	0.098672
C9H20	0.076605
C10H22	0.060061
C11H24	0.049733
C12H26	0.044570
C13H28	0.046695
C14H30	0.043881
C15H32	0.380802

Changed composition		
Formulae	**Weigth frac.**	**rel.diff %**
N2	0.000000	0.0%
H2S	0.000000	0.0%
CO2	0.000000	0.0%
CH4	0.000045	100.0%
C2H6	0.001259	100.0%
C3H8	0.013170	100.0%
C4H10	0.065857	100.0%
C5H12	0.067962	100.0%
C6H14	0.082019	100.0%
C7H16	0.100592	20.0%
C8H18	0.118406	20.0%
C9H20	0.091926	20.0%
C10H22	0.072073	20.0%
C11H24	0.059680	20.0%
C12H26	0.053484	20.0%
C13H28	0.056034	20.0%
C14H30	0.052657	20.0%
C15H32	0.164838	-56.7%

Table 3 Compositions used to assess the influence on an oil compositional change.

The changes are considered significant percent vise. The compositional change caused a corresponding change in oil mass attenuation as shown in Table 4.

keV	Base composition	Change composition	rel.diff %
LE	-0.0248762	-0.0248885	0.05%
HE	-0.0171944	-0.0172001	0.03%

Table 4 Relative change in oil mass attenuation coefficients caused by changed composition.

As seen from Table 4, the relative change in the oil mass attenuation coefficients is small and one does not expect a large influence on the flow-rates. The relative change was applied to the current mass attenuation coefficients in the Vx and the test data re-processed. The results for Vx 1 are shown in Table 5.

		Orig.data	Proc.data	diff %
QO average	actm3/h	5.649	5.643	-0.11%
QW average	actm3/h	33.71	33.7	0.01%
QG average	actm3/h	46.4	46.4	0.01%
ROO line	kg/m3	854.6	854.6	0.00%
ROW line	kg/m3	1013.5	1013.5	0.00%
ROG line	kg/m3	11.9	11.9	0.00%
QT average	actm3/h	85.7	85.7	0.00%
GVF average	%	54.1%	54.1%	0.00%
WLR average	%	85.6%	85.7%	0.01%
ROOstd	kg/m3	895.419	895.419	0.00%
Paver	bara	16.4		
Taver	C	67.2		

Table 5 Influence of composition on metrological performance for Vx 1.

Vx 1 is the multiphase flowmeter with operating conditions closest to standard conditions. The results in Table 5 clearly indicate that the compositional change for the oil has a minor impact on the metrological performance. The same exercise has been conducted for Vx 2, with operating conditions significantly different form the standard conditions. The results are shown in Table 6.

		Orig.data	Proc.data	diff %
QO average	actm3/h	26.654	26.655	0.00%
QW average	actm3/h	0.468	0.462	-1.30%
QG average	actm3/h	41.3	41.3	0.04%
ROO line	kg/m3	795.2	795.2	0.00%
ROW line	kg/m3	1026.2	1026.2	0.00%
ROG line	kg/m3	139.9	139.9	0.00%
QTaverage	actm3/h	68.4	68.4	0.01%
GVF average	%	60.4%	60.4%	0.01%
WLR average	%	1.7%	1.7%	-0.02%
ROOstd	kg/m3	879.812	879.812	0.00%
Paver	bara	114.2		
Taver	C	49.7		

Table 6 Influence of composition on metrological performance for Vx 2.

Despite that the operating conditions are quite different, the compositional impact on the metrological performance is also in this case minor.

The conclusion from this exercise is that one should not be too concerned about the oil mass attenuation coefficients when the composition changes. However, as shown in the previous section, one might benefit from putting an effort into getting the oil density correct.

6.2.2 Water mass attenuation coefficients sensitivity

Also for water, the mass attenuation coefficients have been altered and the corresponding influence on the metrological performance calculated. First the mass attenuation coefficients for seawater were calculated, then Na and Cl were increased with 15% and new mass attenuation coefficients calculated. The test case is summarized in Table 7.

		Seawater	Changed comp.	rel.diff %
myw32	m2/kg	-0.036960	-0.037488	1.4%
myw81	m2/kg	-0.017061	-0.017131	0.4%
Na	mg/l	11136.6	12807	15.0%
Cl	mg/l	20030.355	23034.90825	15.0%

Table 7 Changed water mass attenuation coefficients as a result of increased salinity.

The water composition on Heidrun is not known yet, therefore the relative changes shown in Table 7 have been applied to the measured in-situ values to simulate a changed salinity. For Vx 1 the results are summarized in Table 8.

		Orig.data	Proc.data	abs. diff	rel. diff %
QO average	actm3/h	5.6	6.8	1.20	21.2%
QW average	actm3/h	33.71	32.6	-1.07	-3.2%
QG average	actm3/h	46.4	46.3	-0.04	-0.1%
ROO line	kg/m3	854.6	854.6	0.00	0.0%
ROW line	kg/m3	1013.5	1013.5	0.00	0.0%
ROG line	kg/m3	11.9	11.9	0.00	0.0%
QT average	actm3/h	85.7	85.8	0.09	0.1%
GVF average	%	54.1%	54.0%	-0.1%	-0.1%
WLR average	%	85.6%	82.7%	-3.0%	-3.0%
ROOstd	**kg/m3**	895.419	895.419	0.0%	0.0%
Paver	**bara**	16.4			
Taver	**C**	67.2			

Table 8 Effect of salinity change on Vx 1 metrological performance.

The oil flow rate increased with 21.2%, however, the absolute change is 1.2 actm^3/h. One should note that the absolute change in oil and water flow rates is of the same order. This will always be the case since changing salinity will affect the split between oil and water and only to a minor degree the total liquid flow rate. For this reason one should be cautious when reading relative differences if either the oil or water flow rate is small.

The WLR is reduced with –3.0%. This means that, if Vx 1 was setup with seawater and the water in the meter really did contain 15% more Cl and Na, the Vx would over predict the WLR with 3.0%. The water flow rate would be over predicted by 3.2%. The corresponding results for Vx 2 are shown in Table 9.

		Orig.data	Proc.data	abs diff	rel. diff %
QO average	actm3/h	26.7	26.7	0.024	0.09%
QW average	actm3/h	0.47	0.45	-0.019	-4.07%
QG average	actm3/h	41.3	41.3	-0.003	-0.01%
ROO line	kg/m3	795.2	795.2	0.000	0.00%
ROW line	kg/m3	1026.2	1026.2	0.000	0.00%
ROG line	kg/m3	139.9	139.9	0.000	0.00%
QTaverage	actm3/h	68.4	68.4	0.002	0.00%
GVF average	%	60.4%	60.4%	-0.01%	-0.01%
WLR average	%	1.7%	1.7%	-0.07%	-0.07%
ROOstd	**kg/m3**	879.812	879.812	0.00%	0.00%
Paver	**bara**	114.2			
Taver	**C**	49.7			

Table 9 Effect of salinity change on Vx 2 metrological performance.

The influence of changed salinity on Vx 2 is much less pronounced than for Vx 1.The reason is the different operating conditions. Vx 1 operates around 80% WLR and any changes in water data will have a greater effect on flowmeter performance than for Vx 2, which operates with a small amount of water. Since there is so little water flowing through Vx 2, any changes in water data will not affect the Vx performance much. Although the water flow rate in Table 9 was reduced with 4 % the absolute change was only 0.02 actm^3/h, and thus it did not influence the oil flow rate much.

6.2.3 Conclusions

The findings from the sensitivity analysis on the mass attenuation values for oil and water have shown that

- The oil mass attenuation coefficients are not significantly influenced by changes in the oil composition. The base case oil composition was changed from –56 to 100% for the compounds CH_4 to $C_{15}H_{32}$, and still only minor changes were observed on the calculated flow-rates.
- The minor changes were expected since a usual hydrocarbon mixture contains only C and H atoms and thus it is the ratio of the number of atoms, which governs the mass attenuation value. In addition, the atomic number for C is 6, whereas it is 1 for H. The higher the atomic number the more influence the component with the high number will have on the mass attenuation coefficient. Thus, the carbon in the oil will dominate the mass attenuation coefficient.
- The water mass attenuation coefficients can exhibit a larger variation in values since water can contain many components with different atomic numbers. This was demonstrated by calculating flow rates for increased water salinity.
- Although the relative influence on the water rates was similar for Vx 1 and Vx 2, the impact on the absolute oil flow rate was largest for Vx 1 because it measures more water, around 30 actm^3/h, than for Vx 2, which measures around 0.5 actm^3/h.

Based on these findings it is recommended to make some effort finding the water composition for well streams containing significant water. For the oil analysis, it is sufficient to do the analysis down to C_{15+}. For the oil one will benefit more from an accurate density description than an accurate compositional analysis.

One should note that increased salinity would be observed on the Vx as increased WLR, which can be used as an indication that one might benefit from doing a water sample analysis. Thus, by monitoring the WLR it is possible to get an early warning when any injected water is breaking through.

6.3 Empty pipe parameters

The empty pipe measurement is performed on an empty multiphase flowmeter at atmospheric conditions either on air or nitrogen. The empty pipe parameters are important reference parameters and the empty pipe measurement process is often referred to as empty pipe calibration. In fact, the empty pipe measurement is the only calibration necessary. Setting up the Vx with correct PVT parameters and mass attenuation coefficients is not a calibration, it is providing correct input parameters. The empty pipe parameters are logged until the standard deviation in the parameters are less than 0.02%, this usually requires minimum 20 minutes logging time. For high GVF applications, above 90%, one usually aims at a standard deviation of 0.01%. For N0LE a 0.02% standard deviation will typically correspond to 5 counts per second (cps), for N0HE the number is 2.5 cps. If we have an empty pipe recording out of specification, let say by 10 cps for the N0LE and 5 cps for N0HE. The change corresponds to a change of 0.04%, which is twice the 0.02% aimed for. The influence on the flow rates can be calculated. For Vx 1 the results are presented in Table 10.

		Orig.data	Proc.data	abs. diff	re. diff %
QO average	actm3/h	5.6	5.7	0.04	0.674%
QW average	actm3/h	33.71	33.7	-0.03	-0.077%
QG average	actm3/h	46.4	46.3	-0.06	-0.128%
ROO line	kg/m3	854.6	854.6	0.00	0.000%
ROW line	kg/m3	1013.5	1013.5	0.00	0.000%
ROG line	kg/m3	11.9	11.9	0.00	0.000%
QT average	actm3/h	85.7	85.7	-0.05	-0.055%
GVF average	%	54.1%	54.0%	0.0%	-0.040%
WLR average	%	85.6%	85.6%	-0.1%	-0.092%
ROOstd	kg/m3	895.419	895.419	0.00	0.000%
Paver	bara	16.4			
Taver	C	67.2			

Table 10 Influence of empty pipe parameters on Vx 1 performance.

As seen from Table 10, the changes are negligible.For Vx 2 the changes corresponding to 0.04% were that N0LE changed with 14.6 cps and N0HE with 7 cps. The results are shown in Table 11.

		Orig.data	Proc.data	abs. diff	rel. diff %
QO average	actm3/h	26.7	26.7	0.062	0.231%
QW average	actm3/h	0.47	0.45	-0.020	-4.353%
QG average	actm3/h	41.3	41.2	-0.083	-0.202%
ROO line	kg/m3	795.2	795.2	0.000	0.000%
ROW line	kg/m3	1026.2	1026.2	0.000	0.000%
ROG line	kg/m3	139.9	139.9	0.000	0.000%
QTaverage	actm3/h	68.4	68.4	-0.042	-0.062%
GVF average	%	60.4%	60.3%	-0.08%	-0.085%
WLR average	%	1.7%	1.6%	-0.08%	-0.078%
ROOstd	**kg/m3**	879.812	879.812	0.000	0.000%
Paver	**bara**	114.2			
Taver	**C**	49.7			

Table 11 Influence of empty pipe parameters on Vx 2 performance.

The changes in WLR and GVF are comparable to Vx 1. The water rate was changed by –4.4%, however, the absolute change is small, 0.02 actm3/h.

Based on these findings it can be concluded that the empty pipe measurement is a robust measurement. That is, a variation of the empty pipe count rates twice the targeted standard deviation did not influence the flow-rates much.

The flow rates measured by Vx 1and Vx 2 have been tested against a test separator. The test separator on Heidrun is equipped with a coriolis meter on each liquid leg and a v-cone on the gas outlet. One comparison period for each Vx will be presented.

7 PhaseWatcher AND TEST SEPARATOR COMPARISONS

First Vx 1 installed on well A was tested against the test separator. The primary goal was to compare the rates on a mass basis. The reason is that to limit issues with PVT parameter needed to convert data at line conditions to standard conditions, we wanted to compare data at line conditions on a mass basis. The comparison challenge is illustrated in Figure 6. One should compare the rates at the same condition. According to Figure 6, there exist at least three choices, MPFM, TSP or standard conditions. If one chooses standard conditions that means that the MPFM and TSP rates both needs to be converted to standard conditions. This introduces the uncertainty of PVT parameters, as oil shrinkage, gas in solution and z-factor. The availability of such parameters at a uniform uncertainty over a range of pressure and temperature are usually limited.

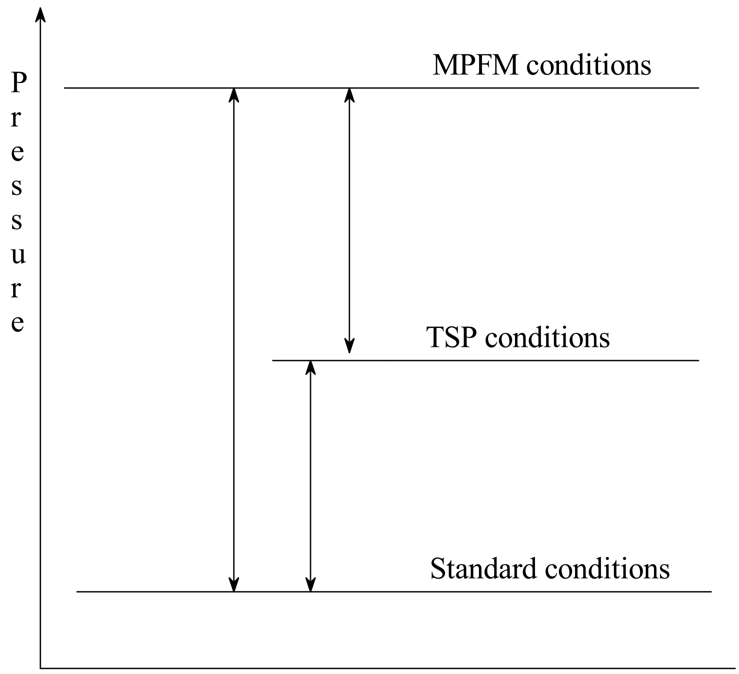

Figure 6 Conversion between different states.

Therefore, one might benefit from converting the data either to the TSP or MPFM conditions. Though, that still means that essential PVT data are needed for the TSP and MPFM conditions. At this time, these data were not available and another approach was chosen. The MPFM data were converted to a mass basis with the purpose to compare total mass of hydrocarbons. Independent of the phase transitions, the total mass of hydrocarbons is constant independent of operating conditions.

At this stage a problem occurred. Although the TSP is equipped with coriolis meters, the densities at TSP conditions were not known. The reason was that at the time the tests were performed, the TSP densities were not properly stored in measurement system. Thus, to convert the TSP flow rates from a volumetric to a mass basis, the same black oil model as used in the MPFM was used to calculate the oil and gas densities at TSP conditions. Although the aim is to compare total hydrocarbon mass, also the individual oil, water and gas mass flow rates are compared.

This comparison is not correct unless one first convert the data from either TSP to MPFM conditions or from MPFM to TSP conditions. This conversion has not been done here due to lack of PVT data, and thus mass flow rates at MPFM conditions are compared to mass flow rates at TSP conditions. In the future the necessary data will be available, and a proper comparison can be performed. The oil, water and gas mass flow rates for Vx 1 is compared to corresponding TSP mass flow rates in Figure 7, Figure 8 and Figure 9. Note that the test data does not correspond to the data set used to perform the sensitivity analysis in the previous sections.

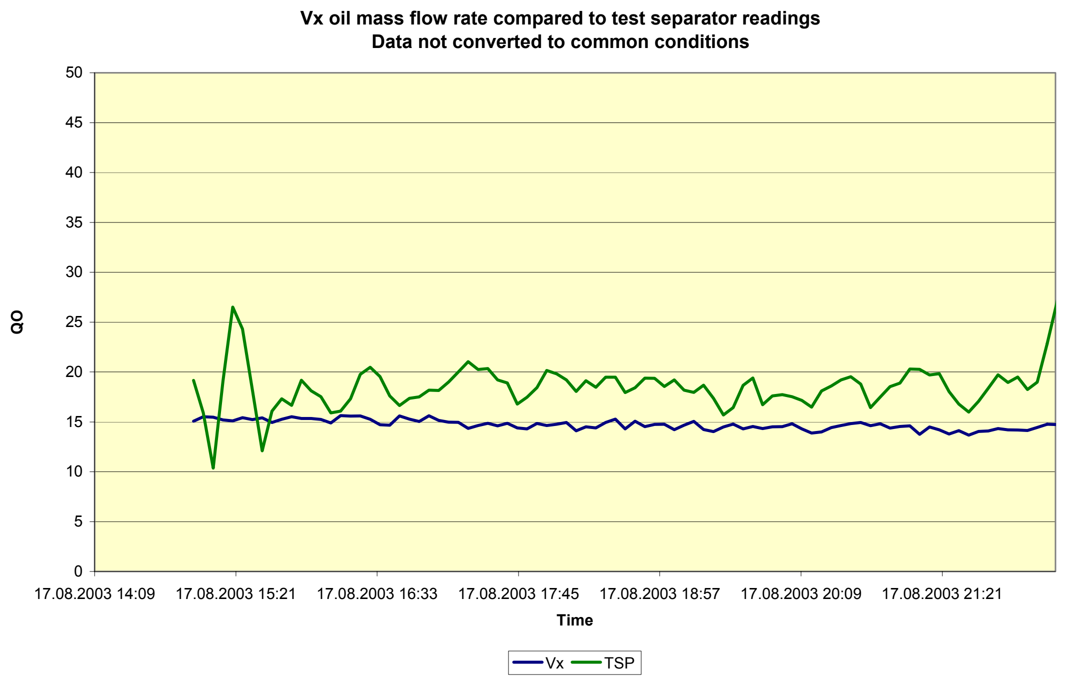

Figure 7 Vx 1 oil mass flow rates compared to test separator mass flow rates.

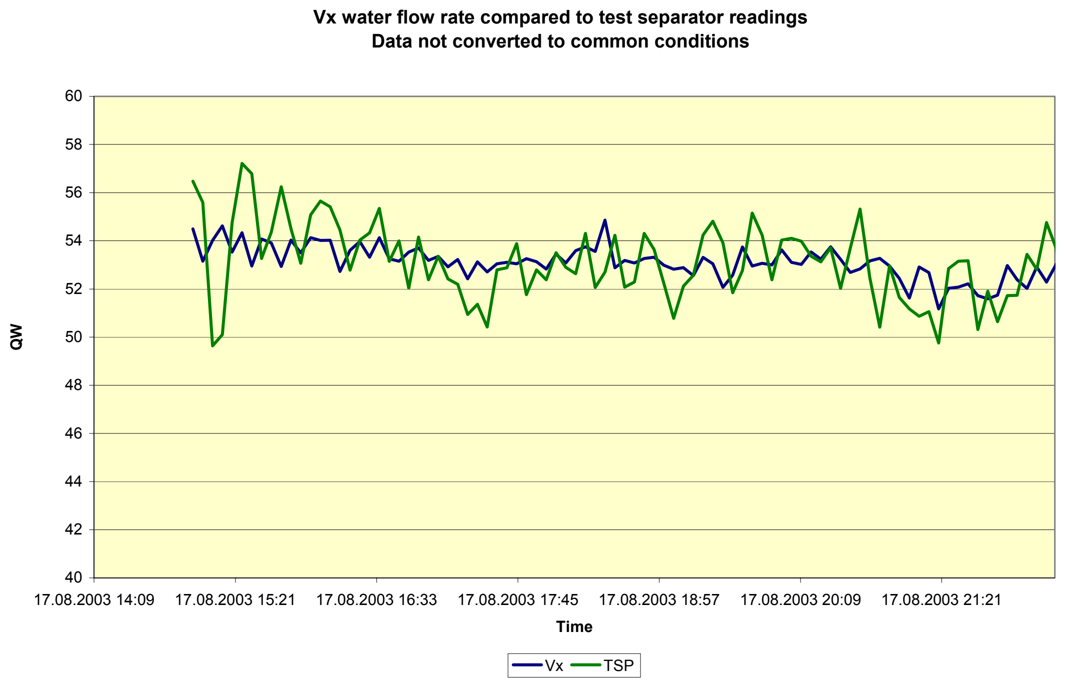

Figure 8 Vx 1 water mass flow rates compared to test separator mass flow rates.

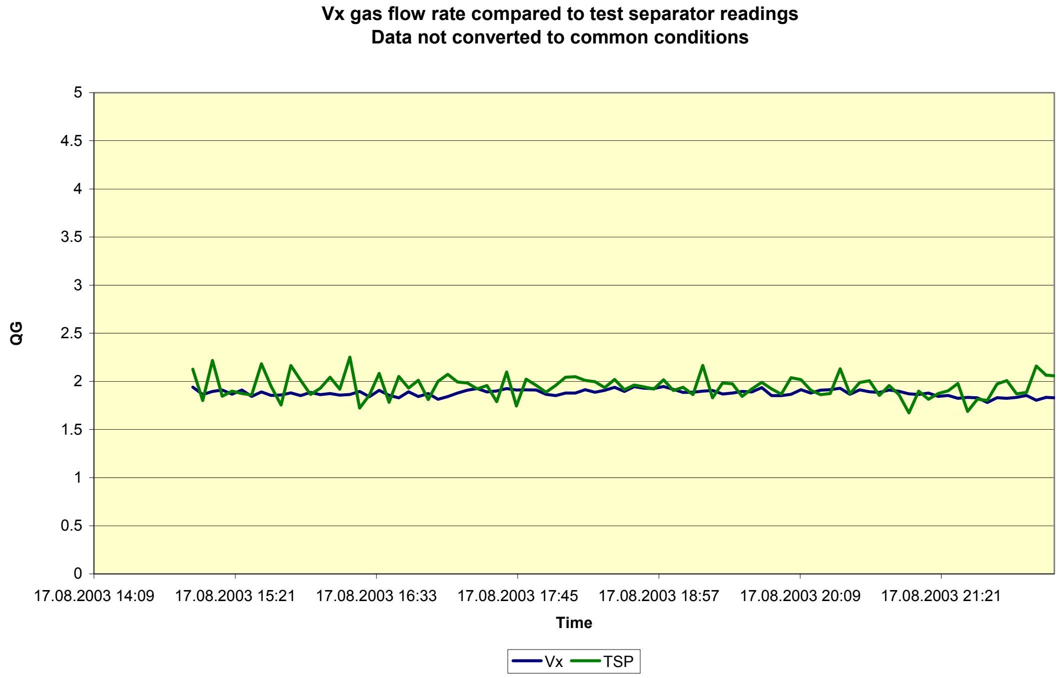

Figure 9 Vx 1 gas mass flow rates compared to test separator mass flow rates.

The water and gas flow rates correspondence is quite good, with an average relative difference to the test separator equal –0.1% and –3.6% respectively. The oil flow rate is off by 3.4 tons/h or –18% relative, which is unusual high. This is typical when something is wrong with the MPFM setup or the TSP. The pressure and temperature at the MPFM are 20 bara and 71 C respectively, which is close to the separator pressure and temperature, 14 bara and 68 C respectively. Hence, any large discrepancies cannot be attributed to uncertainties in PVT data alone.

One should note that the flow rate from the Vx is much more stable than from the separator. In fact, the separator oil flow rate fluctuates with almost as much as 5 tons/h, which represents a relative variation of +-12% of the base flow rate. Such variations could be caused by water being carried over into the oil leg. Future tests with simultaneous recording of coriolis densities might shed some light on this issue.

A similar comparison between Vx 2 and the test separator has been done and the graphics are shown in Figure 10, Figure 11 and Figure 12. The main difference between the Vx 1 and Vx 2 is the operating conditions. The Vx 2 data were acquired at a pressure of 125 bara, which should be compared to the 14 bara test separator pressure. Vx 2 temperature was 47°C, whereas the TSP temperature was 35°C.

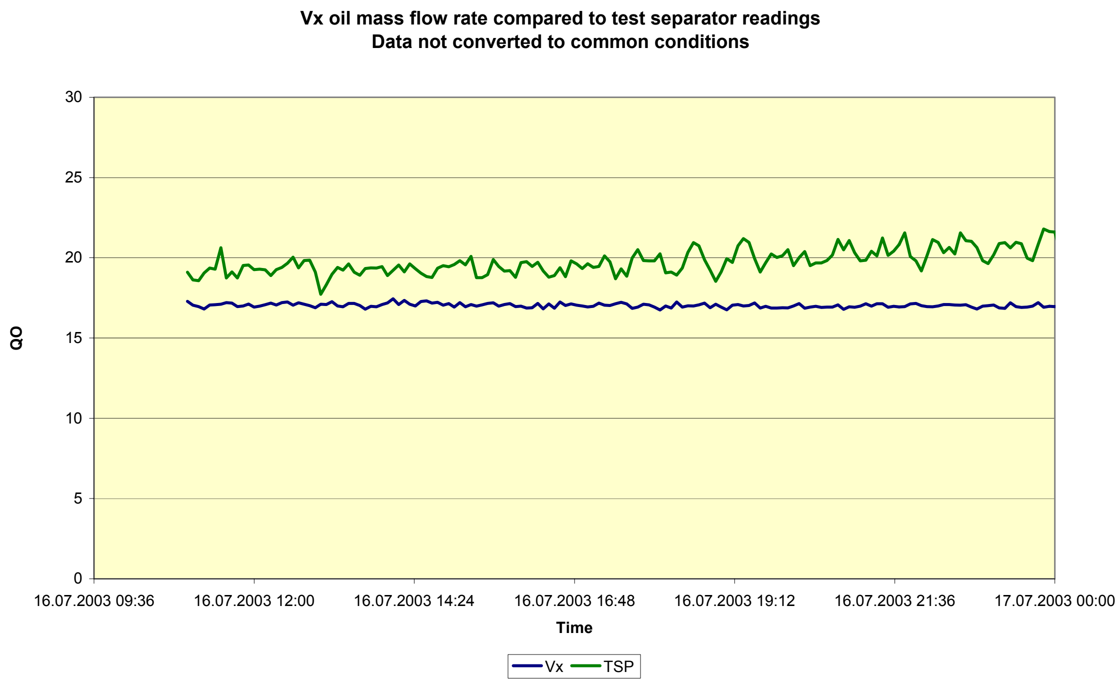

Figure 10 Vx 2 oil mass flow rates compared to test separator mass flow rates.

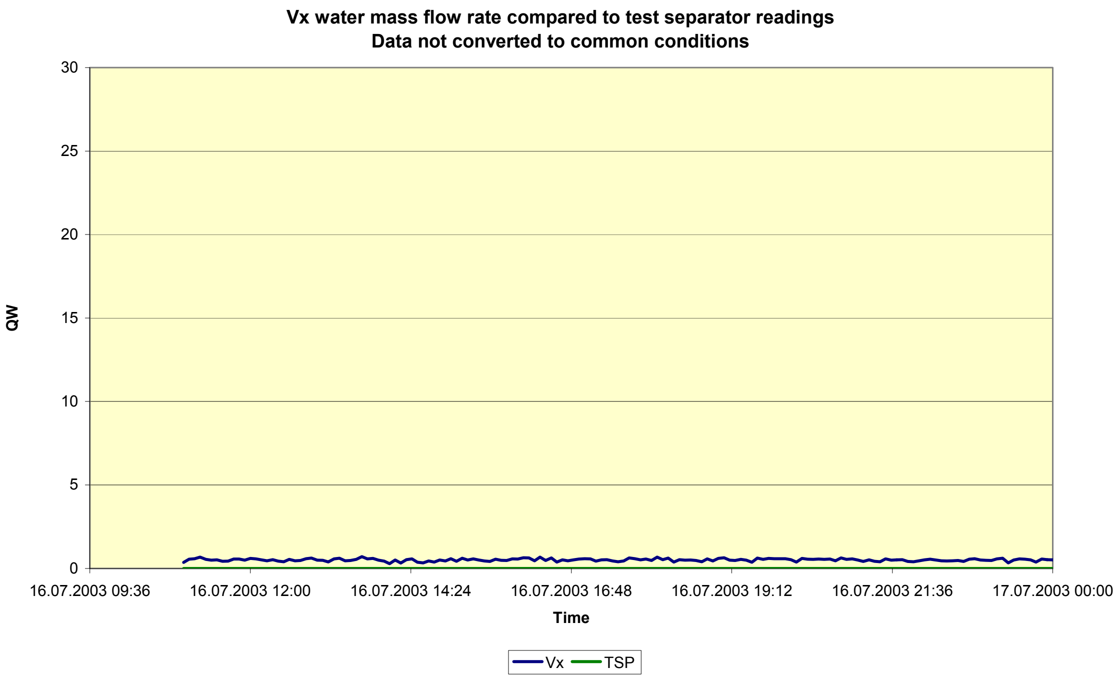

Figure 11 Vx 2 water mass flow rates compared to test separator mass flow rates.

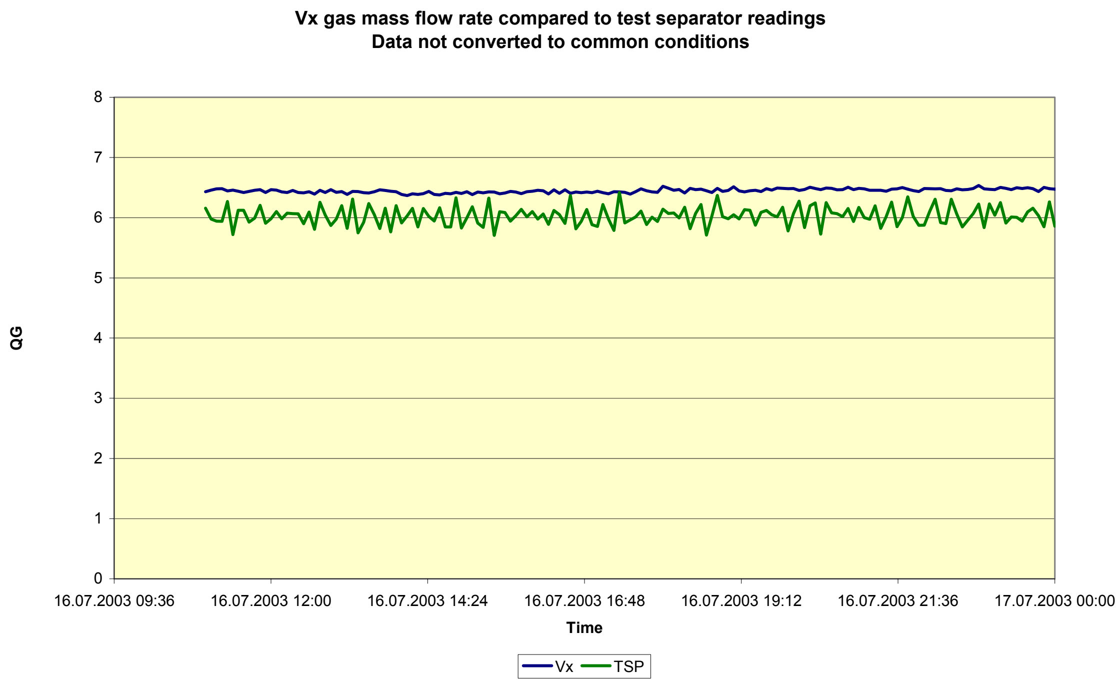

Figure 12 Vx 2 gas mass flow rates compared to test separator mass flow rates.

The comparison shows that on average the gas is off by 6.9%, the oil flow rate with –13.4%. The water leg on the test separator has been closed during the test due to small water production. This means that the water level has been building up inside the test separator. The relative difference in oil flow rate is too high, however, one should consider the high Vx pressure and the limited PVT data input. In addition, the separator oil flow rate in Figure 10 does fluctuate and exhibit an increasing trend over the test period, whereas the flow rate from the Vx meter is very stable.

The Vx normally catches the process dynamics much better than a test separator, which leaves the fluctuations in the separator oil flow rate as an open issue for future tests and scrutiny.

When the test results are assessed one should also bear in mind:

- Individual phase flow rates have not been converted to a common reference.
- The measured TSP densities have not been available.
- A black oil model has been used to estimate the TSP densities and thus the TSP mass flow rates.

Given these conditions, the test results are satisfactorily. The results indicate that the Vx certainly provide good flow rate estimates at this stage given the circumstances. We hope to get the opportunity to present proper comparison data at a future occasion.

8 PhaseWatcher Vx DYNAMIC RESPONSE

Much attention is usually devoted to the comparison between the Vx multiphase flowmeter and a test separator. Such comparisons are at the test separator terms. In multiphase flowmeter feasibility studies one should also keep in mind the superior dynamic performance compared to a test separator. This is especially evident in multi rate well testing jobs, which is performed much faster than with a test separator. The well response to a choke change is immediately reflected in the multiphase flowmeter readings. For one of the wells on Heidrun, the choke position was varied and the corresponding total flow rate reported by the multiphase meter is shown in Figure 13.

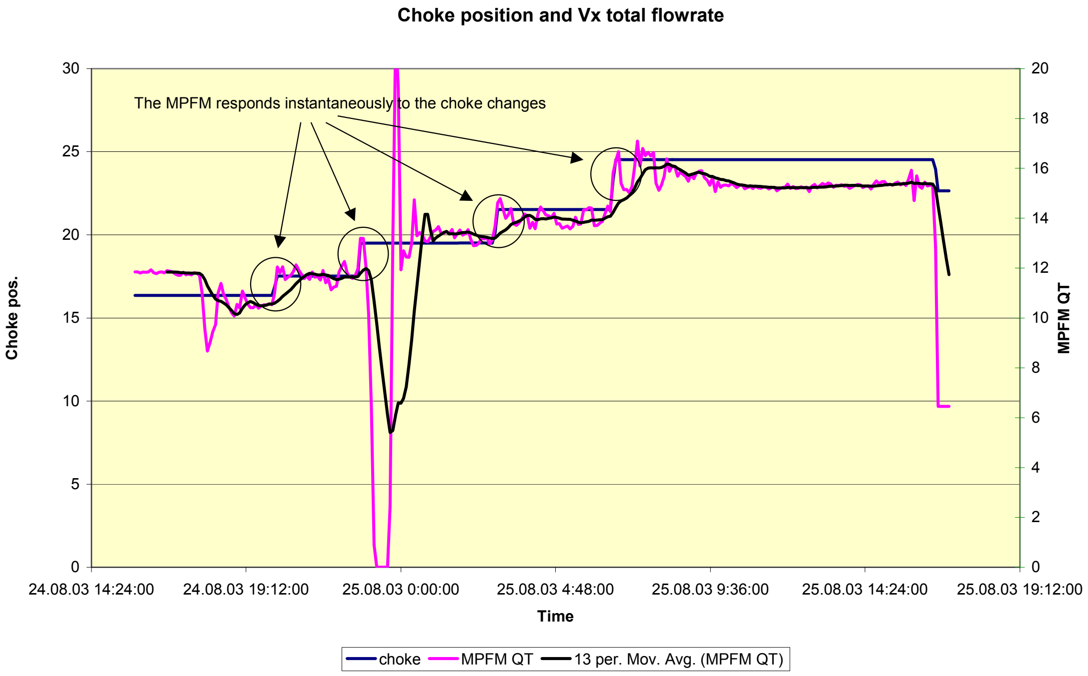

Figure 13 The MPFM total flow rate reflects the choke changes.

The multiphase meter does not need any stabilization time after a choke change, the time required on each choke setting in a multi rate test is governed by how fast the system settles down. The fast dynamic response is also very useful to detect slugging conditions and to optimize the gas lift in gas lifted wells.

9 SUMMARY AND FUTURE WORK

The three Vx multiphase flowmeters on Heidrun have been working since commissioning this year, however, due to insufficient PVT data the accuracy is not yet according to specifications. To amend this situation one will:

- Get PVT analysis data for the three wells where the Vx multiphase flowmeters are installed.
- Include coriolis measured density into the data read from the coriolis meter.
- Use the PVT analysis to calculate sufficient PVT parameters to allow for conversion between Vx and TSP conditions, or from Vx and TSP to standard conditions.
- Perform longer test runs for a better comparison between the test separator and the Vx multiphase flowmeter.
- Investigate any significant fluctuations in separator liquid flow rates to establish their cause and the influence on the measurements.

When the multiphase flowmeter is finally configured they will provide valuable information regarding GOR, WLR and rates to the production engineer. In fact, they do provide useful information as they are operated today since the relative changes are clearly shown.

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.