

Paper 8.2

Validation and Operational Experience of a Dualstream II Wet Gas Meter in a Subsea Application on the Statoil Mikkell Field

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1. ABSTRACT

Wet Gas flow measurement has now been utilised on many projects over the last decade. Early systems required frequent well testing to enable corrected gas and liquid flow rates to be generated however over more recent years the drive to remove the requirement for well testing has led to the development of 'intelligent' wet gas metering systems.

In subsea applications the need to remove well testing requirements cannot be overstated and the use of a proven 'intelligent' measurement technology for royalty allocation may be the only economically viable route for a project to proceed. During 2003 Statoil validated, commissioned and put into operation two Solartron ISA Dualstream II meters for subsea allocation purposes on the Mikkil Field. Mikkil is a gas condensate field located 80 km south-east of the Åsgard field. The Mikkil field is connected to the 'mother' platform via a subsea tie-in to the existing flowline from the Midgard field. The meters are installed at a depth of approximately 220m. The "mother" platform is Åsgard B.

Dualstream II meters have been utilised on several applications to date so this paper will focus primarily on the measurement issues relating to meter validation at a wet gas test facility, commissioning, and also the testing carried out once the meter was installed subsea with reference to the methodologies used and the accuracy obtained.

Operational experience to date will be discussed particularly with respect to meter reliability and hydrocarbon mass flow rate accuracy achieved. Because of the tie-in to the existing flowline from Midgard the verification of the Dualstream II meters is challenging and is based on a 'by difference' method using topside instrumentation. In addition we will discuss how the dual redundant instrumentation and hydrate prevention measures, normal operational requirements in subsea applications, can impact measurement uncertainties

2. BACKGROUND

2.1 Mikkil Project

The Mikkil field development consists of a sub-sea production system tied back to an existing processing platform, Åsgard B, via the Midgard Z template and the 20" production flowlines from Midgard, as shown in Figure 1. The Mikkil well stream is commingled with the well stream from Midgard Z and routed to Åsgard B for processing. Stable condensate and rich gas are the export products from Åsgard B

Gas is exported together with Åsgard gas to the Åsgard pipeline and brought onshore at the Kårstø terminal near Haugesund. At Kårstø onshore gas terminal NGL is recovered. The stable condensate is exported with Åsgard condensate by Shuttle tankers via the Åsgard C storage.

2.2 Mikkil Metering concept

The Mikkil field can never produce without having a minimum production for the Midgard field. This is due to problems with hold up of liquid in flowlines. Liquid hold up will increase the danger of slugging and hydrate formation. This is the background for developing a reliable sub-sea wet gas metering system for allocation purposes and as a basis for a topside 'by difference' calibration method using topside metering points

Two Dualstream II meters are deployed, one on each of the two Mikkel subsea templates, to measure the total fluid stream that exists at the templates.

The corresponding Mikkel hydrocarbon stream is calculated by subtracting any measured glycol and any calculated or measured water from the total fluid stream. This is carried out within the Dualstream II computer system. Gas and liquid densities at operating condition used in the flow calculation, are calculated by a PVT package provided by Calsep, in a subroutine in the Dualstream II computer

On each of the three wells, which feed the two Mikkel templates, multiphase meters are installed for well monitoring and well allocation. The multiphase meters will be used for water detection meters and as extra back up should the Dualstream II meters fail.

Periodic meter validation is carried out against reference meters located on the Åsgard platform. The primary gas measurement is carried out using a 14" V-Cone meter together with 4" orifice plate meters on the condensate/MEG separator. A 6" Danfoss Ultrasonic meter and 2" Danfoss Coriolis meter are provided for condensate and water/MEG metering respectively. Density measurement is carried out using Solartron 7812 and 7835 densitometers. All instrumentation used for Dualstream II validation are calibrated at a traceable laboratory to a known uncertainty.

The reference flow calculations from the 14" V-cone, 4" orifice, 6" USM and 2" Coriolis, are performed in the Simrad PCDA system. Logging and data storage from both the Dualstream II meters and the reference flowmeters are carried out on 5 minute and 30 minute average intervals. Historical data is available through the HIS and EpView package for Åsgard B.

The Dualstream II data is collated and the flow calculations conducted in a dedicated flow computer. In addition raw data and calculated figures are exported to an Excel spreadsheet.

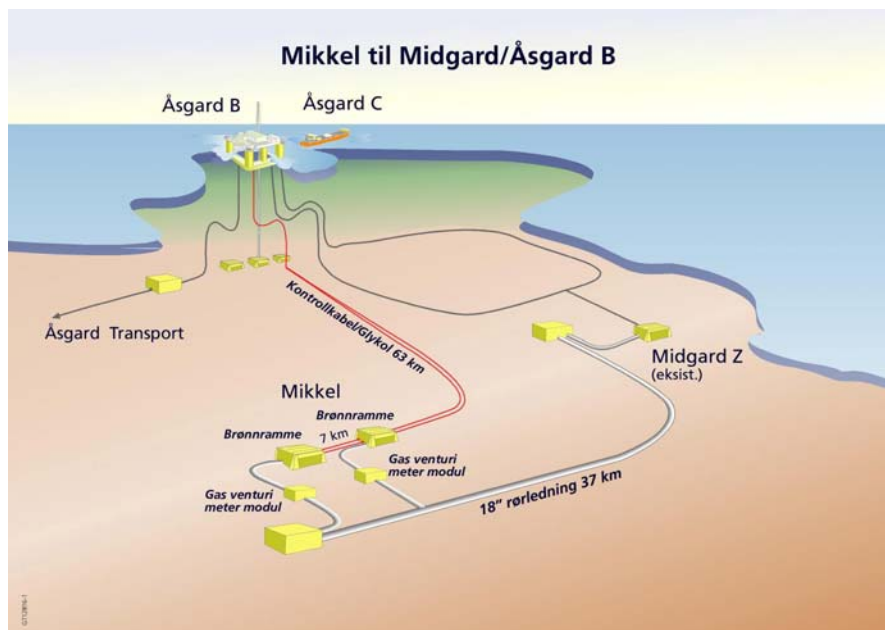


Fig.1 Mikkel tie-in to Åsgard B

2.3 Dualstream II meter concept

Small quantities of liquid in a gas stream will generally cause a differential pressure based flow meter to yield a gas flow rate in excess of the true value. However, if the liquid rate is known then several correlations have been proposed that can be used to correct this erroneous reading. In traditional wet gas systems, correlations by Murdock [1], Chisholm [2] and De Leeuw [3] are now commonly used for allocation applications. In applications where

well test facilities are not readily available, most commonly in subsea applications similar to the Mikkell project, 'intelligent' wet gas meters are now often requested.

The Dualstream II was developed as an 'intelligent' wet gas meter and was the first meter capable of generating both gas and liquid flow rates on-line. The system was developed in conjunction with Advantica Technologies (formerly BG Technology).

The Dualstream II uses the concept that if two devices exhibit different over-read characteristics then two simultaneous equations exist that can be used to determine the liquid fraction. The meter is a combination of a mixer, venturi and wedge device. The venturi provides a primary gas measurement or indicated flow rate (Q_{gi}) whilst the combination of venturi and wedge devices generate a gas mass fraction for implementation within the wet gas correction algorithm.

3. METER CALIBRATION & VALIDATION

3.1 Dry Gas Calibration

During manufacture Dualstream wet gas meters are routinely calibrated on single phase hydrocarbon gas at the Advantica calibration facility near Bishop Auckland to determine the discharge coefficient for the meter. The reasons for this are well established following a notorious calibration of wet gas meters in the early 1990's[4]. In addition the Mikkell project wanted to confirm meter and transmitters performance at that stage in the project.



Fig. 2 Dry Gas calibration at Advantica, UK

3.2 Wet Gas Calibration & Validation

Once manufacture was complete a meter was sent to the K-Lab wet gas test facility in Norway for validation testing. The meter was validated at pressures of 80 Bara and 105 Bara using hydrocarbon gas, condensate and water.

Initially the meter was given an approximate calibration using preliminary algorithms which represented Solartron ISA's best estimate of meter performance at the range of gas densities expected. This estimate was based on previous observations of meter performance at a number of test loops with various fluids and gas densities. The meter to be tested was 10inch diameter (ID 215.86mm), whereas prior to these trials no Dualstream II greater than 6inch (ID

146.33mm) had been calibrated on a test loop. Also it was understood that the large capacity of the loop (up to ~ 2000Am³/h) and the genuine three phase functionality (condensate and water separately injected into the line) would allow the meter to be exercised over a large range of superficial gas velocities (Vgs) and liquid densities. Consequently it was expected that the calibration would need to be refined in the light of the data obtained. The full test matrix is shown in figure 3.

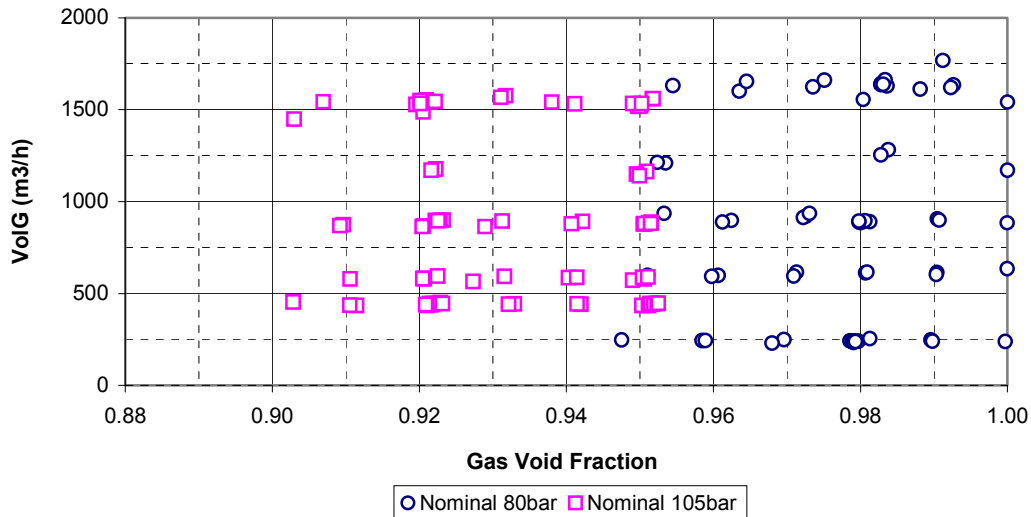


Fig. 3: The complete test matrix performed at K-Lab.

To give an understanding of the evolution of the final algorithms a summary of the performance of the preliminary algorithms during these trials, is shown below. The error plots refer to total hydrocarbon mass flow as this is the parameter of primary interest to Statoil. Figures 4 to 7 below show the performance as a function of superficial gas velocity, gas Froude number and gas and liquid densities respectively.

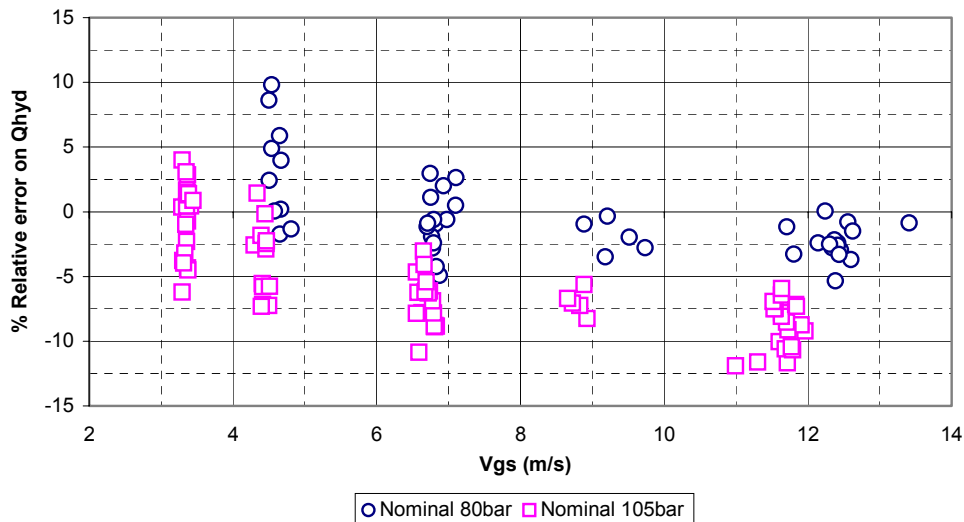


Fig. 4 Performance of the preliminary algorithms as a function of superficial gas velocity.

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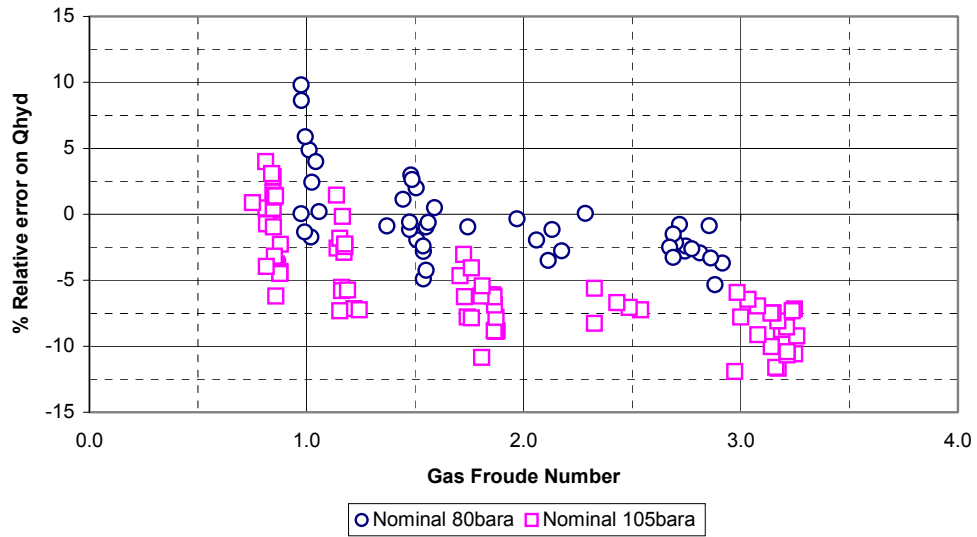


Fig. 5 Performance of the preliminary algorithms as a function of gas Froude number.

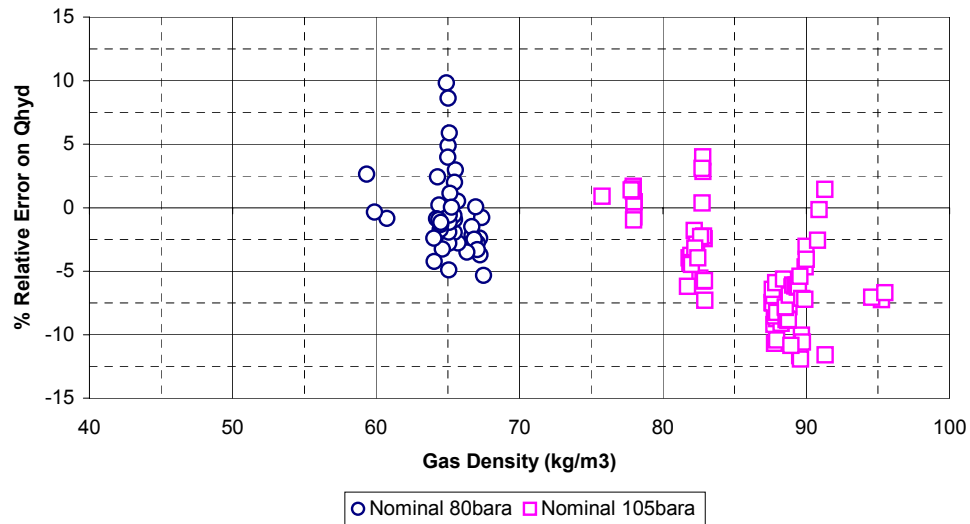


Fig. 6 Performance of the preliminary algorithms as a function of gas density.

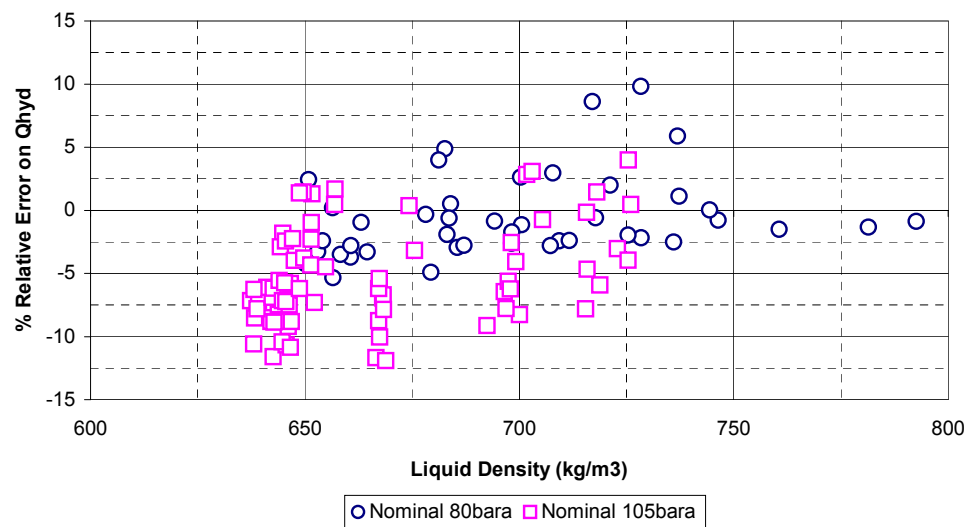


Fig.7 Performance of the preliminary algorithms as a function of liquid density.

Although much of the 80 Bara data is within 5% some of the points have larger errors. Larger errors were observed at 105 Bara. It can also be observed that the errors are not independent but clearly correlated with each of the variables considered to a lesser or greater extent. The most pronounced effect is that of superficial gas velocity and/or gas Froude number. The dependence upon liquid density is less pronounced but still quite clear. Gas density is actually included in the model used for the preliminary algorithms and so would not be expected to correlate with the measurement error. At the low density end this seems to be the case, although the level of scatter caused by other parameters does complicate the picture. At the high density end there seems to be a clear dependency upon gas density. This probably reflects the quality of calibration data previously available at the different gas densities.

To further investigate the dependency upon superficial gas velocity and the gas density in more detail further testing was carried out by varying only one parameter at a time. This was done by holding pressure and gas flow rate constant whilst a batch of test points was performed by varying liquid flow rate only. Due to practical limitations of the loop, the gas flow rate (and pressure) tended to drift by small amounts between test points. This is likely to contribute to scatter on the calibration plots generated and also complicates the development of the improved algorithms.

3.2.1 Refined Algorithms

Because of the multi-variable dependency of the calibration it was necessary to use an empirical approach to optimising the algorithms. The refined algorithms were obtained by using the preliminary algorithms as a starting point and then introducing correction factors to allow for the effects of gas density, liquid density and flow rate and gas Froude number.

The performance of the refined algorithms is shown in the following plots. Fig 8 is a conventional error plot for a wet gas meter of error vs. GVF. Meter performance is generally independent of GVF at the high GVF end, although a bias is apparent at the lower GVF end. Figure 9 through to Fig 11 show the error as a function of gas Froude number and phase densities. It can be seen that there is very little residual bias caused by any of these variables.

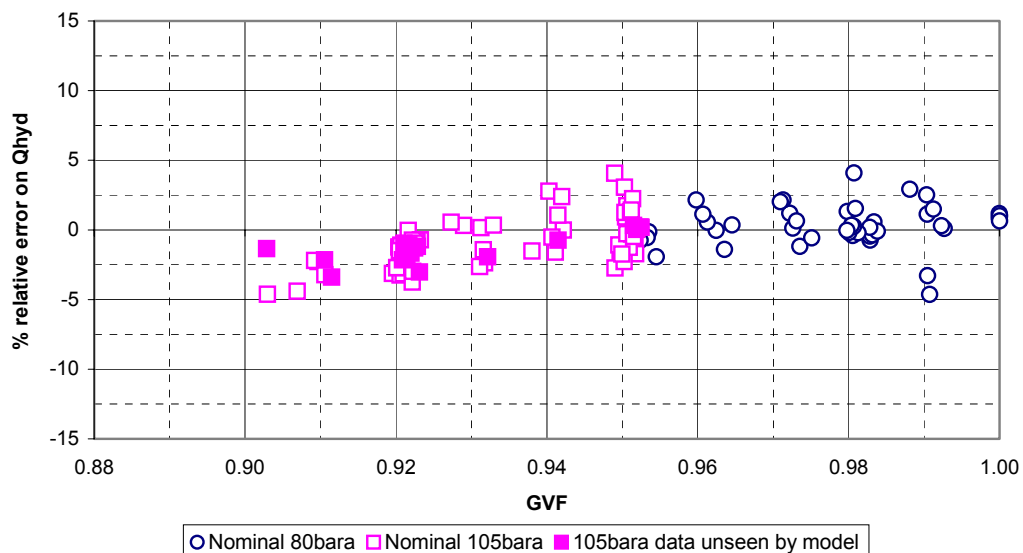


Fig. 8 Error on total hydrocarbon mass flow vs GVF for the refined algorithms

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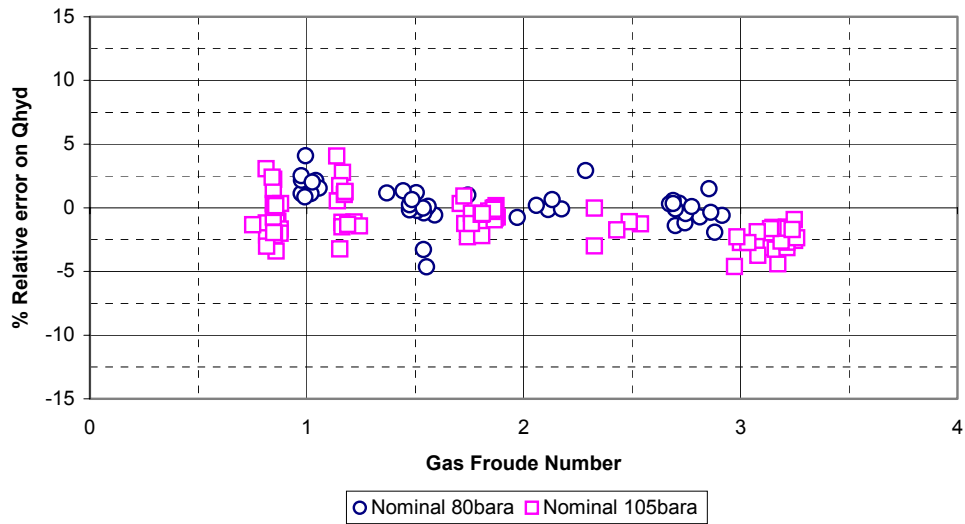


Fig. 9 Error on total hydrocarbon mass flow vs FrG for the refined algorithms

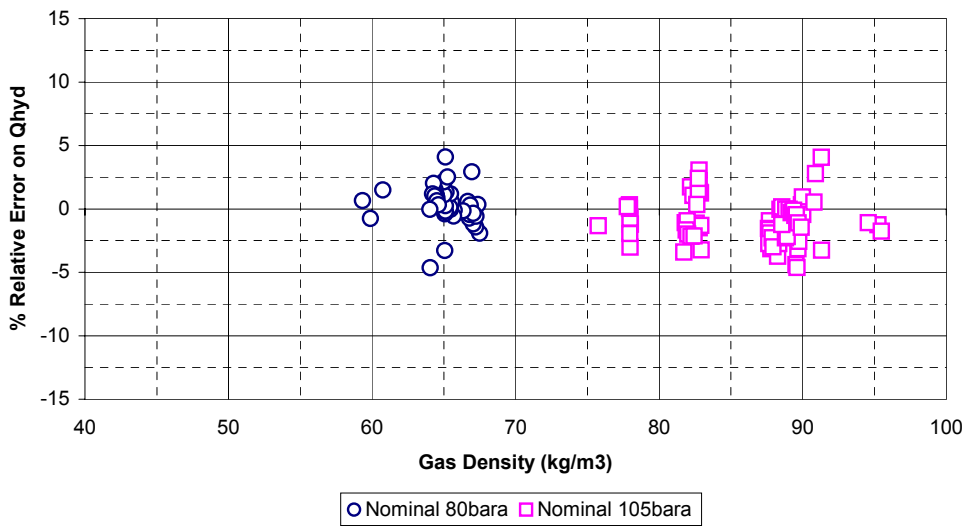


Fig. 10 Error on total hydrocarbon mass flow vs gas density for the refined algorithms

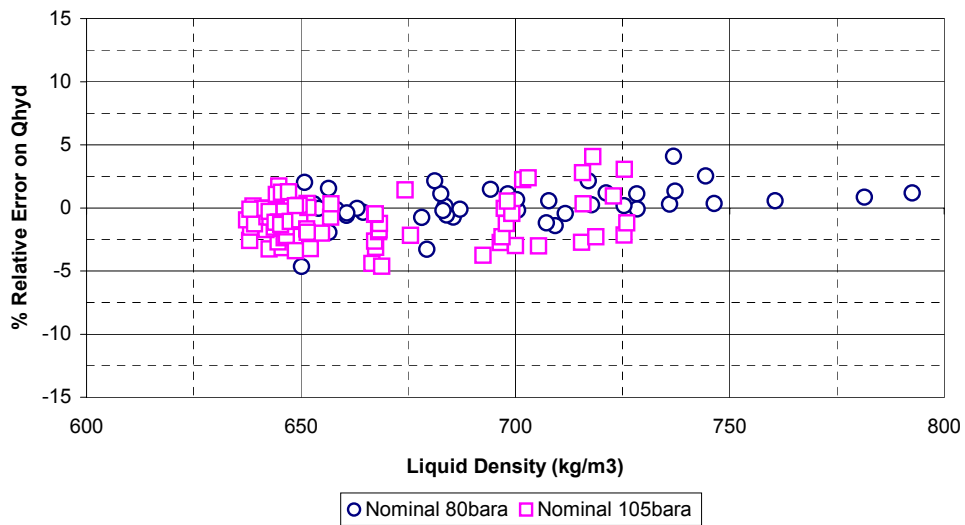


Fig.11 Error on total hydrocarbon mass flow vs. liquid density for the refined algorithms

On completion of the revised algorithm uncertainty on total hydrocarbon mass flow measurement was reduced from 5 -15% down to 2.5 - 5%.

4. IN-SITU VALIDATION

The two Dualstream II meters are used as allocation meters for the Mikkell field. The agreement between the Mikkell group and the Asgard A group for the tie-in and processing of the well stream is that a validation of meter performance should be carried following start up and after 6 months production. Production started on 1st October 2003 therefore the 6 month evaluation was carried out in April 2004.

4.1 Test Method

Both Dualstream II meters are tested in series with the reference topsides meters on Asgard B. Tests are carried by a 'by difference' method against the Midgard wells Y1, Y2, Y3 and Y4.

Midgard wells Y1, Y2, Y3 & Y4 are used as the baseline through a linear relationship between WHP and flow rate from a three point check against the topside reference meters. A simulation tool (OLGA) has been used to establish the expected stabilisation time.

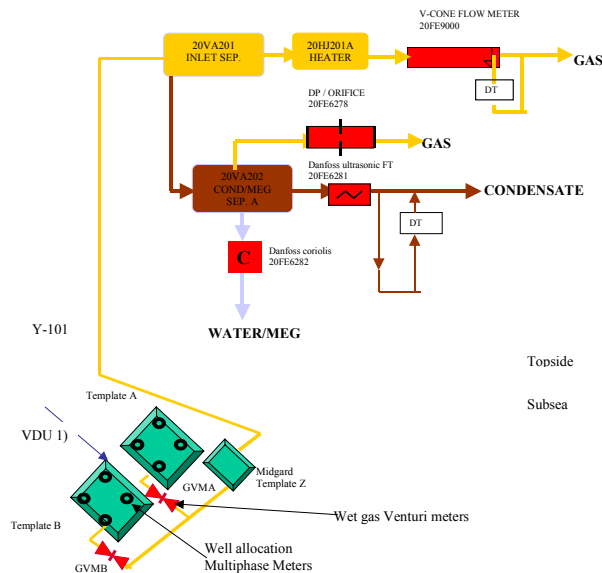


Fig. 12 Validation Schematic

One of the most difficult yet important conditions is to ensure stationary conditions through the test for the logging period. These include :

- Mikkell wellhead
- Midgard Y template including wellhead instrumentation
- 37km 18" Mikkell pipeline
- 53km 20" Midgard pipeline
- Topsides systems including heating, regulation and metering.

To ensure the system was stable a set of parameters have been established. These are:

- Minimum flush twice the time for liquid transport from the last disturbance
- Mikkell reading from sample periods to be stable within predefined limits
- Each sample period shall be of minimum 1 hour
- 3 sample periods shall be within predefined limits during a total approved test period for minimum 6 hours
- Midgard WHP readings to be stable within predefined limits
- Pressures at Midgard manifold, Mikkell manifold and upstream topside choke to be stable within predefined limits
- MEG/Water topside readings to be within predefined limits

Throughout the test period MEG is injected at a constant rate. If no MEG/water accumulation occurs in the pipeline, stable readings should be found on the topside MEG/water meter.

4.1.1 Midgard Flow Rate calculation Method

To enable the 'by difference' to be utilised it is of prime importance to have a stable and accurate method of determining flow from the original Midgard well stream. The following method was developed to determine the Midgard inflow rate.

- There is little variation of WHP on Midgard, typically 162-164 Bar. A linear relationship is therefore assumed between the WHP and well volume and mass flow rates within a small WHP interval, see typical example in figure 13.
- Three test points have been assumed to establish a correlation between the Midgard WHP and the well HC mass flow. Linear regression (Root Mean Square) is used.
- Theoretical production from well performance curves have been used to establish the relative flow rate from each Midgard well for the three test points.
- Midgard well streams are considered to have the same composition.
- The upper WHP point was established to investigate the 'back-off' from the Midgard wells due to different pressure in the flowline while Mikkel was producing and hence a slight reduction in Midgard production.
- 'Back-off' investigated with production from Midgard alone and production metered topside .

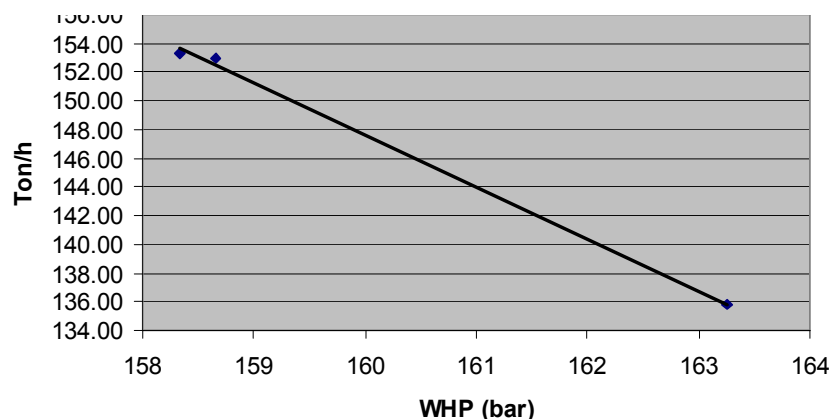


Fig.13 Typical correlation between WHP and mass flow

4.1.2 Mikkel reference HC flow rate calculation

When stable conditions have been established according to criteria described in 4.1 and 3 stable periods of minimum 1 hour from a stable period of minimum 6 hours have been recorded, the average flow rates are used from the following locations to calculate the Mikkel HC mass flow rate.

- a) Topside gas flow from inlet separator
- b) Topside gas flow from condensate/meg separator
- c) Topside condensate flow from condensate/meg separator
- d) Midgard well Y1 flowrate based on WHP formulae
- e) Midgard well Y2 flowrate based on WHP formulae
- f) Midgard well Y3 flowrate based on WHP formulae
- g) Midgard well Y4 flowrate based on WHP formulae

Mikkel reference HC flow rate = a+b+c-d-e-f-g

4.2 Uncertainty on Mikkel flow rate

The following input parameters have been used in the uncertainty evaluation of the Mikkel reference flowrate. The analysis is based on the 2.9 millSm³/d from Mikkel.

The uncertainty calculations are based on figures from suppliers and recognised principals and the full analysis will not be covered in this paper.

	Uncertainty term	St. uncert (k = 1)
1	Gas out 14" V-cone -	0,25 %
2	Cond. out 6" USM -	0,50 %
3	Gas out of 4" orifice -	0,80 %
4	Repeatability topside HC -	0,30 %
5	Approximation method for Midgard flow calculation	0,45 %
6	Non stationary conditions in pipeline - Midgard alone	0,30 %
7	Non stationary conditions in pipeline - Mikkel & Midgard	0,20 %

- 1) Includes the effect of non-linearity and drift in V-cone, densitometer, DP, P and T readings.
 - 2) Includes the effect of non-linearity and drift in the flowmeter- (USM) and densitometer-system.
 - 3) Includes the effect of non-linearity and drift in the flowmeter and associated instruments.
 - 4) Based on actual readings of total HC throughout the 6 hour test-period.
 - 5) Includes the uncertainty in the assumptions of linear relationship between WHP and flowrate.
 - 6) and 7) Includes the uncertainty of stationary pipeline conditions throughout the test period. This effect has been included due to the small observed pressure changes in Midgard Y manifold and in 20" production flowline upstream topside choke, during the test. The changes have been in the order of 0.05 - 0.25 bar/6hour. A pressure change of 0.15bar / 6 hour corresponds to a pipeline inventory change of 1 t/h.
- Based on the above input, the uncertainty (k=2) in the Mikkel reference figure has been estimated to be approximately 2.5 – 3.0 %.

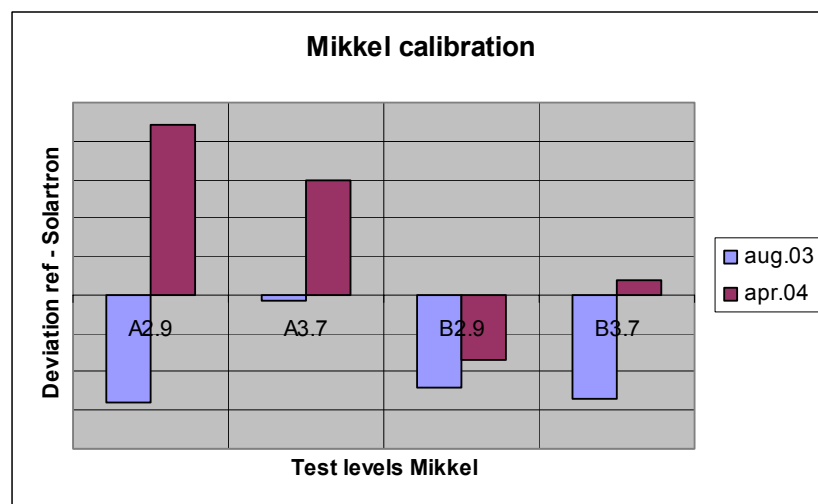


Fig. 14 Deviation from reference

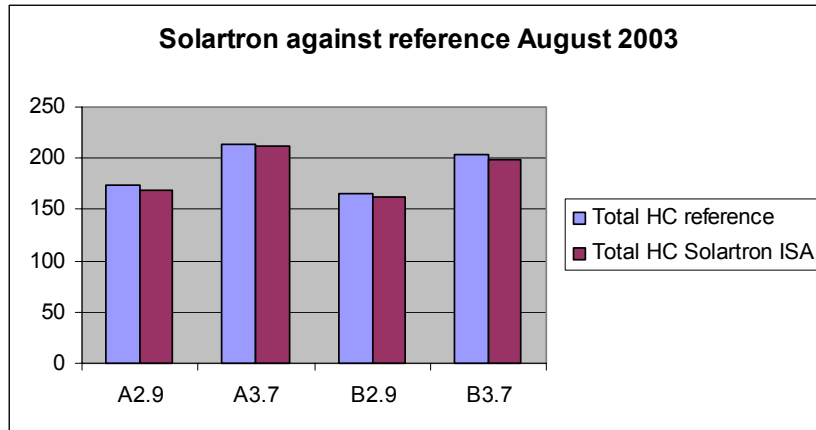


Fig 15. Error against Reference 2003

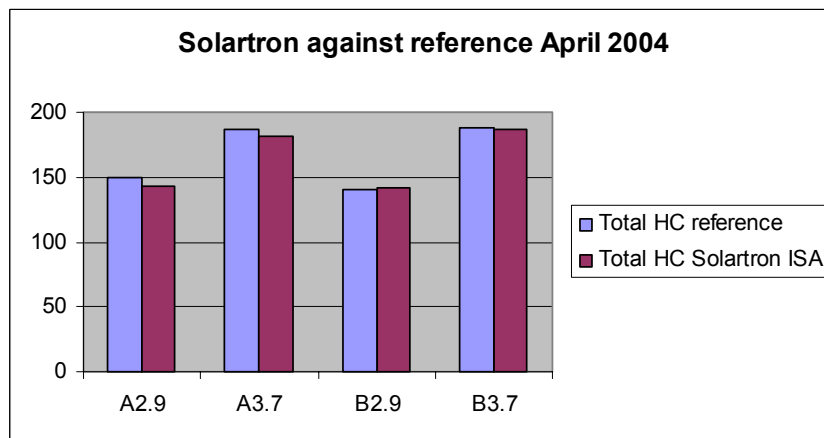


Fig. 16 Error against reference 2004

Fig. 14 through 16 above summarise the in-situ validation results carried out in August 2003 and April 2004. All test points have been within the limits set out between Mikkell partners.

5. OPERATIONAL EXPERIENCE

5.1 Hydrates

All known wet gas meters to date rely on a DP device as the prime measurement. Tapping and impulse lines, due to their small diameters and the cooling effect created by a large mass of cold water, are a prime target for hydrate creation.

The wet gas test and validation process on these meters was carried out at Kårstø (K-Lab) during November/December 2002. Even though special care had been taken during design to minimise the effect of hydrates the cold ambient weather was sufficient to generate hydrates in the impulse lines.

When in service only one meter would see hydrate inhibitor. It was therefore concluded between all parties, including FMC the subsea system supplier, that an insulation material would be applied to the meters to further minimise any impact during production.

The insulation material used was installed not only on the impulse lines but also around the flow line. A heat conductive core was utilised to transfer heat from the flowline to the impulse lines. See fig 17,18.. Once installed a series of cold water soak tests were carried out to evaluate effectiveness prior to installation subsea.



Fig. 17 Before and after insulation.



Fig. 18 Hydrate simulation tests after insulation installation.

Even with these precautions hydrates have been experienced in the impulse lines at start up of production. These hydrates eventually defrost once the flowline has reached the operating temperature, however it can take up to 40 hours for this process to complete.

5.2 Redundant Temperature transmitters

The meters on Mikkil are supplied with dual instrumentation. This is to limit the requirement of costly intervention once the meters are installed on the sea bed and is common practice on most subsea meters. Some Deepwater meters have been installed with triple instrumentation.

The temperature transmitters installed on the Mikkil meters are dual pressure and temperature types. These are non-intrusive sensors mounted between the mixer section and venturi. Both meters have two temperature measurements. As expected differences are seen between transmitters on each meter, however on one meter a discrepancy of 15DegC can be observed. This temperature gradient does not appear to be a malfunction of the transmitter. It is therefore considered that the cooling effect of the seawater is affecting the process temperature at the point of measurement.

Dato/tid	TT1 GVMB	TT2 GVMB
22.09.04 01:00:00	39.12107	54.06599
22.09.04 01:30:00	38.99308	54.00866
22.09.04 02:00:00	39.15671	54.08564
22.09.04 02:30:00	39.16749	54.1033
22.09.04 03:00:00	39.13367	54.11478
22.09.04 03:30:00	39.24527	54.1655
22.09.04 04:00:00	39.20495	54.14516

Fig. 17. Data logger extract for temperature sensor TT1 & TT2

A 15 degree error in temperature measurement will broadly speaking lead to a 5% error in density measurement with a resultant 2% error in gas flow rate. By evaluating other local temperature measurement sensors and through a thermal modelling process sensor TT2 is considered to be accurate and is therefore used in the calculation process.

This phenomenon highlights the difficulties in high accuracy measurement in subsea applications and the obvious potential impact on expected uncertainties. Further evaluation is ongoing.

6.0 CONCLUSION

The Mikkell Dualstream II meters have now been operational for almost 12 months. To date they have provided a reliable and accurate source of data for allocation purposes and are within the uncertainty criteria between the various partners.

'Intelligent' wet gas meters are replacing traditional methods of measurement, however the resultant difficulties in validating performance once in the field are clearly seen on this project. A methodology, although complex, has been established which does enable validation to be carried out without the need for discrete well test equipment for the Mikkell field.

The testing carried out prior to installation has assisted in the development of more robust algorithms now used in the second generation Dualstream II meters proposed on future projects.

The issues raised relating to hydrate formation in impulse lines has been negated by retrofitting insulation however it demonstrates how seriously hydrate issues should be taken when differential pressure devices are used on wet gas applications.

7. NOTATION

Q	Mass Flow rate
x	Gas Mass Fraction
X	Lockhart-Martinelli Parameter
D	Pipe Diameter
β	Beta Ratio
g	Acceleration Due To Gravity
V_{gs}	Superficial gas velocity
ρ	Density
M	Murdock Coefficient
c	Murdock Offset
C	Chisholm Constant
\tilde{C}	De Leeuw 'Constant'
HC	Total Hydrocarbon

Subscripts

<i>g</i>	Gas
<i>l</i>	Liquid
<i>gi</i>	Indicated Gas
<i>gc</i>	Corrected Gas

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