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USE OF A SUBSEA MULTIPHASE FLOW METER IN THE.WEST BRAE/SEDGWICK JOINT DEVELOPMENT.

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1. INTRODUCTION

The West Brae/Sedgwick joint development in the Brae area of the Central North Sea came onstream in October 1997 and is currently producing in excess of 35,000 barrels per day. The joint field development comprises a single Sedgwick production well tied back to the West Brae subsea manifold, where commingled flow is piped to the Marathon operated Brae 'A' platform. There, Sedgwick and West Brae fluids are processed for onward transportation through the Brae and Forties pipeline systems. Under the terms of the Joint Development Agreement, production is allocated 67.5 per cent to the Brae Group and 32.5 per cent to the Sedgwick Group

This paper outlines the development of the project and discusses in detail the performance of the Framo subsea multiphase meter both in terms of its long term repeatability and in terms of its accuracy when compared with the host platforms measurement systems.

2. THE WEST BRAE/SEDGWICK FIELDS AND INFRASTRUCTURE

The West Brae/Sedgwick fields are just two of 20 fields that use the Brae area infrastructure. This is based on three platforms interconnected by gas and oil pipelines and an electricity ring main system to provide processing and export routes for oil to the Forties system and gas to the SAGE system.

2.1. West Brae/Sedgwick fields

The West Brae/Sedgwick fields are located 160 miles North-Northeast of Aberdeen in 350 feet of water and are comprised of two hydrocarbon bearing sands, the Balder and the under lying Flugga. Sedgwick is located in a block adjacent to West Brae and was initially thought to contain a separate accumulation from West Brae. However subsequent drilling has shown that continuity exists at least in the Balder horizon.

Both the Balder and the Flugga are turbidite deposits composed of well sorted, fine grained sands with permeability's in the productive areas in excess of 2000 millidarcies. The Balder is a saturated system with an extensive gas cap overlying the West Brae portion of the field. Water is being injected into the Balder.

The field is drained using horizontal wells with a horizontal section of up to 3000'. The reservoir sand is not competent and sand control is achieved by the use of a sand screen.

Fluid properties are:

- Oil density 890 kg/m^3 (27.5 API)
- gas-oil-ratios (GOR) 250 scf/stb
- In situ oil viscosity's are 3 to 5 centipoise.

At the seabed where the multiphase meter is situated additional fluid parameters are:

- Gas Volume Fraction (GVF) 0.4 to 0.6
- Water Fraction (BSW) 0 rising through field life to in excess of 90%

Recoverable reserves are estimated to be 40 mmstb.

2.2. West Brae/Sedgwick Infrastructure

Fig 1 West Brae\Sedgwick Infrastructure

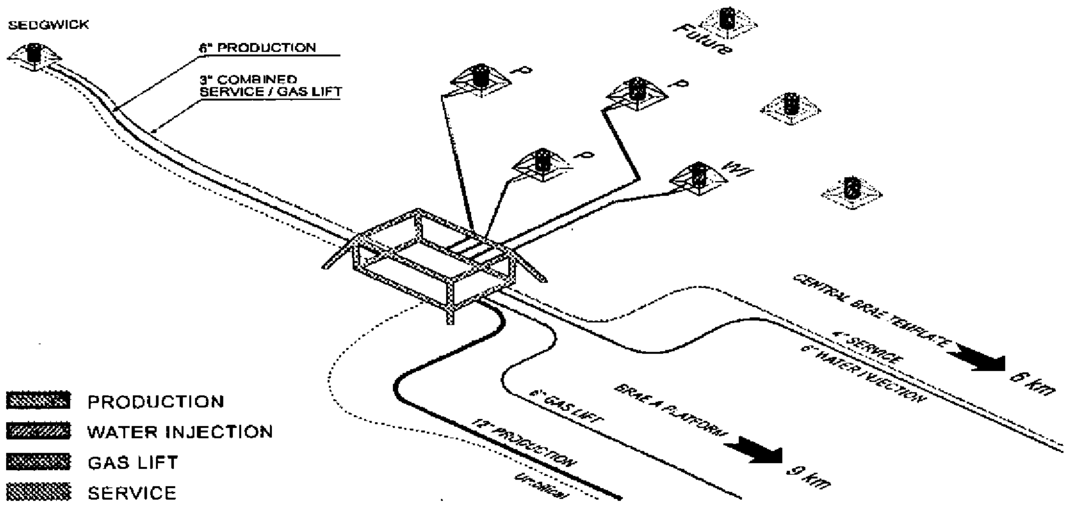


Figure 1 shows the West Brae/Sedgwick Infrastructure, a small part of the Brae area infrastructure. The West Brae/Sedgwick fields are developed using a subsea manifold and well cluster arrangement. The field is essentially ROV friendly but the well tie-ins and any future choke changes require diver intervention. The subsea multiphase flow meter was chosen late in the design of the West Brae/Sedgwick manifold and although the device is of the ROV retrievable type, electrical connections and plating on the manifold would necessitate diver intervention.

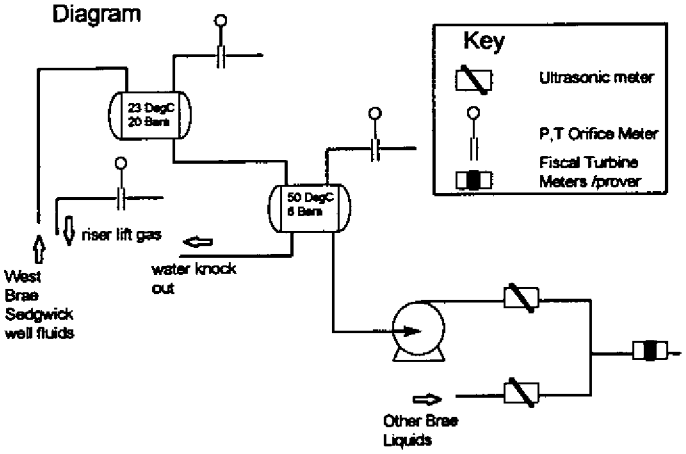
The fields are tied back to host platform (Brae Alpha) which is 8.8 km from the West Brae Manifold. The Sedgwick extension is approximately 2.2 km from the manifold. Gas lift is supplied from Brae Alpha. Water injection and service line facilities are supported from another subsea field (Central Brae) which is approximately 6.2 km from the West Brae/Sedgwick manifold.

3. HOST PLATFORM MEASUREMENT SYSTEMS

Although the Brae A host platform handles numerous fluids from Brae and third party fields, the West Brae/Sedgwick fields have a dedicated process train with full instrumentation. These facilities are described in the following paragraphs.

3.1. Host Platform: Separation and Instrumentation

Fig 2. West Brae/Sedgwick - Simplified Platform Flow Diagram



The West Brae/Sedgwick process train on the Brae A platform (Figure 2) has a two stage separation, with an intermediate electrostatic water separator and oil heater (not shown) to break emulsions anticipated from the fields. The first stage separator is sized to act as a slug catcher.

Gas metering off the separators consists of orifice metering with P,T,Z corrections. These corrections, in addition to ISO 5167 equations, are performed on a continuous basis by the platforms process monitoring computer. ISO 5167 straight length requirements are not fully met.

Riser base lift gas, the only lift gas system commissioned, is used to minimise slugging and improve start up. It is measured in an identical manner to the separator off gas.

Oil metering is performed by an ultrasonic metering tube at the outlet of the booster pump. The tube contains a Danfoss dual path ultrasonic meter and pressure and temperature transducers. A dedicated fiscal standard flow computer continuously computes flow at standard conditions. An identical installation is to be found on the process train handling South and Central Brae production before the two flows are combined and metered by a fiscal export metering package with 4 inch turbine meters and dedicated prover. Typical uncertainty for this later type of fiscal metering is +/-0.25%. Entrained water in the oil is determined by spot samples at the booster pumps and by flow proportional sampling at the fiscal metering.

Water metering from the separators will be by ultrasonic meters to be commissioned when flows become sufficient to measure.

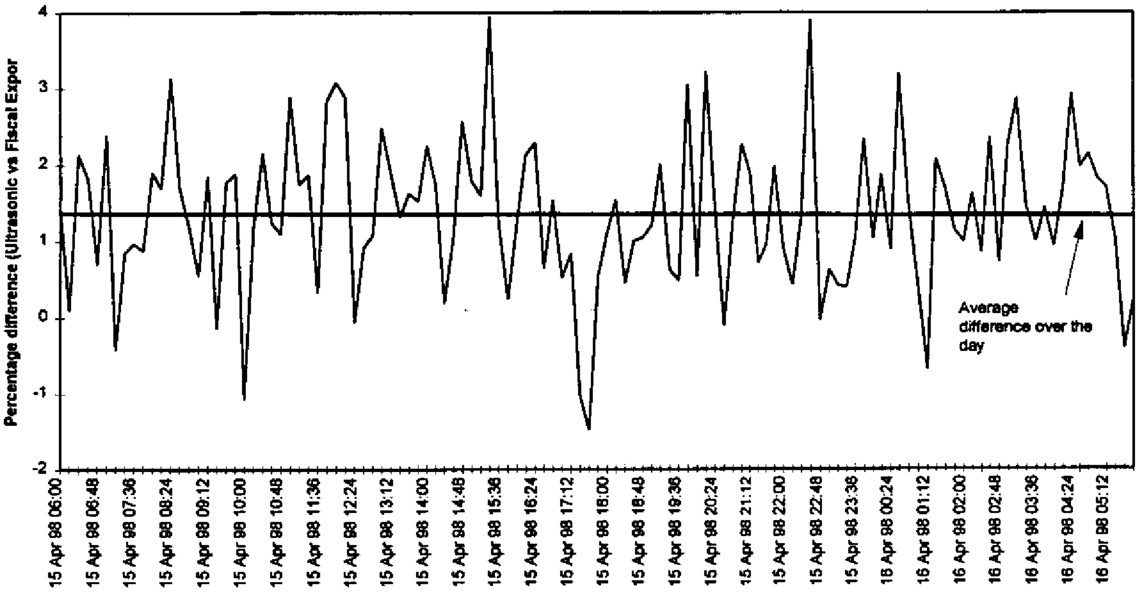
Data produced by the platform instrumentation is gathered by the platforms process monitoring computer. Instruments are scanned at 30 sec to 1 minute intervals. All data presented in this paper are based on 12 minute averages of these readings.

3.2. Host Platform: Performance of Instrumentation

No detailed assessment of the process instrumentation uncertainty is presented. However the oil metering, due to its close proximity to a dedicated fiscal metering package, can be assumed to have an accuracy of +/- 1%. The gas metering on the other hand is assessed as having only a +/-10% accuracy. The following graphs (taken on a typical day) and discussion are made in support of these claimed accuracy's.

Figure 3 below shows the percentage difference between the liquid quantities measured by the sum of the two ultrasonic meters and the fiscal export meters.

Fig 3 Comparison of Ultrasonic Oil Meter with Fiscal Export



The variations in the twelve minute average data points are largely caused by the surging within the process trains and associated pipework. The average difference over the day of 1.3% is typical of the daily balance that has remained within the range 1.1% to 1.5% since start-up.. The Danfoss meters were calibrated on water during factory acceptance tests and are still using their original calibrations with no adjustments. Furthermore, during periods when one of the process trains has been shut in, the balance has remained stable indicating that both ultrasonic meters have the same bias. When, later in this report, a comparison is made between the Framo multiphase meter and the platform ultrasonic liquid meters, account is taken of this bias by reducing the ultrasonic meter reading by the bias relevant for the period of the comparison.

Fig 4 Comparison of Gas Rates During Periods of Varying Lift Gas

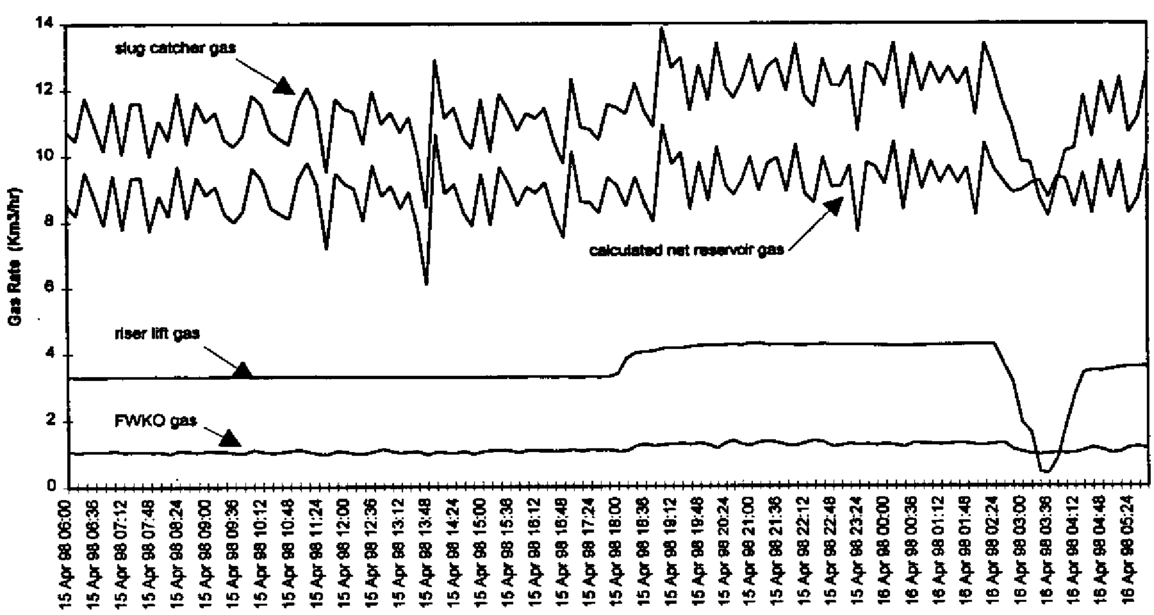


Figure 4 shows the platform measured gas rates over the same twenty four hour period as Figure 3.

The period was chosen to show the effect of riser lift gas on calculated net gas production from West Brae/Sedgwick as riser lift gas rates varied. The calculated net reservoir gas is the sum of the two separator off gas measurements minus the riser lift gas measurement. It can be seen from the graph that the effect of changes in lift gas rate on the calculated net gas are effectively compensated for, allowing the calculated net reservoir gas to be compared with the gas metered by the multiphase meter.

4. FRAMO SUBSEA MULTIPHASE METER

The Framo subsea multiphase meter has been working continuously and reliably since first installed in October 1997. The fluid parameters used in the meter were entered before start-up and were based on exploration data. This data has proved to reasonably reflect that seen during actual production. The Framo meter is capable of using individual data sets for wells with different fluid properties but recorded fluid data to date has shown no variations on a well basis that has necessitated the use of this facility.

Initially the meter was grossly over responsive to the presence of water. This was traced to an erroneous value of the water mass attenuation coefficient, μ_w, set into the meter's software and was corrected some 25 days after commissioning.

The meter's instrumentation was calibrated at the factory prior to delivery and, apart from the correction of the erroneous water mass attenuation coefficient, no onstream adjustments or "calibrations" have been performed.

4.1. Principle of Operation

The Framo meter relies on three principal equations:

- The equation of flow through a differential pressure device

$$\dot{Q}_{total} = C\sqrt{\frac{\Delta p}{\rho_{mix}}} \qquad (1)$$

- The equation relating the dependence of gamma ray attenuation upon fluid mass attenuation coefficients. For a three phase fluid this equation is:

$$N = N_o e^{-x[(\mu_o \rho_o OVF)+(\mu_w \rho_w WVF)+(\mu_g \rho_g GVF)]} \qquad (2)$$

- The equation ensuring that the three volume fractions sum to 1, i.e.

$$OVF+WVF+GVF = 1 \qquad (3)$$

The Framo meter uses a dual energy gamma radiation source and therefore two forms of Equation (2) are established and, in conjunction with Equation (3), are solved simultaneously to give oil, gas and water fractions OVF,GVF and WVF.

Having established volume fractions a mixture density is calculated for use in Equation (1) to determine the volume flow at metering conditions.

Constants used in the above equations are based on the configuration of the instrument (physical dimensions), and the characterisation of the three fluid components in terms of density and mass attenuation coefficient. For water this latter coefficient is predominantly a function of salinity.

4.2. Conversion of Measured Fluid Rates to Platform Conditions

The fluid rates for the three phases measured by the multiphase meter are at metering conditions. For a true comparison with platform measurements three corrections have to be made, viz.

- A correction to allow for the fact that at platform separator conditions some of the liquid will be evolved as gas (liquid shrinkage) ;
- A correction to convert fluids metered subsea to standard conditions of pressure and temperature (1 bara and 15°C) as used by the host platform metering systems, and;
- A correction to allow for the fact that wells manifolded to the subsea meter experience an increased back pressure and resultant drop in flow rate when compared with when they are manifolded directly to the flow-line.

A liquid shrinkage factor was obtained by using the process simulation software HYSIM™. The simulation was fed by a well stream analysis based on extensive fluid sampling and analysis. Fluid components analysed included N2, CO2, C1, C2, C3, iC4, nC4, iC5, nC5. The hexane plus was characterised in weight percents by a 16 cut distillation analysis with cut properties of density and molecular weight determined. A liquid shrinkage factor of 0.96 by volume and a corresponding gas factor of 1.36 were obtained from the simulation. These factors have been used to correct the rates measured by the multiphase meter and allow a direct comparison with the host platform flow measurements.

Normally the West Brae/Sedgwick wells are routed on an approximately weekly basis through the Subsea meter while the remaining wells continue to flow straight from the well to the 12 inch flow-line and on to the host platform for that week. Wells are never started while manifolded to the multiphase meter to avoid possible hydrate damage. When a well is routed to the subsea meter test manifold the back pressure on the well increases causing the flowing bottom hole pressure, as measured by down hole gauges, to rise by 0.1 to 2.2 psi depending on the well and flow rate. From a knowledge of the productivity indices of the wells a good estimate of the reduction in flow rate seen by the meter when compared with the host platform measurement has been calculated and corrected for in the comparison recorded below. The reduction in flow rate when a well is routed through the subsea test manifold is estimated to be 3% on average.

5. COMPARISON OF SUBSEA METER WITH HOST PLATFORM MEASUREMENTS

It would have been ideal to have a dedicated test flow-line from the subsea flow meter to a dedicated test separator on the platform to create a comparison. However, this would have defeated the cost saving intent of installing the subsea meter in the first place. West Brae/Sedgwick wells have been quite stable and therefore the comparison made in this section, between the host platform measurements and the sum of the subsea meter's individual well measurements, is a useful comparison in the absence of the ideal situation.

In order to try and form a comparison between the subsea multiphase meter and the host platform measurements the platform staff were instructed to put each of the four West Brae/Sedgwick wells through the subsea meter over a twenty four hour when the platform process was stable. Except for this instruction the day may be considered to be selected at random and the readings from the platform instrumentation and the subsea meter as typical of the type of data received.

5.1. Comparison of Oil Rates

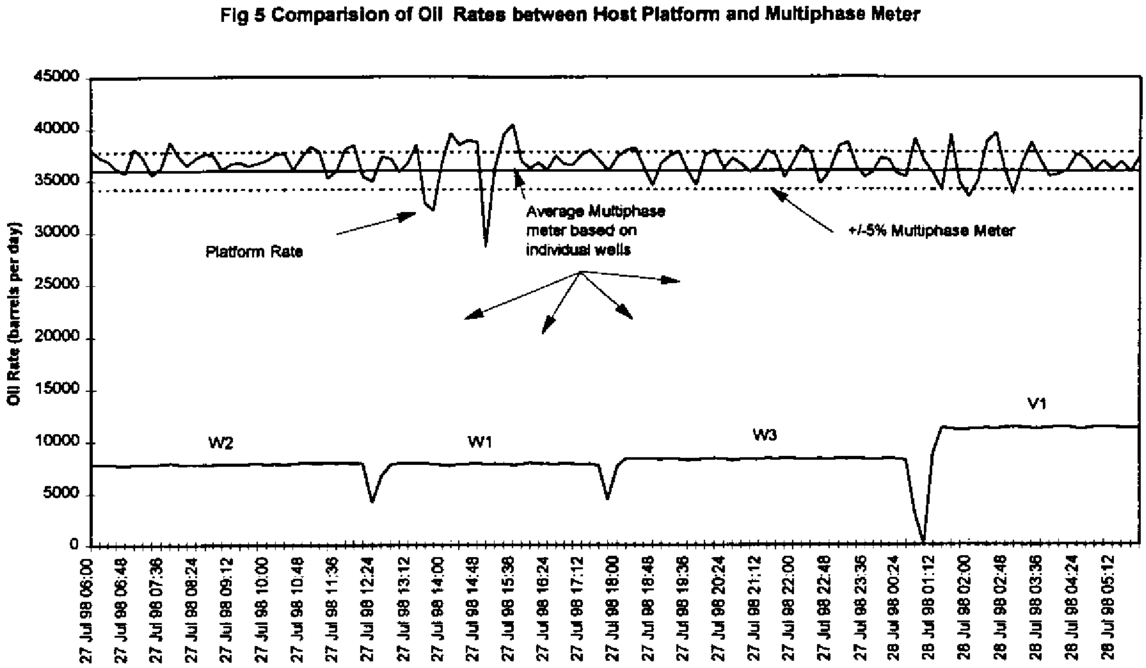


Figure 5 shows the oil flow rates of the individual wells being sequentially put through the multiphase meter for approximately 6 hour periods. Each well can be seen to be steady in rate. The sum of each well average rate while in the multiphase meter is represented by the straight line with +/- 5% dotted deviation limits. The varying platform oil rate over the period is shown. The daily average of the platform oil rate can be judged to be well within 5.0% of the daily average of the multiphase meter.

In the graph the average rate for the sum of the wells through the multiphase meter has been corrected for the effects noted in Section 4.2, while the platform rate has been corrected for the bias in the ultrasonic meter referred to in Section 3.2 and also for an average water cut measured during the day.

5.2. Comparison of Gas Rates

Fig 6 Comparison of Gas Oil Ratios (GOR) between Host Platform and Multiphase Meter

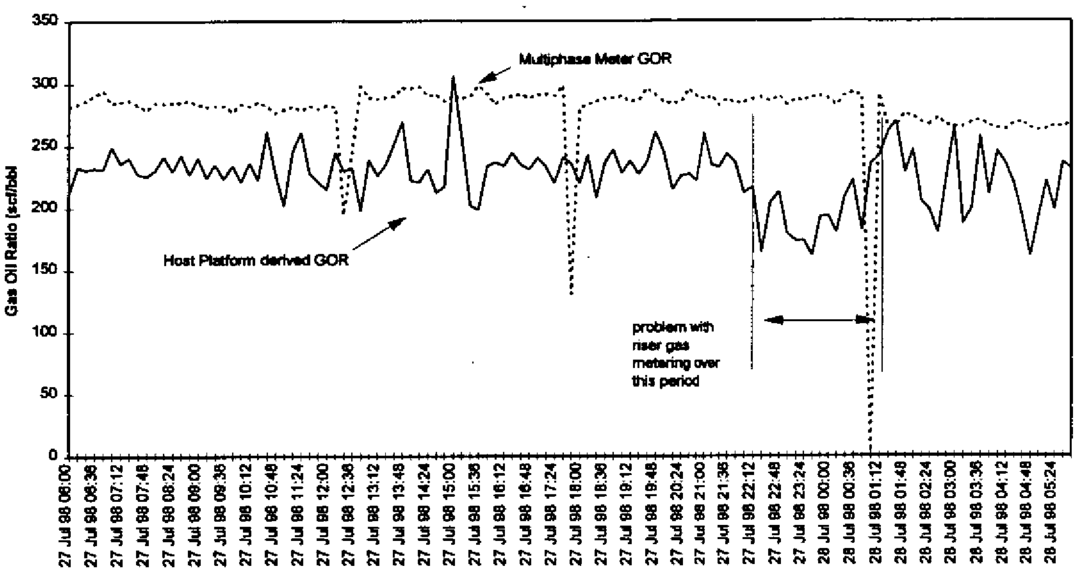


Figure 6 shows the individual well Gas Oil Ratio's (GOR's) as each well is cycled through the multiphase meter over the twenty four hour period. Also shown is the host platforms measured GOR. During an approximately 4 hour period near the end of the day the riser lift gas meter became erratic and therefore the host platform data is suspect over this period.

This apparently large difference in GOR as measured by the multiphase meter when compared with the host platform has not significantly detracted from the usefulness of the meter as a reservoir tool as its long term repeatability, as discussed in Section 6, appears remarkably good.

5.3. Comparison of Water Rates

Fig 7 Comparison of Water Contents (BSW) between Host Platform and Multiphase Meter

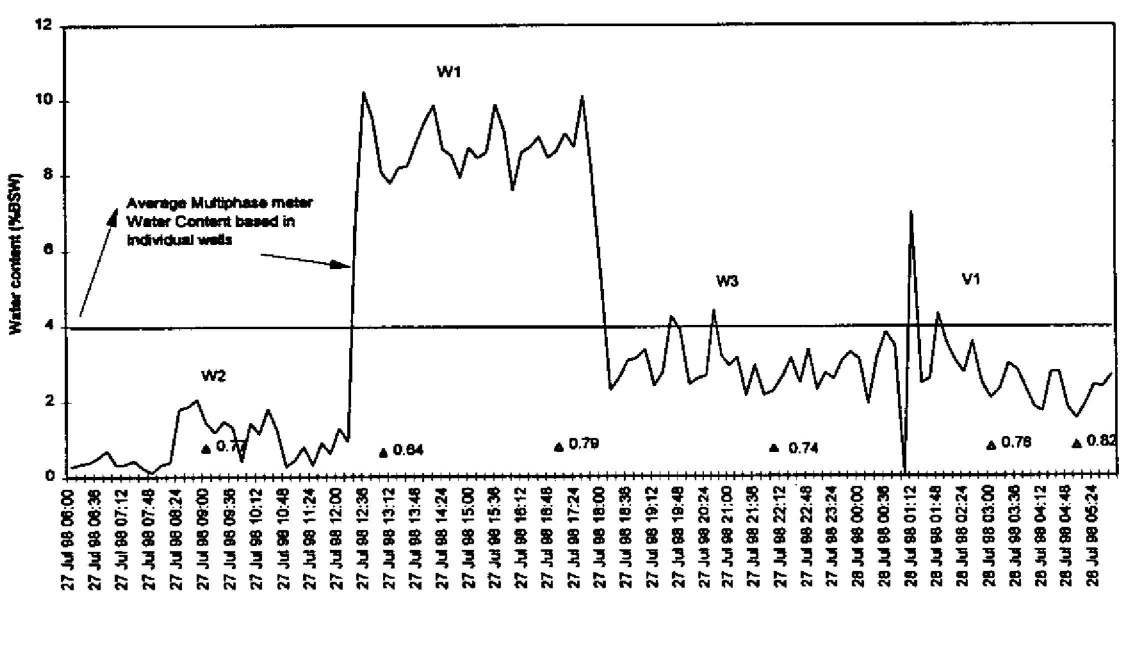


Figure 7 shows a comparison of the average water content determined by the multiphase meter with that of the host platform aggregate determined by spot sampling and analysis through out the day. After the conclusion of the test, and despite trying to ensure that all water legs from the separators were closed during the test, it was discovered that the coalescer water leg was slightly open. Therefore flow line samples at the inlet of the slug catcher were immediately taken and showed a water content of 1.3%. Flow line samples are notoriously difficult to take and therefore may only be considered as indicative. The multiphase meter measured a flow weighted average of 4% for the wells over the 24 hour period.

5.4. Summary of Comparison

The comparison in section five may be summarised by the Table below

	OIL bpd / % Difference	GAS mscfd / % Difference	WATER CUT measured / Difference
RAW DATA	36603	8197	4%
	-0.3%	-6.6%	2.7%
Shrinkage corrected	35146	11177	negligible effect
	-4.3%	27.4%	
Back Pressure corrected	35977	11442	negligible effect
	-2.1%	30.4%	
P&T Corrected	included in Shrinkage Correction	included in Shrinkage Correction	included in RAW DATA

Figure 8 - Summary of Comparison between Multiphase Meter and Host Platform

The data further down the table incorporates previous corrections above in the Table. The percentage differences in the table represent: (multiphase meter - host platform meter) / (host platform meter)*100 and indicate positive when the meter over reads in comparison with the host platform systems.

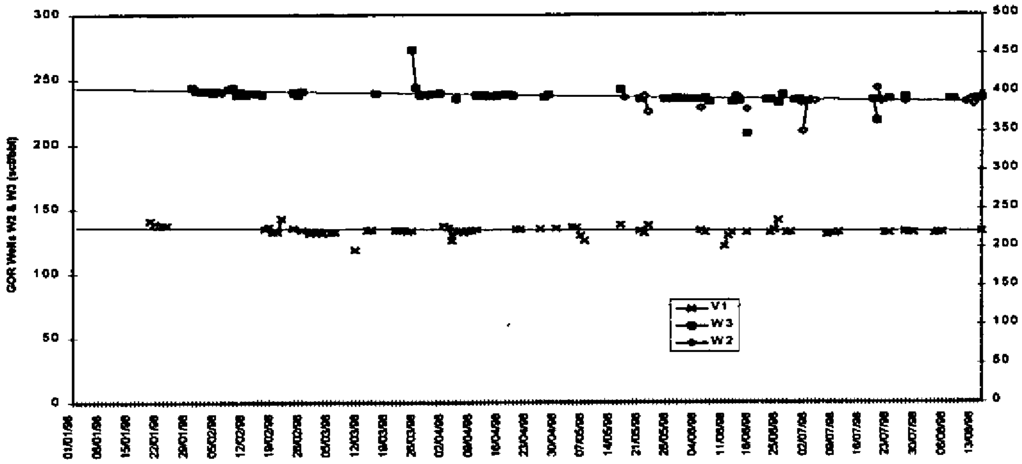
The meter is well within the manufacturers claimed accuracy on both oil and water measurements. The differences found between the multiphase meter and the host platforms gas measurements are unexplained despite extensive efforts to do so. The manufacturer's opinion is that the physical principles on which the meter relies precludes error combinations of this nature and magnitude. The only other information relevant to this comparison is the early drillstem samples whose analysis showed a GOR closer to that recorded by the multiphase meter.

6. SUBSEA METER LONG TERM STABILITY AND REPEATIBILITY

The stability and repeatability of the meter has allowed small changes in well fluid rates to be detected. This is best illustrated by the following graphs and discussion of GOR's over a period from January to August this year.

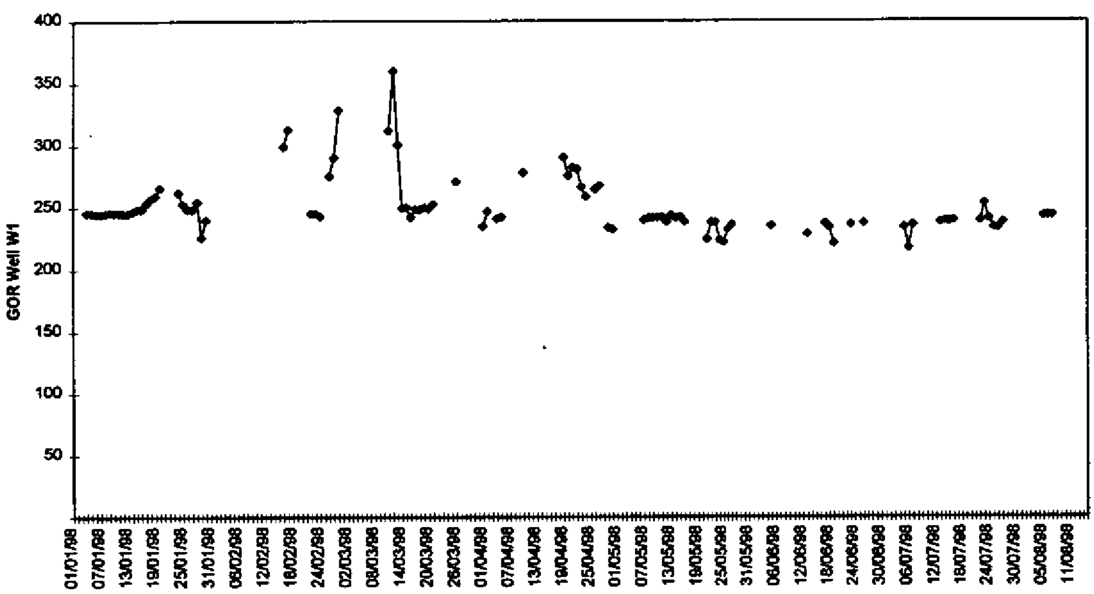
Wells W3 and W2 are located in an area of the reservoir that has a common gas cap and are expected to have a common GOR, as opposed to V1 that is located in an area believed to have a different gas cap and therefore a different GOR. Figure 9 below shows GOR's measured by the multiphase meter have indeed the GOR's expected.

Fig 9 - Well GOR Trends



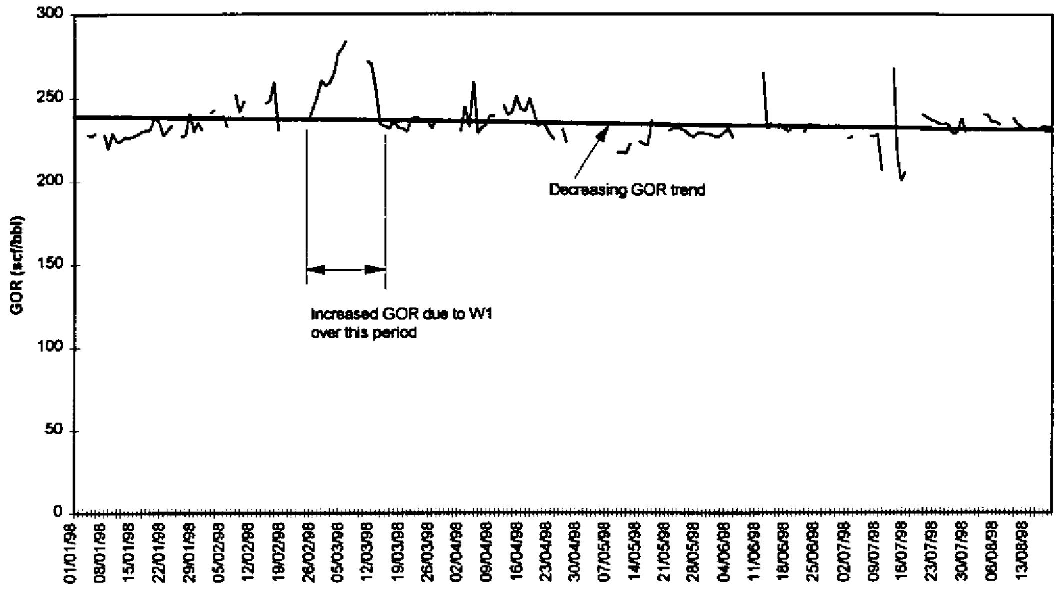
Well W1 was noted to have a rising GOR in February this year and the well was choked back. The resulting response of the well in terms of GOR is shown in Figure 10.

Fig 10 - Well W1 GOR Trend



Overall the wells indicate a slowly declining GOR with time which is being reflected in platform measurements (Figure 11). Also to be seen in the platform measurements is well W1's increased contribution to platform GOR in the February/March period.

Fig 11 - Host Platform Measured GOR Trend



Similar data has been recorded for water content where small changes in water content over time have been recorded by the subsea multiphase meter and subsequently confirmed by platform measurements.

7. CONCLUSIONS

With this meter two overriding benefits are being obtained in reservoir management.

- the ability to relate changing fluid receipts on the host platform to individual well changes.
- the ability to detect changing individual well behaviour at an early stage while it is otherwise indiscernible from general variations on the host platform.

To obtain these benefits "repeatability" and "reliability" are crucial parameters and to date the Framo meter seems to have excelled in these areas.

Manufacturers claimed accuracy for oil and water measurement are supported in the range measured. At this time, and despite extensive efforts, the cause of the difference in gas measurements is unresolved. The difference is beyond that that can be explained by even the combined uncertainties of the multiphase and host platforms instruments (Section 5.4 refers).

The decision to install a sub-sea multiphase meter instead of a dedicated test flow line has been justified. As a result of changing well GOR's and water cuts measured by the multiphase meter, reservoir decisions have been taken early to optimise production.

8. ACKNOWLEGEMENTS

The authors wish to acknowledge the support of Marathon's partners in the West Brae/Sedgwick development and in particular their support in using what at the time was considered innovative technology.

Marathons co-venturers in the West Brae/Sedgwick development are:

BG Exploration and Production Limited; BP Exploration Operating Company Limited; Burlington Resources (U.K.) Inc.; British-Borneo Oil & Gas Limited; Kerr-McGee Oil (U.K.) PLC; Lundin Oil & Gas Limited; Talisman Energy (UK) Limited; Summit Oil UK Limited.

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.