Implementation and Operational Experience of a Multiphase Meter

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Summary

This paper presents experience gained in the use of a Fluenta multiphase meter (MPM) on Anasuria. Initially verification was achieved by comparison with the first stage separator and testing by difference. Following the introduction of a new third party field, Cook, separator constraints prevented the use of testing by difference and an alternative method of verification was required. The paper goes through the lessons learnt in developing an MPM for use on a platform and explains how reservoir management is achieved using the MPM, geochemical fingerprinting and allocation metering. In addition, an operational example of using the meter for well monitoring is described.

1. Introduction

The Anasuria is a purpose built FPSO monohull vessel specifically designed to produce the Guillemot, Teal South and Teal fields in the North Sea (Figure 1). The hull was built by Mitsubishi heavy industries in Nagasaki Japan and towed to the Amec yard at Wallsend where the topside process equipment was installed. Production commenced 5th October 1996. The vessel was designed for a twenty-year service life and it is currently projected that the vessel will remain on station for at least ten years before returning inshore for a major survey and inspection.

A Fluenta multiphase meter (MPM) was installed on the Anasuria FPSO in the rigid piping upstream of the swivel stack in place of a test separator for well testing purposes. The saving to the project resulting from using a multiphase meter in place of a test separator was £4M in Capex. The MPM was seen as a means of introducing the latest metering as a cost-effective option on a state of the art vessel. At the time the multiphase meter was installed on Anasuria, the technology was very new. During the conceptual design phase of the project the metering philosophy was developed and appropriate features designed into the system to provide alternative methods of well testing and for verification of the MPM. During the detailed design phase a number of minor cost reduction modifications were made which reduced the facility to prove and verify the MPM. The system installed is shown in Figure 2.

The meter is provided as a common facility, with each flowline capable of being manifolded to it via the test header. As Teal South can only be routed up the test header and this is the only access route to the MPFM, it is necessary to close in Teal South and sustain a deferment if individual wells are to be tested. The only alternative is testing by difference with Teal South.

2. Operating History

When production started on 5th October 1996, there was a tremendous appetite for information regarding well performance from Reservoir Engineering, Production Technology and Production Programming. As the MPFM was new technology to everyone concerned, the performance of the meter was monitored closely by a wide cross section of disciplines within Shell including the guarantee team, which had been formed to shake down the post start-up problems and consisted of project team members.

After the first suite of well tests had been completed, several issues emerged which prevented detailed analysis of the data.

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[1] Shell U.K. Exploration and Production (Shell Expro) is operator in the U.K. sector of the North Sea on behalf of Shell, Esso and co-venturers.

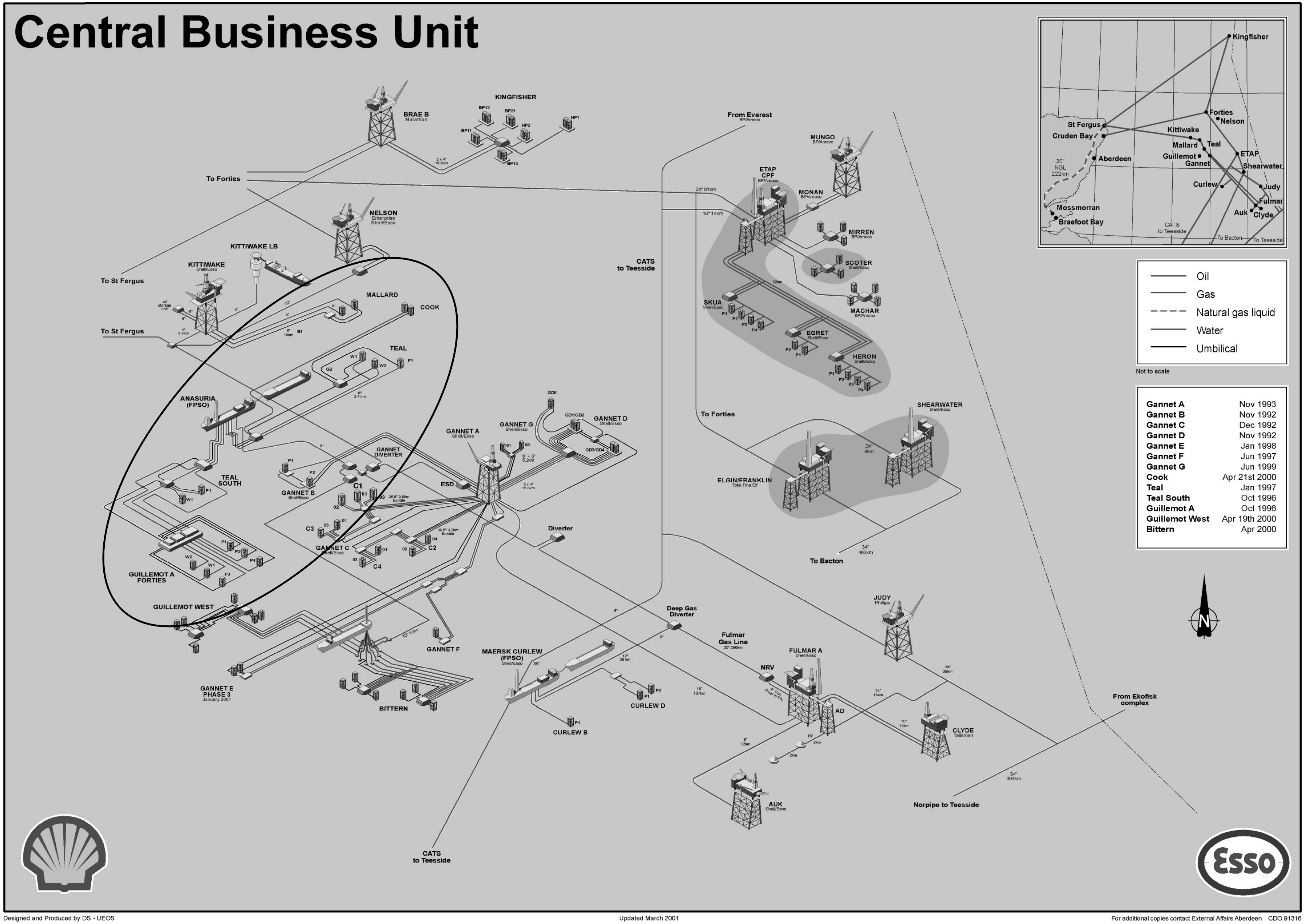

Figure 1. Location of Anasuria

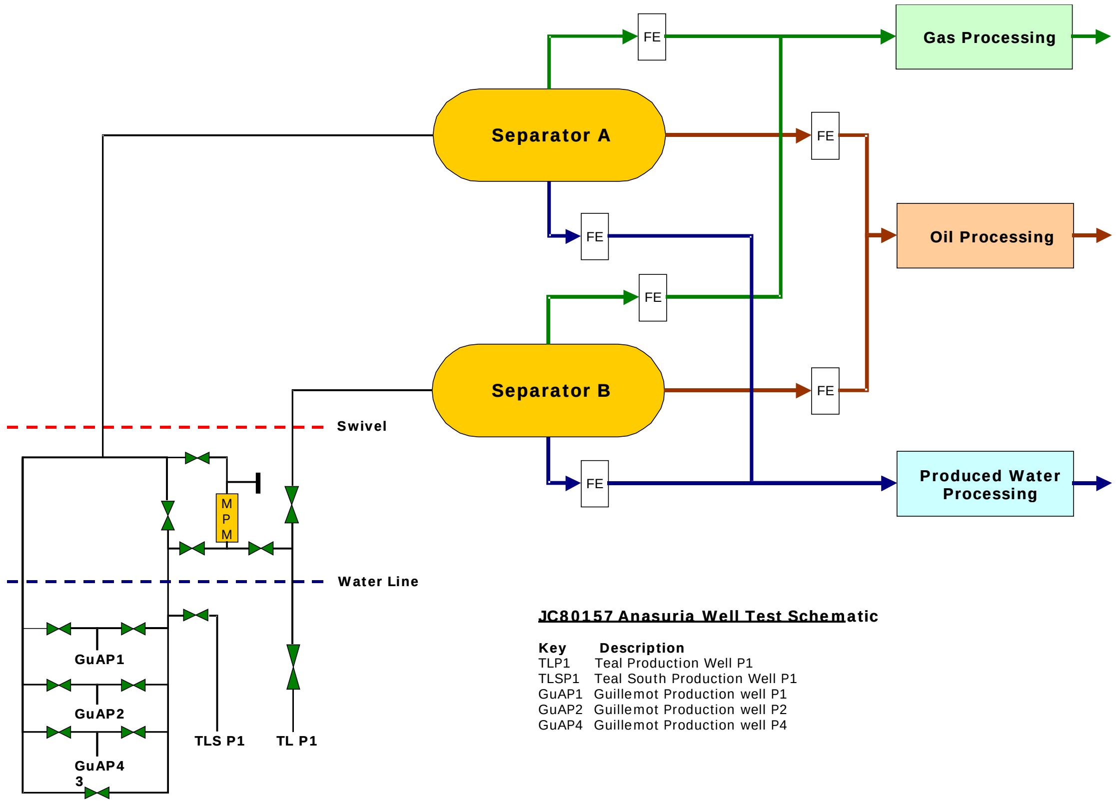

Figure 2. Schematic of Anasuria (pre-Cook)

The sheer volume of data downloaded from the meter was extremely confusing and raised more questions than answers. As the operating conditions at the meter were different to those at the 1st stage separator, it was not apparent what conditions the measurements were being converted into e.g. standard conditions @ 1st stage separator. In addition, errors in flow and associated parameters from the Fluenta MPM were investigated and it was found that the MPM had not been set up correctly for the wells flowing through the meter on Anasuria.

Once these initial problems were rectified the flow and associated parameters from the Fluenta MPM were used for reservoir management. However, these values did not agree with and could not be reconciled with those obtained from other metering systems on the FPSO. The MPM then failed mechanically and was taken out of service. When the MPM was re-instated on Anasuria a test programme was developed in conjunction with Fluenta. In January 1998 after the meter was reinstalled it was agreed that the separator metering would be reviewed to determine whether it provided a reliable basis for checking the MPM.

Reviewing the separator metering it was found that the gas metering system was not reading correctly. The differential pressure measurement across the orifice plate was handled by an algorithm in the DCS which was incorrectly set up for calculating the flow at operating conditions.

A new algorithm was developed and input to the DCS for the gas metering resulting in considerable improvement in the gas readings. Prior to a preliminary set of tests being run to compare the MPM and metering on the separators in August 1998, all associated instrumentation on the oil, gas and water metering on the separators was calibrated. The results showed that the huge discrepancies between the separator metering and the MPM had reduced, the liquid results were within 15-20% and the gas between 10-15%. The differences between the measurements from the two first stage separators were about the same as those between the multiphase meter and either of the separators.

In October 1998, having established that the MPM was giving reasonable results, a more extensive test programme was carried out. In the tests, wells were swung between the two separators and the corresponding increase and decrease in flows compared with the flows obtained from the MPM.

Based on the results of this well test programme an uncertainty study was carried out. This confirmed that there were major uncertainties in the well test results due to inadequate conventional metering equipment and the procedure of testing by difference. It was recognised that comparison between the existing conventional metering systems and the Fluenta MPM may therefore never be very good. A summary of the uncertainties is given in Table 1. The uncertainties associated with testing of each of the wells was considerably larger than users of the data had believed they would be, for example the uncertainty in the oil flow of testing Teal South by difference was +/-25%.

In verifying and understanding the accuracy of the MPM, the flow rates had to be compared with these uncertain results obtained from the separators. Thus, it was very difficult to establish how well the MPM was performing. As a result of the confidence gained through this extensive test programme it was agreed that the MPM would be used for well testing. However, the results of the next well test carried out in December were inconclusive and did not agree with the separators. The meter was removed from the platform and returned to Fluenta. The meter was stripped down and on inspection Fluenta found that the meter had failed mechanically.

Between January and July 1999 the internals of the meter were redesigned with support from the instrument, materials, mechanical and electrical disciplines in Shell Expro. In addition, Fluenta improved the electronics and associated software for watercut measurement during this period. When the meter was ready for assembly Shell staff went to Fluenta to witness assembly of the meter. The meter was tested at the Christian Michelson Test rig and witnessed by the metering engineer and operations prior to the meter being sent to Anasuria.

The meter was re-commissioned on Anasuria by Fluenta in August 1999. It was agreed with Operations that the wells flowing on the test/production header would flow through the meter for a month prior to the well test programme scheduled for September when the accuracy and reliability of the meter would be assessed. During this four-week period the aim was to ensure that the flow readings from the MPM were consistent and repeatable and to observe any potential system failures. The aim of the well testing in September 1999 was to establish whether the Fluenta MPM would be suitable for use on the forthcoming Cook project. A summary of the operating history is given in Table 2.

		Teal (dry well)	Teal South	Guillemot P1	Guillemot P2	Guillemot P4
Oil	Quantity m^3/day	4428.00	252.61	805.06	1327.38	373.08
	Relative Uncertainty +/-%	1.00	25.07	26.35	10.63	50.49
Water	Quantity m^3/day		1306.74	2624.64	77.62	2473.87
	Relative Uncertainty +/-%		6.45	9.53	193.53	9.33
BS&W	Current Value %		83.8	76.53	5.52	86.90
Gas	Quantity m^3/day	9887.00	1290.60	1038.25	814.45	337.05
	Relative Uncertainty +/-%	5.27	53.81	97.83	123.80	296.57

Table 1. A summary of the uncertainties in the oil, gas and water measurements when testing the wells using the first stage separator (results obtained following the test programme carried out in October1998).

October 1996	First oil from Anasuria FPU
April 1997	Errors in flow and associated parameters from the Fluenta MPM investigated and it was found that the MPM had not been set up for the wells flowing through the meter on Anasuria.
July 1997	The liner on the MPM failed and meter could no longer measure water cut
August 1997	Fluenta meter returned to Norway for the liner to be replaced.
January 1998	Fluenta meter returned to Anasuria
January 1998	Fluenta personnel visited Anasuria to check the meter, separator and MPM. The readings were not in agreement. Programme devised to determine the conventional system uncertainties and to check the conventional metering systems were operating correctly
August 1998	Further MPM tests against separators. Reasonable results but some inconsistencies
December 1998	Fluenta advised Shell of the results from their analysis. Request to return the meter for investigation
January - July 1999	Meter examined and problems reported. Redesigned with Shell support and re-installed
August – October 1999	Meter in operational service. Two visits by Fluenta to support commissioning. Best results to date obtained

Table 2: Summary of key dates during the development of the Fluenta MPM

3. Cook Project

In 1999, agreements were made to process the Cook fluids. In order to process these fluids one of the first stage separators was to be dedicated to Cook, with all of the Shell/Esso wells producing through the other first stage separator (i.e. Teal, Teal South, Guillemot P1 and P2), see Figure 3. As a result a method was required to manage the Shell/Esso wells. A study was carried out with the aim of developing a metering system to provide data for each of the Shell/Esso wells on Anasuria for reservoir management. A number of options were considered for managing the Shell/Esso wells including tracers but with slugging wells this was unsuitable. After carrying out a study to assess the options it was recommended that the Fluenta MPM be retained for reservoir management of the Shell/Esso wells when Cook was in place. The purchase of an alternative MPM was considered but the results from another MPM would not be significantly better and we had been through considerable development with Fluenta and a lot had been learnt. In addition, the results obtained from the testing in August 1999 showed that the Fluenta MPM was now mechanically sound and providing consistent results.

The situation on Anasuria (a number of different wells of varying production and water cut and some with very high water cut) was very demanding to be metered by one MPM. An additional method of measurement was required to both verify the meter and understand the flow from each well. Geochemical fingerprinting had started to be used in Shell Expro to provide the percentage split of wells by mass, this method was then considered for verification of the meter. The final result was to use the Fluenta MPM with geochemical fingerprinting and the allocation metering on the first stage separator for verification. As part of the Cook project the first stage separator metering was also improved to measure oil and gas to 3%, water to 5% providing better metering for comparison with the MPM.

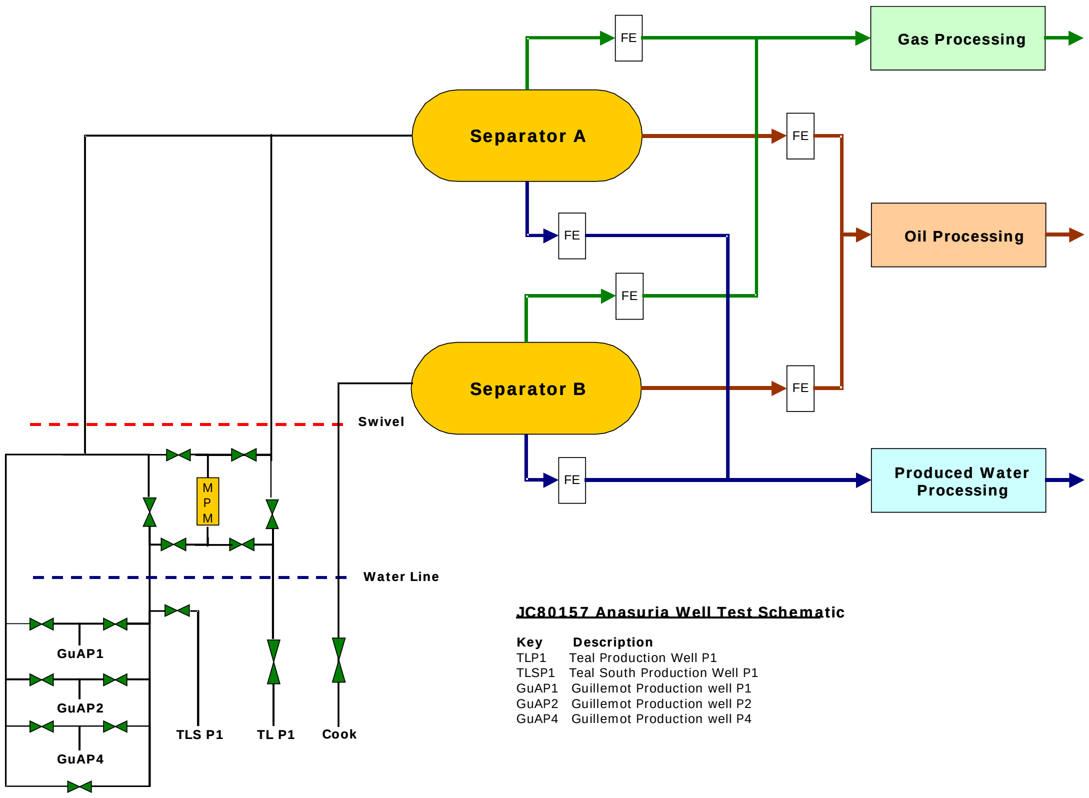

Figure 3. Schematic of Anasuria (post-Cook)

Modified from FLOW Ltd. report, 1998.

3.1 MPM Improvements

Once the decision to use the Fluenta MPM had been made a number of improvements were identified by engineering and operations in order to overcome some of the problems encountered in the preceding three years. Shell worked closely with Fluenta to ensure a satisfactory system was achieved. In addition, Fluenta improved the mechanical design of the meter to ensure the mechanical failures would not recur.

The meter installed on Anasuria went through a rigorous set of hardware modifications, including updated electronics and associated software for improved watercut measurement. A well test programme was carried out in September 1999, which was successful in proving the meter was operational and the results were reliable and consistent. However, a number of additional items were identified to ensure effective operation once Cook was producing. These were carried out in conjunction with Fluenta and Shell and completed in time for Cook coming on line.

The following items were added to improve operator interface and operability of the meter:

- An operations procedure was developed for the MPM including input of conductivity and temperature for each well combination.
- A procedure for periodic well tests by difference possibly on an opportunistic basis was agreed as back-up to the MPM and to ensure periodic calibration.
- Communication between the DCS and the MPM was improved so that the conductivity and temperature could be input and a well test initiated from the console in the control room.
- A data link to PI was made available so that data from the MPM could be accessed on the beach.
- The operating envelope for the meter was established and the flow regimes where the meter cannot be used were determined.
- The DP range required for the meter was identified and the DP transmitter was re-ranged.
- A service contract was set up for support of the meter to ensure immediate assistance could be obtained from Fluenta as required.
- A link was set up between Fluenta and Anasuria enabling Fluenta to see exactly what the meter is seeing offshore so that immediate support for the meter could be obtained without mobilising personnel offshore.

In view of the demanding role for the MPM on Anasuria it was identified that a resource should be available onshore in order to analyse the data and assess the ongoing performance of the meter. It was also recommended that the meter be online at all times so that trending data can be obtained to help in proving the meter and to build up confidence in the meter.

3.2 Geochemical Fingerprinting

Fingerprinting of oil samples using gas chromatographic techniques has been used by geochemists for many years to help understand reservoir compartmentalisation in producing fields (Kaufman et al., 1990). The technique is based on the observation that oils from the same reservoir compartment have nearly identical fingerprints, while oils from a separate compartment usually have a different fingerprint. The fingerprints generated from high resolution gas chromatographs (HRGC) or multi-dimensional gas chromatographs (MDGC) (Ganz et al., 1999) are usually displayed graphically as polar starplots using peak height ratios or concentrations (Figure 4). The use of a starplot display provides a simple visual evaluation of the differences between oil samples. Figure 5 shows the starplots for oils from the four wells being produced on the Anasuria FPSO. These oils were analysed using MDGC of the aromatic compounds between C8 and C10. Various ratios of eleven aromatic compounds are used to create the starplots.

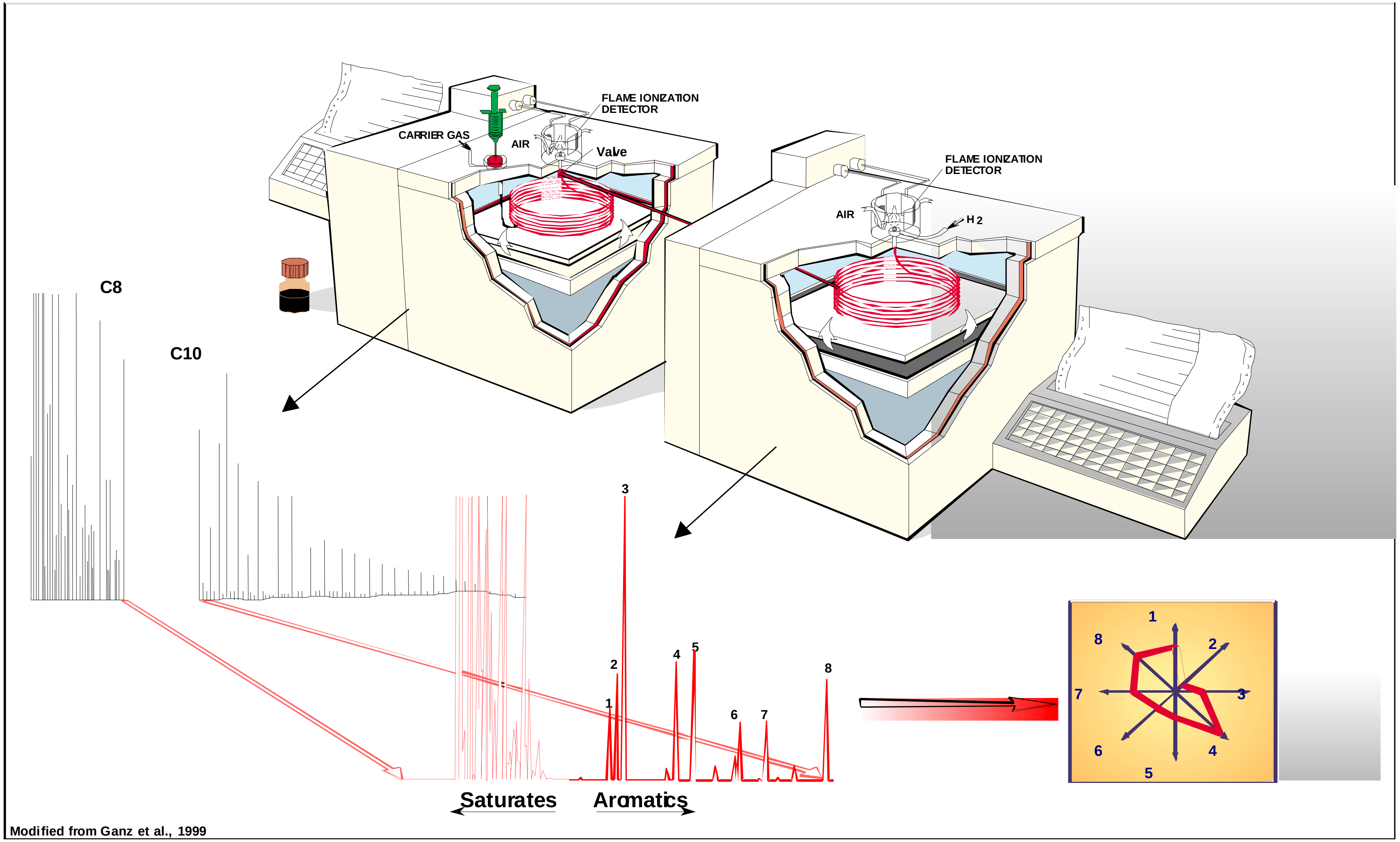

Figure 4. Starplot fingerprints of oils are generated from aromatic compound concentration ratios in the C8-C10 range Multi-Dimensional Gas

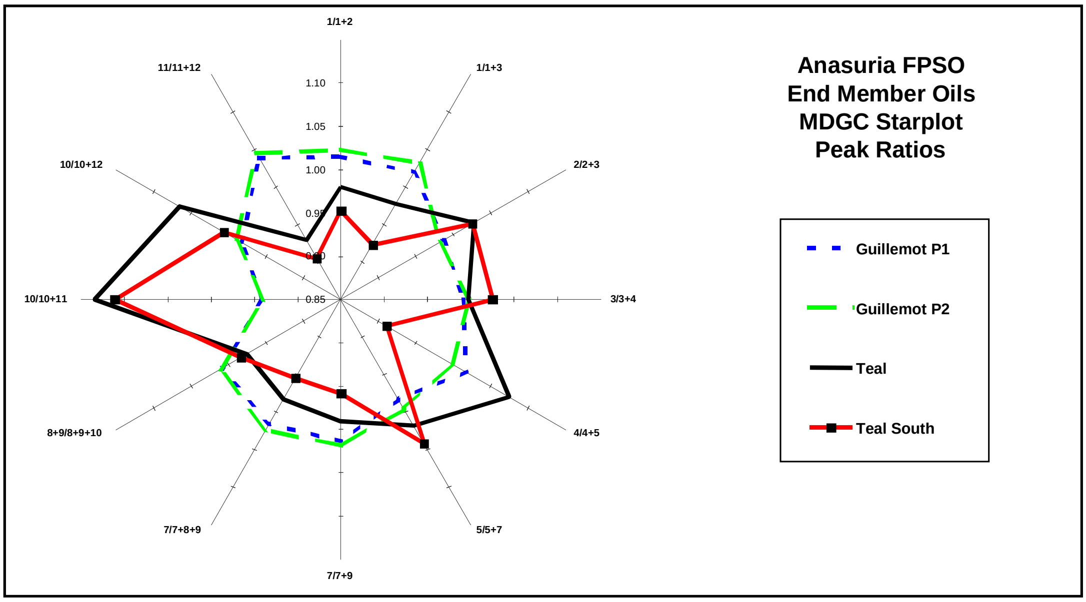

Figure 5. MDGC Starplots for the endmember oil samples from Anasuria. Note that the starplots from oil samples from the Guillemot P1 and P2 are nearly identical and cannot be distinguished.

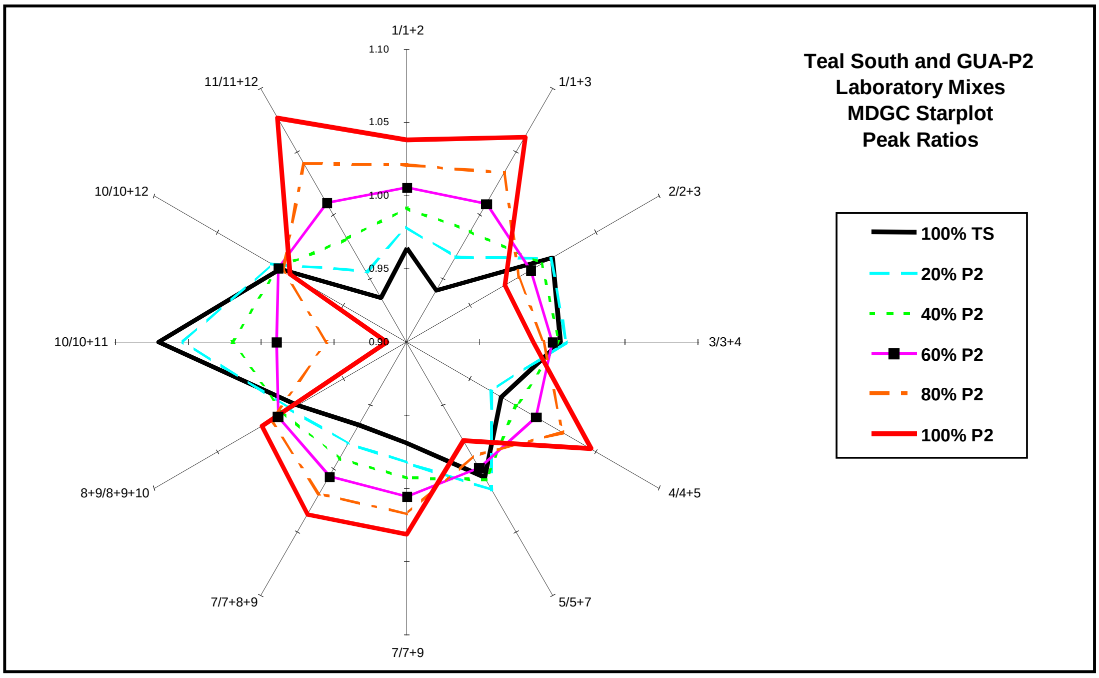

Figure 6. MDGC Starplots for laboratory mixes using Teal South and Guillemot P2 as end members. Note how the mixture starplots always fall in the same order for each ratio value.

Of the four oils being produced at Anasuria there are three distinct starplots. The two samples from the Guillemot P1 and P2 are nearly identical to each other, while the oils from Teal and Teal South are unique. Because there are differences in these oils we can use the starplot data to help determine relative contributions of each well in a commingled sample. Kaufman et al, 1990, showed that if two oils with different starplots are mixed together, the resulting starplot of the mixture is intermediate to the starplots of the two oils. They utilised this conservative mixing property to determine relative contributions of end-members in a commingled oil sample.

Figure 6 shows the starplots of a series of laboratory mixtures (by weight) using the oils from Teal South and Guillemot P2 as end-members. At most of the ratios, the starplots of all of the mixtures fall between the end-members in an orderly progression reflecting the relative proportions of each mixture. Those ratios that appear to provide good mixing trends are further tested to see how well they could predict the relative contributions of the end-members in some additional laboratory mixes. Figure 7 is an example of one of the calibration lines from one of the ratios. The absolute peak ratio data for each laboratory mix sample is plotted against the relative proportion of the Guillemot P2 oil. The best-fit line used is a polynomial because the mixing of ratios is generally not linear. Because the MDGC technique is very reproducible the R^2 of the best-fit lines is very high (>0.98) when there are large enough differences in the absolute ratio values of the end-members. To determine the relative proportion of an "unknown" mixture, the ratio values are plotted along the best-fit line and the proportions are read off the y-axis. In the example in Figure 7 the commingled production contains about 60% Guillemot P2. All of the ratios are evaluated for their ability to accurately predict a series of 'known" laboratory mixes and in this case seven of the ratios appeared to provide satisfactory predictions. The average and standard deviation of all seven mixing lines is used to determine the relative proportions in a commingled production sample. Errors are generally less than 5 %.

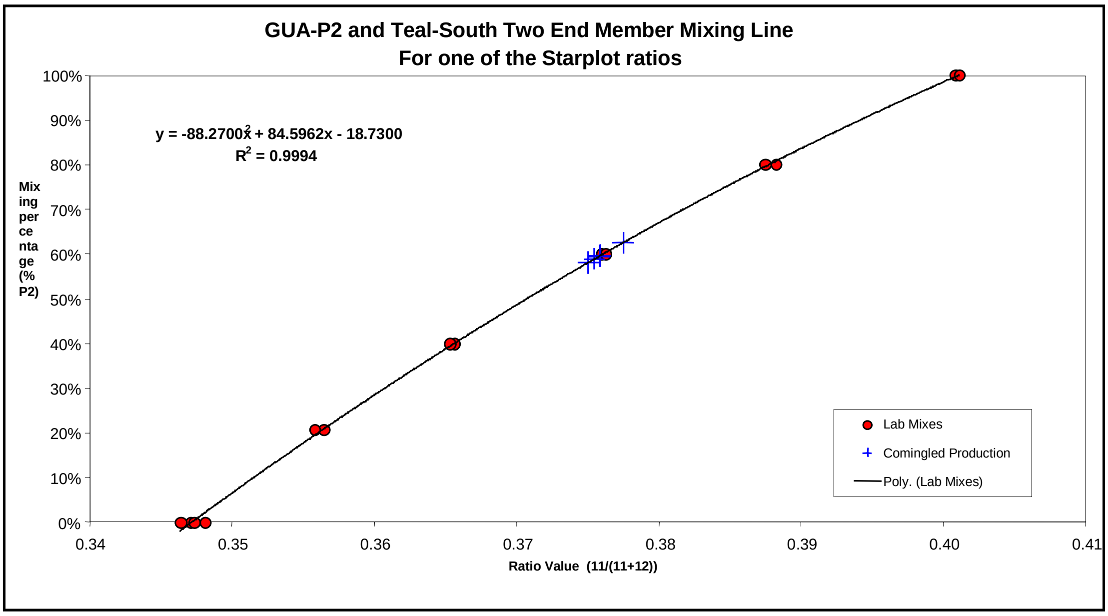

Figure 7. Calibration mixing line for peak ratio 11/(11+12). The equation of the best fit polynomial line is used to predict relative proportions in a commingled sample.

To determine relative mixes of a three end-member mixture, partial least squares analysis is used. Similar to the two end-member calibration a series of laboratory mixes are made and analysed. Calibration equations and coefficients for each ratio are determined and a series of 'known" laboratory mixes are used to determine how well the model can accurately predict the correct relative proportion. Figure 8 is a display that shows how well the partial least square model predicts the relative proportion of the Teal oil in a series of laboratory mixes between Teal, Teal South, and combined Guillemot P1 and P2 oils. The errors are larger in the three end-member mixtures than the two end-member mixtures but they are generally <10%.

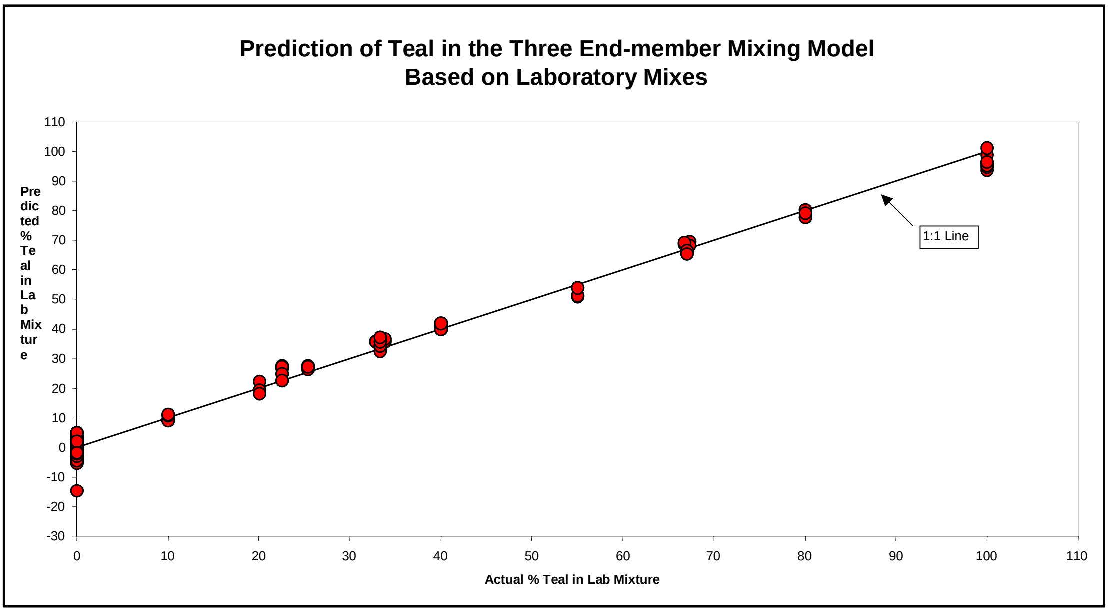

Figure 8. The predicted vs actual proportion of Teal oil in the laboratory mix samples using partial least square analysis. The predicted values are generally within 10% of the actual values.

The Anasuria FPSO commingling provided an interesting test case to apply the geochemical production allocation technique. The final commingled production was a mixture of four different wells, but there were only three unique fingerprints among these oils. But the manner in which these wells were commingled and the available sampling locations provide us with a way to solve for all four wells. Figure 9 is a schematic of the flow lines and sampling locations. Since the oils from the two Guillemot wells could not be distinguished, two different allocations had to be determined to provide an answer. The allocation determined at the location #5 (Separator Outlet) would be a three end-member relative proportion of Teal, Teal South, and Guillemot P1and P2. The allocation determined at location #2 would be a two end-member relative proportion of Teal South and Guillemot P2 commingled production. The ratio of production of these two wells can be used to back out the proportion of Guillemot P2 determined at the Separator Outlet (#5) and the amount of Guillemot P1 can be determined.

Samples were collected and geochemical production allocation determined at two different times in 2000. The results of these predictions are found in Table 3. The values are the averages and standard deviations for oils collected over five days. The results compare very well to the allocation determined by the separator well testing and Multiphase Flow Meter well testing. The errors for the Guillemot P1 production are a larger percentage of the actual production than the other wells because the production for this well is very small and the P1 production is determined indirectly. But in general it appears that geochemical production allocation can be used to help determine the relative amounts of commingled oil production. One important advantage of geochemical production allocation is that it does not require any deferment of production, samples can be collected at any time and the results can be used to help plan when conventional well testing is required.

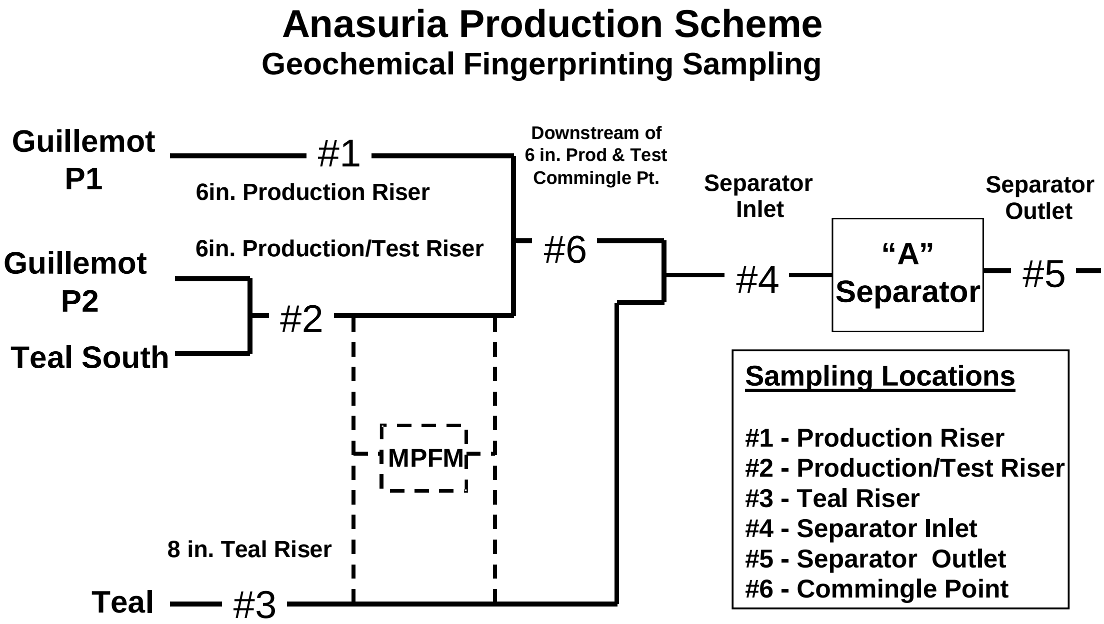

Figure 9. Schematic of the flow lines and geochemical sampling locations on the Anasuria FPSO. Sample locations #2 and #5 were used to determine the mass percentage split by geochemical fingerprinting.

4. Results

An extensive well test programme was carried out in September 2000 to assess the functionality of the measurement system developed for Anasuria post Cook. During the well test programme the following results were used to monitor the wells.

- Results from a Shell proprietary statistical package, "Welldone", were used during well testing to determine the well parameters. This software reduces the well test time.
- Flow through the MPM.
- Individual oil, gas and water flows at the outlet of each phase of the first stage separator.
- Results from geochemical fingerprinting.

The final results given in Table 3 were obtained by using the results from the Teal well test and then subsequent well test results were obtained by difference. The flow rate for Teal was obtained from Welldone as this provides the most accurate result as a baseline. In order to compare the flow values from the MPM and the separator these needed to be converted to the same conditions, as the MPM only provides flow at operating conditions at the MPM. For comparison all results were converted to the same conditions by applying shrinkage factors determined by process modelling. The separator provides flow values at standard conditions and at first stage separator operating conditions.

The results from the MPM were within the accuracy of the meter. For Teal, the major producer and a dry well the results for the separator and MPM were within 2%.

	Separator				MPM				Geochemical Fingerprinting	
	Gross	Riser BS&W	Net Oil	% Split	Gross	Riser BS&W	Net Oil	% Split	June 2000	September 2000
Teal	5579	0%	5579	84%	5691	0%	5691	82%	80% +/- 1	81% +/- 4
Teal South	4400	95%	220	3%	4245	95%	212	3%	8% +/- 1	6% +/- 1
Gu P1	3713	92%	297	4%	4030	92%	322	5%	1% +/- 1	3% +/- 3
Gu P2	661	21%	522	8%	868	21%	686	10%	11% +/- 1	10% +/- 1
Total	14353		6618		14834		6911			

All flows given in m^3 @ standard conditions

Table 3: Results of the Well Test Programme Carried Out in September 2000

5. Discussion

A number of learning points have been identified as a result of the MPM installation on Anasuria, these include general learning points applicable to any new technology as well as the more specific learning points from the installation on Anasuria.

When a new technology is installed, co-operation between the design and operations teams is required to ensure it is installed in an effective manner. In addition, during the conceptual and design phases it is important that the specification and design philosophy are fully defined to ensure the new technology is fit for purpose. During the conceptual phase the support required to prove the technology should be identified so that this is allowed for during commissioning and operation, additional support may be required over and above that needed for normal operation. In order to prove a new technology consideration should be given to providing a means of verification. However, if an alternative means of measurement is available then the new technology may cease to be used for measurement especially if there are teething problems.

The implementation of the MPM on Anasuria was meant to be straightforward, however, it turned out to be a development project. Firstly, rectifying the mechanical problems of the liner and subsequently the sealing problems. Secondly, improving the software to provide realistic water cut readings. In addition, the reduction of pipework in the initial stages reduced the ability to verify the MPM readings and build up confidence in the meter. Also the effect of reducing the pipework and the addition of the Teal South well meant that apart from the Teal South well all other wells could only be tested by difference with Teal South unless this well was closed in. Testing by difference introduces additional errors. The MPM has mainly been used during well testing, however, if the normal configuration of Teal South and Guillemot P2 were continuously flowed through the MPM then some of the problems with the meter failing would have been picked up quicker. The arrangement on Anasuria means that the demands on the MPM are a challenge for any MPM, as there is both a combination of wells and hence widely varying flowrates and high watercut. The MPM therefore needs to operate over a large range.

Good documentation and onshore support to the operation teams is key for successful implementation of any new device or technology. The MPM by its nature has many parameters and it is important that these are not changed either inadvertently or otherwise unless through a controlled environment. In the initial stages the documentation provided for setting up and operating the MPM was inadequate. As part of the Cook project this has been improved and an Operations and Maintenance manual specifically for the Anasuria installation has been provided to the platform and onshore operations teams. In addition, in the course of development of the MPM the software was upgraded. Good management of software is of paramount importance especially during the development and updating stages. In an offshore environment the only software available should be the operating software not previous versions because if the system goes down there will be confusion as to which software to load especially with the changing shifts. These were problems encountered during the development.

Geochemical fingerprinting has been developed through the course of this work to provide mass percentage split of production for four wells, in the past this technique had only been used on two wells. Advantages of geochemical fingerprinting are:

– it can be used to indicate whether a well is still producing oil when the water cut is very high and possibly increasing.
– If the requirement for a well test is identified because of changing production from wells, geochemical fingerprinting can be carried out to confirm this whilst authority for carrying out a well test is organised without any loss of production.

A disadvantage of geochemical fingerprinting is the delay in obtaining the results, normally the results are available 2 weeks from taking the sample.

The MPM has now been in routine operation for a year. Recently the meter has been used to monitor performance of the Teal well by continuously flowing this well through the MPM. The gross liquid flowrate is being monitored to identify any decline in the flowrate which will indicate whether the well is starting to scale. This in turn optimises the frequency of squeezing the well.

In using a MPM, it is important not to concentrate solely on absolute flowrates for each of the three phases but to look at the wider use of the information available to improve reservoir management. In designing a multiphase metering system, location of the meter and configuration of pipework are key to maximising potential benefits from the meter.

6. Conclusions

In conclusion, the installation of the MPM on Anasuria has been successful but it has required commitment from both Shell and Fluenta to get a fully working system. The measurement system now includes the MPM as one form of measurement, the geochemical fingerprinting and the first stage separator also form part of the measurement system and must be used as such. This measurement system minimises deferment whilst obtaining well test results.

The number of wells to be tested by the MPM and the widely varying water cuts and well flows place a high demand on the MPM, nevertheless the final measurement system has been successful.

Although the MPM implementation was meant to be straightforward it became a development project which then needed to be resourced accordingly. Further work is ongoing to improve the water cut readings.

For a dry well, Teal, the MPM and separator oil flow measurements were within 2%.

7. References

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