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North Sea FLOW Measurement Workshop

Index

Session 5

Discussion Paper No 1

Kerr-McGee North Sea (UK) Limited – Gryphon Alpha FPSO Monetary Application for Multiphase Meters

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1. SUMMARY

In 2001 Kerr-McGee (KMG) and its partners made the decision to develop the marginal Maclure and Tullich oil fields, by tying them back to the Gryphon Alpha FPSO. Both of the new fields have a markedly different ownership to the Gryphon field.

Whilst there was a compelling requirement for accurate measurement of production between the three fields, it was similarly important to minimise Capex to ensure the developments were economically viable. Given this, multiphase metering was considered to allocate between the different ownerships, as opposed to traditional separator metering.

The Maclure and Tullich fields first produced oil in July and August 2002 respectively.

This paper discusses the multiphase meter selection criteria, installation, independent testing and the first three months of operation. The meters selected were the Framo/Schlumberger Phase Watcher (Vx) in two different sizes (52mm and 88mm). Independent flow tests, conducted at the U.K. National Engineering Laboratory and at ChevronTexaco's Humble facilities demonstrated that an accuracy on the oil phase of 5% of reading could be achieved for typical gas volume fractions of 60 to 80% and water cuts less than 20%. Offshore the multiphase meters are verified against the test separator coriolis meters, these verifications reveal that the accuracy on the oil measurement is within the target range of 5% of reading.

2. INTRODUCTION

Kerr-McGee North Sea (UK) Limited executed the Gryphon Expansion Projects which involved the installation of additional subsea infrastructure and topsides facilities on the Gryphon 'A' FPSO to augment the operating life and oil production capacity of the facility.

The first three projects, which were initiated in 2001, comprise (in chronological order):

- The Maclure field development – a single well tie-back to Gryphon 'A' from the BP operated Maclure field which initially will produce 17,000BPD of oil. This project involved the installation of a new gas compressor and gas dehydration system.
- Installation of a sales gas export pipeline to Beryl Alpha and Global Producer III at the Leadon field; the former used for onward sales of the Maclure, Gryphon and Tullich export gas into the SAGE system, the latter to provide fuel/lift gas for Leadon.
- The Tullich field development – a four well sub-sea tie-back to Gryphon 'A' from the 100% owned and operated Kerr-McGee Tullich field, adding another 22,000BPD of oil production.

Both of the new fields have a markedly different ownership to the Gryphon field, whose equity is made up from Kerr-McGee (61.5%), Conoco (25%), Cairn Energy (10%) and Oranje Nassau (3.5%):

- Maclure is operated by BP (33.33%), with partners Kerr-McGee (33.33%) and Beryl Group (ExxonMobil, Enterprise, Amerada Hess, OMV) (33.33%);
- Tullich is operated by Kerr-McGee (100% ownership).

Both Maclure and Tullich oil fields are marginal UKCS developments; it was thus important to minimise CAPEX to ensure the viability of the projects. This prompted the development team to consider the use of multiphase metering for each of the new fields, rather than installing additional separation capacity equipped with singe phase metering. The accuracy of the multiphase metering was thus important given all three fields (viz. Gryphon, Maclure and Tullich) have significantly different partner equity[1]. To ensure the accuracy of the multiphase meters, an extensive onshore third party evaluation was carried out and the offshore test separator metering upgraded to enable verification of the multiphase meters.

The Maclure and Tullich developments came onstream in July and September 2002 respectively.

3. PROCESS OVERVIEW

The Gryphon topsides processing facilities comprises of a single 100% two stage separation and heating train plus coalescer to produce tanker quality crude which is stored in the Cargo Oil Tanks and ultimately exported via shuttle tanker. The original oil handling capacity on Gryphon was 60,000 BPD however due to the increasing water-cut of the Gryphon wells this has subsequently reduced to lower than 47,000 BPD. The modifications undertaken during the Maclure and Tullich Projects have returned the oil handling capacity to higher than 55,000 BPD. Gas handling is provided via three off three-stage electric motor driven reciprocating compressors: two existing (each sized at 13 MMScf/d) each and one new 30 MMScf/d unit installed as part of the Maclure field development. A new dehydration system sized for 90 MMScf/d was also installed as part of the Maclure Project.

The compressed gas supplies gas lift, fuel, injection and export requirements. A Test Separator is also available sized for ca. 20,000 BPD of fluids. Prior to entering the test separator the fluids pass through a heater.

The Maclure field was developed using primary recovery (no reservoir pressure support) as a single well, sub sea tie back and will produce at an initial rate of up to 17,000BPD. Potential future development options for Maclure include an additional production well (as an upside) or alternatively water or gas injection wells, the latter two for potential future reservoir pressure support. Maclure is linked to an aquifer although only moderate water production is expected, in latter field life gas breakthrough will occur and thus both the arrival pressure and gas flow rate increase significantly.

Similarly the Tullich field was developed using primary recovery and four production wells, these being tied back to a subsea manifold producing at a rate of ca. 20 - 25,000BPD. Wells can be routed to either a 8” production flow line or a 6” test flow line. Further development options are another production well and / or water injector. Tullich is linked to an active aquifer and significant water production is expected.

Both fields utilise gas lift. The expected arrival temperature of the Maclure and Tullich fluids is approximately 40^{o}C however, to aid water and oil separation the fluids are heated to approximately 95^{o}C. The Maclure meter pressure would range from approximately 40bar at start of field life to approximately 70bar at the end of field life, whereas the Tullich meter would operate at approximately 20 – 35 bar(g) through out its field life. The Maclure, Tullich and Gryphon fluids are of similar composition with oil and water densities of approximately 925 and 1040kg/Sm^3, oil viscosity of 7cP at operating temperature and the well gas being approximately 90% Methane and 2.8% CO2 (mole) with zero H_2S (less than 1 ppm).

[1] Neither the Gryphon, Maclure or Tullich fields pay PRT or Royalty tax.

4. CAN WE USE A MULTIPHASE FLOW METER?

Evaluation / Screening

A multiphase meter, whether in-line or of the compact separation type, offers several advantages over traditional three phase separators equipped with single phase metering. The main advantages of multiphase metering (MPM) are:

- Significantly reduced space requirements
- Significantly reduced weight requirements
- Increased safety due to reduced hydrocarbon inventory
- Reduced CAPEX and OPEX cost and
- For Tullich the possibility of measuring subsea and thus avoiding the cost associated with a test line.

However, a significant disadvantage of MPM is that the accuracy can be poorer than that which can be obtained using a correctly instrumented separator and the meters typically incorporate a radioactive source.

The installation of two new three phase separators, one each for the Maclure and Tullich fields, equipped with meters, would have made the project uneconomic. In addition, space on the Gryphon FPSO was severely limited, the project was already installing a new gas compressor complete with coolers and dehydration skid.

The project partners agreed that MPM meters could be utilised provided the accuracy was acceptable, the acceptable accuracy was later defined as an oil uncertainty less than 5% for gas volume fraction's (GVF) less than 65% and water cuts (WC) less than 10%[2]. This relatively low uncertainty level (for a MPM) was essential as the Gryphon production would have to be determined by difference; this was due to the Gryphon fluids rate being too large for a single MPM and there were too many wells (12) for each to be fitted with a MPM. However, the accuracy targets had to be realistic otherwise the meter would be deemed a failure. Therefore, the task given to the design team was to determine the accuracy that could be expected from a MPM and to determine a means of verifying this offshore. Once the design team had determined the accuracy then the project partners would be able to decide if this accuracy was acceptable prior to sanctioning the project.

The accuracy of a MPM is primarily governed by process conditions such as GVF, WC and fluid velocity through the meter. In addition, effects such as small difference between oil and water densities, changes in salinity and the presence of compounds such as scale, wax, sulphur, H_2S and CO2 can also affect the meter's accuracy. Therefore, the accuracy of an in-line MPM, located upstream of the choke is pre-dominantly determined by the reservoir performance; if the reservoir performs poorly (and they can be unpredictable!) the pressure will decline resulting in increasing GVF, the flow rate may decrease and the water cut may rapidly increase to in excess of 90%. These uncertainty effects are different to single-phase meter's whose accuracy is typically dependent upon the meter installation (straight lengths) and the accuracy of the secondary instrumentation.

For the four well Tullich development is was decided that either a test line or subsea MPM would be required. The cost of a test line was significant, however it was felt that subsea MPM's were not sufficiently mature to be utilised[3]. If the meter failed then the mean time to repair could easily be 6 months and this could result in significant deferment. In addition, the test line offered the advantage that if one well had a lower productivity index it could be flowed into the test separator without affecting production/arrival pressures from the other wells. Thus it

[2] The full uncertainty specification was a maximum of 5% on the oil phase when the GVF is less than 65%, water cut less than 10%, the static pressure is greater than 5bar and the liquid flow rate is in excess of 10,000BPD (at 15C).
[3] At the time of the project the subsea version of the Vx was not available, Roxar did not want to sell the MFI meter and thus only the old Framo design, Fluenta or Kvaerner (which required a composite spool) were available.

was decided that two topside MPMs would be procured for Tullich, one for the production line and the other for the test line. The Tullich test line MPM would ensure that further well testing demands on the existing test separator were minimised as this vessel is needed to maximise production from the ageing Gryphon wells.

It was decided that the MPM's would be verified against the test separator, this being upgraded by fitting coriolis meters on the oil outlet. However, the maximum Tullich flow rate exceeded the test separator capacity and thus at maximum rate the Tullich production meter would have to be tested "by difference" using the main production separators, to achieve this the gas outlet and crude oil to storage meter were upgraded.

As Maclure was initially a single well development, subsea MPM offered no benefit other than a higher meter pressure (resulting in a lower GVF). However, this benefit would be partly negated by the need to use a process model to calculate the increased oil shrinkage factor.

In mid 2001 there were several vendors manufacturing MPM (Framo, Fluenta, Roxar, Daniel, Agar, Kvaerner and Jiskoot to name a few) and each manufacturer used significantly different techniques. For example Daniel used compact separation as a means of minimising the GVF to improve the accuracy and operating range of the meter. However, vendors such as Framo claim that the compact separation was not required. When it comes to determining oil in water content then again techniques differ, Framo use gamma attenuation whereas Fluenta[4] use conductivity measurements. Finally, some vendors use cross correlation to determine fluid velocity whereas others use venturi meters. The different techniques used and vendor claims ('our meter is the best!') can seem baffling…. but to the design team there was only one question to answer and this was which MPM would give the best accuracy?

Meter Selection

An enquiry package for the Maclure MPM was issued to several vendors in Q3 2001. The selection criterion was predominantly for a meter that would deliver the best accuracy on the oil phase (not total liquid and water cut). At the time the bids were received the project team concluded that it would be difficult to install a MPM using a compact separator within the turret due to its large size and weight. Thus there was a strong desire to use a compact in-line type of MPM. To achieve the optimum accuracy from an in-line MPM the GVF would have to be kept to less than 80%. This meant that the MPM would need to be installed upstream of the topsides choke and not downstream as originally intended. If the meter was located downstream of the choke then the operating pressure would only be 9bar as opposed to 40 to 70bar and in early field life the GVF would be approximately 90% but rapidly rising to 99%. To maximise the pressure at the meter the subsea choke would have to be kept fully open. Figure 1 details the through life multiphase composition for several well probabilities; these figures include the effect of lift gas and are for the scenario of the meter being located upstream of the topsides choke. All are reasonably similar and show that the MPM will be operating in its optimum region. The disadvantage of locating the meter upstream of the choke is that some of the gas would remain dissolved in the

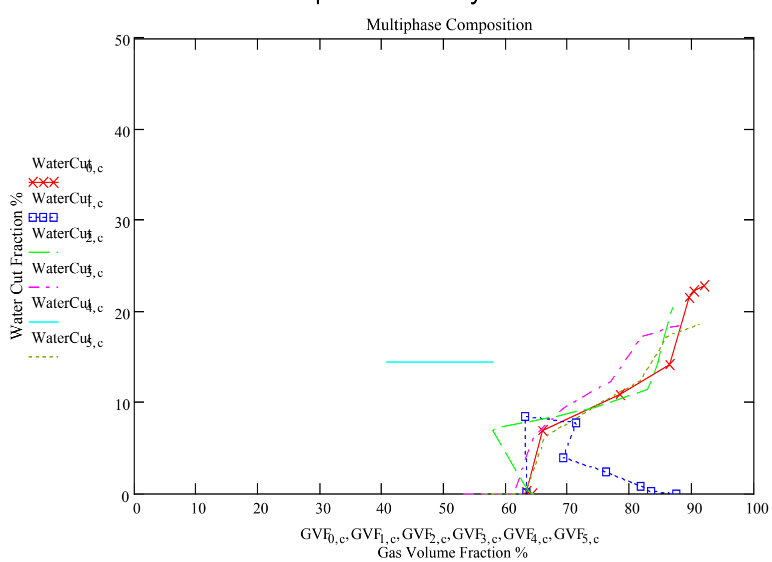

Figure 1 Maclure Composition for Different Probabilities

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[4] Fluenta was subsequently taken over by Roxar

oil thereby increasing the oil shrinkage across the choke. This would give an increased requirement for process modelling and its associated uncertainties. However, as both the Maclure and Tullich gas is very rich in methane and uncondensibles (> 96%) the majority of the gas will still be in the vapour phase upstream of the choke. Calculations predicted that the oil shrinkage would be less than two percent on a mass basis.

The vendors bids were evaluated on the basis of which meter would provide the optimum accuracy but other factors such as the number of meters in service were also considered. At the bid clarification stage Roxar stated that due to obsolesces issues they would prefer to supply the Fluenta meter as opposed to the popular MFI meter.

The Framo/Schlumberger Vx meter had performed well during the Joint Industry Project testing ref [1] and was compact. However, there was no recorded use of it being applied for equity[5] metering and it was a relatively new design. Although, approximately 100 of these meters were built they had almost all been supplied to Schlumberger for well testing and thus would not have to meet such onerous accuracy specifications. When all things were considered, it was concluded that the performance of this meter was likely to meet the project requirements and that we had sufficient confidence in the design, manufacture and robustness of the meter. Framo were also happy to submit the meter for independent testing. The disadvantage of the Framo/ Schlumberger meter was that its velocity meas-urement utilised a venturi meter as opposed to cross correlation and as such the meter had a relatively limited turn down. In addition, its GVF and WC measurement utilised a dual energy radio-active source ($Barium^{133}$) and this had a relatively short half-life (10years). This short half-life makes the meter accuracy dependant upon mathematical modelling of the radioactive decay or alternatively frequent empty pipe count checks would have to be carried out. The limited turn down was overcome by accepting that the maximum differential pressure would be 3 bar; accepting this high differential pressure meant that the meter covered all but the upside two well production scenario. If the second well was drilled then the 52mm diameter meter would need to be changed for a 88mm. If the 88mm were fitted now it would have significantly increased the measurement uncertainty.

During the field life the meter would be subject to slug flow however this was not considered a problem as most MPM are designed to cope with slug flow conditions and in particular the Vx has a high sampling frequency of 50hz. However, due to the unsteady nature of multiphase flow, integration times of 10 or more minutes might be required to obtain an accurate measurement.

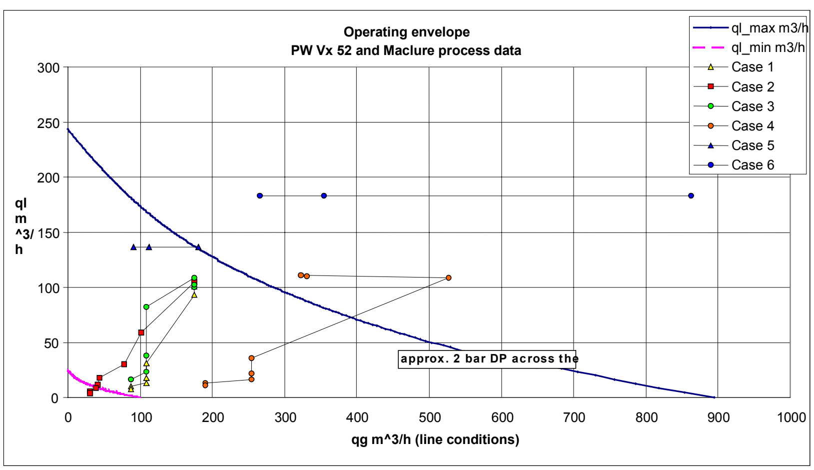

Figure 2 Operating Envelope of Maclure 52mm Vx (courtesy Framo)

Figure 2 shows the operating envelope of the 52mm Vx for the various production profiles through out the field life, the horizontal line is the design case as taken directly from the instrument data sheet! To size a MPM correctly the actual through life well profiles must be used not the topsides design minimum and maximum values. To mitigate the effects of having to change the meter, the pipe work was carefully designed to enable the meter size or type to

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[5] Equity metering is defined here as metering that is used to determine how much money each partner in the field is allocated. This is similar to fiscal metering except there is no tax differential.

be changed without requiring either welding or a shut down. As such a bypass was installed as this had several benefits notably providing access for a static calibration and unplanned maintenance such as removal of scale or wax build up both of which would affect the meter accuracy[6]. In addition, if deemed necessary the meter could be bypassed during the well clean up operation thus avoiding any possible damage.

The pipe work design required for the Vx was typical of most multiphase meters and consisted of a blind tee to induce mixing, flow vertically upwards through the meter, then on the outlet of the meter a 360^o change in direction (thus preventing back wards flow through the meter during slug flow). In addition, a bypass and vent/drain points (required for the static calibration and if necessary the injection of scale/wax removal acids) were fitted. The MPM also had hubs fitted.

To aid rapid troubleshooting a remote access telephone link was installed.

With the exception of double block and bleed valves being fitted to the differential pressure and static pressure transmitters the Vx meter would be of the standard Framo/Schlumberger design. In addition, with the exception of the densitometer and software upgrades this design was identical to that submitted to NEL as part of the JIP.

5. VOLUME CORRECTION FOR OIL SHRINKAGE AND GAS EXPANSION

Design Intent

As a hydrocarbon reservoir fluid is reduced in pressure, the equilibrium of the fluid will change, resulting in the oil becoming more ‘stable’. This is due to the solution gas progressively ‘flashing off’ as pressure reduces, leaving a ‘heavier’ more stable crude oil product. This trait is seen similarly with increasing temperature: the higher the operating temperature, then the greater quantity of gas liberated from the fluids. In the same way that oil will ‘shrink’, it is found also that the associated gas stream will accordingly ‘expand’, giving an increase in mass flow as pressure is reduced, and temperature increased.

On the Gryphon Alpha FPSO, the handled crude oil is characterised as ‘heavy’, the water / oil separation is thus relatively difficult to achieve. To this end the crude stream is heated to a temperature in excess of 85°C to maximise the water separation efficiency, whilst also being treated at low pressure (less than 1 bar(g) to achieve the crude product vapour pressure specification.

This treatment will thus result in a ‘shrinkage’ of oil mass flow between the MPM conditions of typically. 30 – 40 bar(g) and 40 – 50°C and 2nd Stage Separator conditions of ca. 0.5 bar(g) and 85°C. Similarly there will be variations in volume flow on account of the different densities of the oil at the different temperatures.

Following the decision to place the MPM upstream of the choke valve, as a means of minimising the GVF, and hence maximising oil measurement accuracy, attention was paid to developing a robust means of estimating the ‘shrinkage’ of the oil stream between the measured conditions at the meter and the rundown stream into the Cargo Oil Tanks. This was important to satisfy the Partners that the quantities reported by the MPM produced faithful estimations of the actual quantity of *stable shipped product*, this was of particular importance as the Gryphon allocation is measured by difference of the total rundown crude, and the MPM measured streams of Maclure and Tullich.

One parameter in the favour of the project is that all three reservoir fluids are characterized as being heavy crudes (containing very little intermediate component content, C3 / C4 / C5) and the associated gas is extraordinarily lean with greater than 95% non-condensibles (C1 / CO2 / N2). For this reason the ‘shrinkage’ is relatively low, less than 2% in mass terms from MPM conditions to rundown crude.

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[6] To ensure the bypass valves were not leaking, leak seal detection equipment was fitted.

Two approaches were originally considered to estimate crude shrinkage:

- Application of fixed factors based on ‘one-off’ process simulations, backed up by verification against the Test Separator;
- Application of a ‘real time’ process simulation model integrated within the flow computer system, measuring shrinkage on a continuous basis using measured Temperature (T) and Pressure (P) parameters direct from the process train.

It was decided to adopt the second of the above, on the grounds that it would be the most technically correct solution. However it was recognised during the design phase, that there would need to be provision for adopting a simpler technique if problems were found with this (ambitious) system during meter operation. This was duly incorporated into the metering agreements developed for the project.

To permit the ‘real time’ method to be used, a multi stage flash simulation was programmed into the Daniel DMS+ system. This flash calculation was based on the NEL PPDS2 software. This software was intended to be used for (a) converting the MPM readings to test separator meter conditions thus ensuring an accurate comparison could be carried out and (b) for calculating the stock tank volumes. A well sample was obtained during the development drilling and ‘clean-up’ operation and subjected to a laboratory separator test thus enabling the PPDS2 model to be tuned to faithfully reproduce the shrinkage.

The PPDS2 model was set-up for the simulation flow scheme depicted in figure 17 (‘Process Simulation’). All of the temperature and pressure parameters are measured values taken from either the PCS link or meter readings direct into the DMS+ system. The equations shown were developed to provide a simple multiplication factor on measured oil and gas based on the status of the ‘real time’ simulation. A ‘toggle switch’ was used to inform the software as to whether the MPM’s were routed to the Test Separator or 1st Stage Separator.

Precommissioning

The well test results (re-combined analysis) were duly obtained for the Maclure crude oil stream and the results analysed using both PPDS2 and HYSIS.

The full range of simulation options was not available to the PPDS2 software in the DMS+ system, as it was important to simplify the system to avoid slowing down the system operation, which ran in ‘real time’. The simulation model was premised on three consecutive flashes only, hence the only ‘degree of freedom’ available to match densities and GORs was adjustment of the heavy-ends pesudocomponent properties. With a full simulation function it would have been possible to add or remove gas to calibrate the package fully.

During the development of the definitive PPDS2+ model the emphasis was to faithfully reproduce the oil densities and volume shrinkage. This was achieved with an identified constant systemic ‘bias’ of ca. 3%. Unfortunately it was found that if the accuracy on the oil stream measurement were maximized, then the gas volume could be in error by as much as 25% based on the meter conditions, although the 1st Stage / Test gas simulated volume was good to within 2 – 3 %. This trend was identical using PPDS2 or Hysis, and was not possible to remove given the limited functionality of the simulator as programmed into the DMS+ system (it did not have the functionality to add or remove gas).

Notwithstanding the above, the system was still programmed with the developed parameters, to test during system commissioning. It was still felt that the oil accuracy would be good, and the gas measurement accuracy could be improved using a systemic bias function. The results of the offshore commissioning are discussed later in Section 6 & 7.

6 INDEPENDENT FLOW TESTING

In December 2001 the Maclure MPM was sent to the U.K. National Engineering Laboratory (NEL) for testing. The NEL multiphase facility was custom built for multiphase meter evaluation and development. This facility uses as the working fluids brine substitutes and dead crude oil (Forties/Oseberg and Exxsol D80 with a density of 865kg/m^3 @ 20^{o}C) and it uses nitrogen for the gas phase, operating at approximately 7 bar(g). However, this pressure decreases significantly as the flow rate increases. To simulate a typical brine, magnesium sulphate was added to deionised water at 50g/l giving a density of 1025kg/m3 @ 20^{o}C. The temperature is held constant by heat exchangers at approximately 40^{o}C. The oil and water pass through the reference metering section and are then combined in the mixing section. The nitrogen is then injected into the mixing section after passing through the gas metering. This three phase mixture is then flowed into the test section which runs horizontally for approximately 40m to the Vx MPM. The accuracy of the reference metering is 1%.

Figure 3 Maclure MPM Installed at NEL

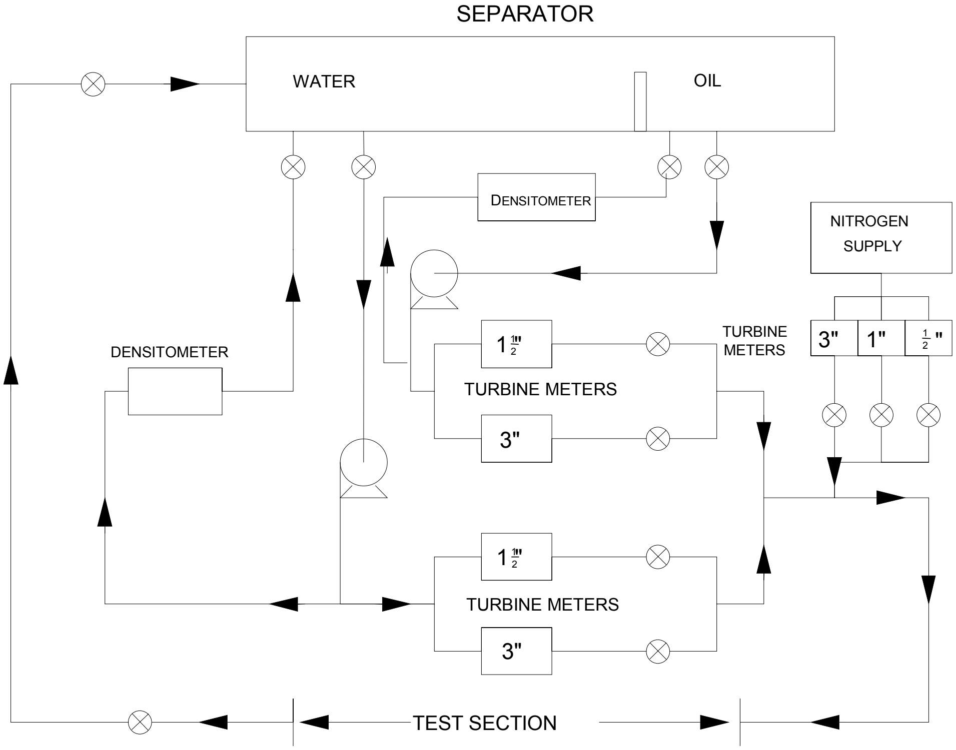

Figure 4 NEL Multiphase Test Facility

Framo were present at the tests and carried out the empty pipe count calibration (on air at atmospheric pressure) and the oil, water and gas static calibrations (the latter at operating pressure on nitrogen). At the beginning of each test point, the input reference flow conditions were set up and left to stabilise for between 10 and 20minutes prior to the measurements being taken. During the test it became necessary to revise the test matrix to ensure that the static pressure at the MPM remained above the manufacturer's low limit of 5bar; to achieve this some of the liquid flow rates had to be decreased. In addition, some of the lower flow rates had to be increased to keep the differential pressure above the manufacturer's limit of 80mbar. Some of the test points were repeated in order to test the repeatability of the meter.

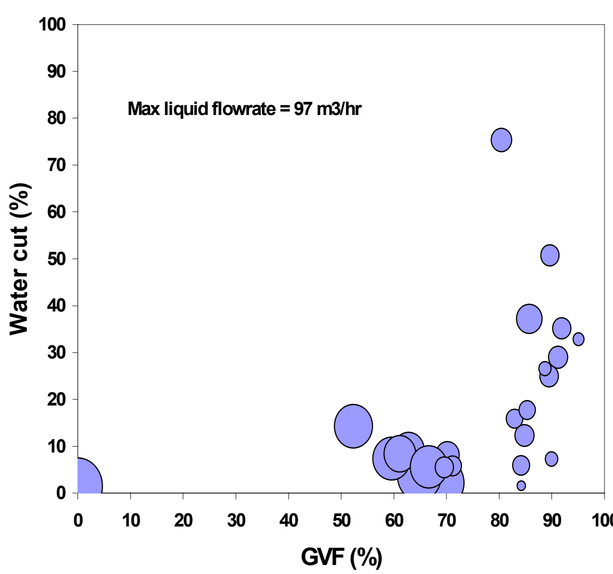

Figure 5 NEL Test Matrix for Maclure

Figure 5 details the actual test matrix completed at NEL. The size of the bubble represents the liquid flow rate, the larger the size the higher the flow rate.

Nearly all of the test points were within the manufacturer's specification. In particular the water cut performance was well within the specification (typically within 2% at all GVF's) even though the difference in the operating oil and water densities was only 150kg/m^3. It was noticeable that as the liquid flow rate decreased the liquid error increased. In order to achieve an accuracy of 5% on the oil phase the meter turn down had to be restricted to no greater than 6:1 (an approximate minimum of 3600BPD of liquid). The repeatability, on liquid flow rate, was typically within 1%.

While the meter was at NEL the opportunity was taken to train offshore personnel.

Note: The main reason for the testing was to enable partners to see the meter operating at conditions similar to those experienced offshore and thus gain confidence in the meter performance. The testing was not devised to enable the meter, in particular the venturi coefficient of discharge, to be calibrated.

Table 1 details all the test results and errors for the Maclure 52mm Vx. Figure 6 below shows the percentage oil error versus oil flow rate. From this it can be seen that there is a slight tendency for the meter to over read. This phenomena was observed during the JIP and attributed to the difficulty of calculating the mixture viscosity at high GVF's.

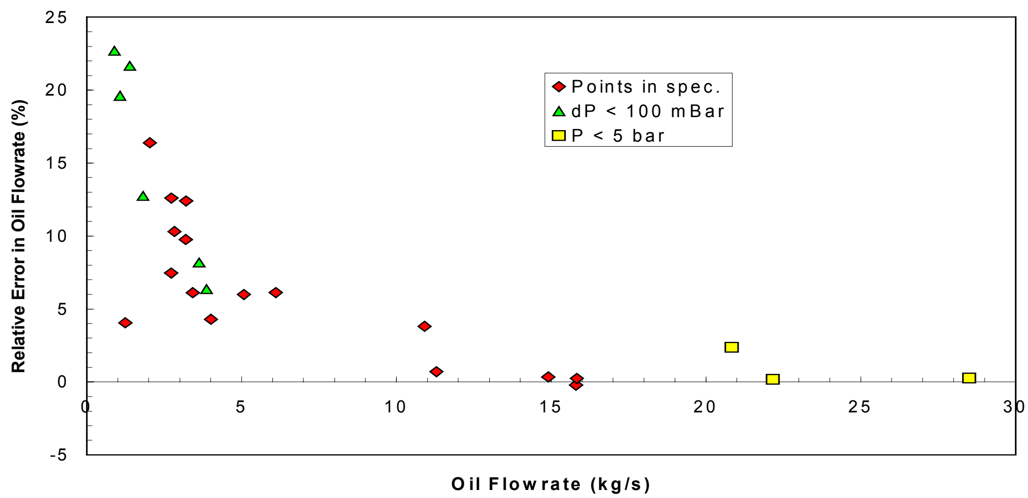

Figure 6 Maclure 52mm NEL Oil Results

Figure 7 below shows the percentage gas error versus gas flowrate, from this it can be seen that the gas error increases from typically 10% at low flow rates to 20% at high flow rates.

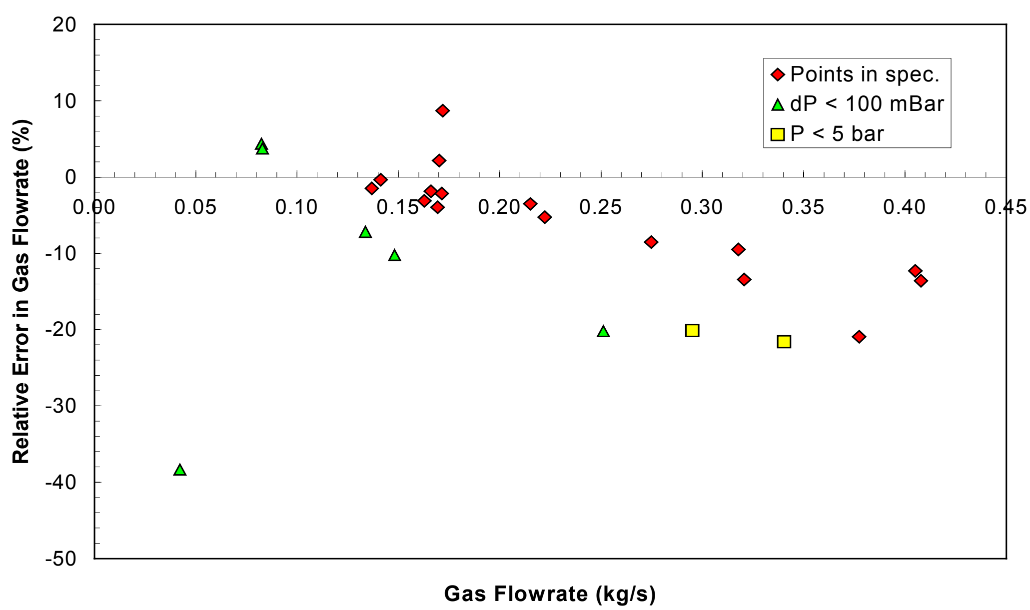

Figure 7 Maclure 52mm NEL Gas Results

Whilst the results of the meter were good, Framo pointed out that there was a significant difference between the expected field and NEL flow loop conditions. In the test the pressure was typically between 3.2 and 7.2bar whereas in the field the pressure would be between 40 to 70bar. At pressures lower than that usually experienced in the field there will be a large density difference between liquid and gas. This was deemed to influence phase slip and mixing performance thus increasing measurement uncertainties.

To correct for the over reading on the liquid flow rate the Daniel DMS+ system was programmed with a user enterable correction factor, this factor would be constant for all liquid flow rates. The water and oil flow rates would then be calculated post correction. To correct for the gas under reading the Daniel system would apply a correction based on the gas flow rate and GVF. It must be pointed out that these correction factors can only correct for bias, they cannot correct for random scatter which can be significant in MPM.

Humble Test of 52mm & 88mm Vx Meter

In November 2001 the Tullich development was sanctioned. This development comprised of four wells each with a maximum operating flow rate of 1000m^3/day. However, the expected normal flow rate through the 88mm production meter would typically be for three wells resulting in a maximum flow rate of 3000m^3/day. It was expected that all four wells would perform in a similar manner. The expected GVF's ranged from 70 to 80% with an average of 73% and the water cut ranged from approximately 5% at the start of field life to approximately 92% in year 13. Two more MPMs were required and the Framo/Schlumberger meter was deemed particularly suitable as the gamma densitometer would give reliable results across the oil/water continuous transition region, subsequently a second order was placed with Framo. For the 52mm test meter the maximum liquid flow rate would be that of two wells and thus approximately 2000m^3/day. As a contingency against a poor performing well it was decided that the 52mm test meter should be tested at GVF's up to 90%. This corresponds to the well pressure decreasing to 15barg and an additional 4mmscftd of lift gas. It was recognised that few test facilities could manage such high liquid flow rates at such high GVF's. As the meters delivery was due in April 2002 and they had to be offshore in June 2002 the hunt was on for a test facility that could meet our time frame and flow rate requirements.

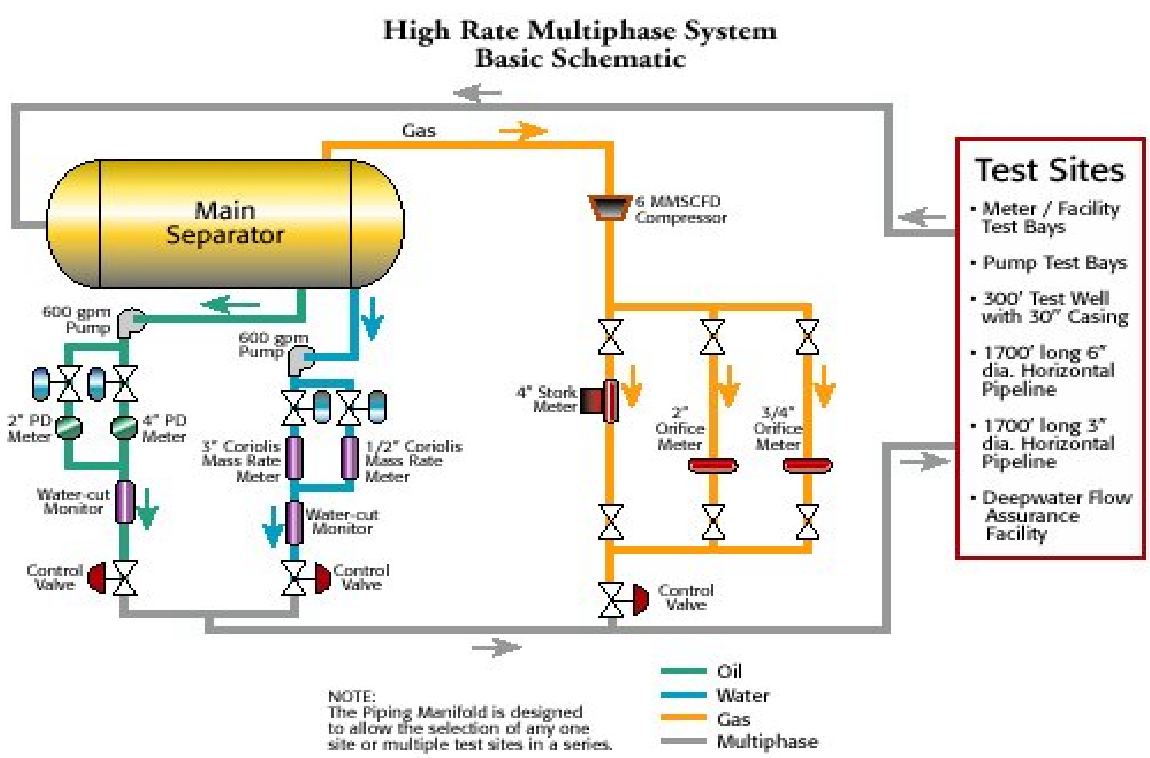

Figure 8 Humble Test Facility

Kerr-McGee commissioned NEL to devise a test matrix that would cover both the expected operating range and the potential operating range and to select a suitable test facility. The independent testing was particularly important for the production meter as its maximum flow rate exceeded the test separator capability thus it would only be possible to verify it at the maximum flow rate onshore. Taking into account a practical limit on the total number of test points NEL devised the test matrix. Further constraints were the test facility minimum operating pressure would have to be greater than 5bar at maximum flow, to avoid any inaccuracies caused by high slip ratio's at low pressures. NEL studied the following five facilities, theirs, Framo's, Humble, IFP and SWRi. IFP was unavailable, SWRi could only manage a small number of the required test points, Framo was limited by their maximum flow rate and weren't considered to be independent, NEL was limited by pressure and flow rate. Given the above, it was clear that the only suitable facility that was available was ChevronTexaco's facility in Humble Texas. Humble could operate between 3 and 35bar and achieve an accuracy on the reference measurements of 1%. The disadvantage of Humble was the cost to the Project. Humble was significantly more expensive than the other options because NEL and Framo personnel had to be mobilised from Europe; also it used live fluids[7] from a test well and thus a process model would have to be used to determine the mass transfer that would occur between the MPM and reference meters, which are at different pressures and temperatures to the separator. Further, Humble stated that Kerr-McGee would be responsible for calculating the mass transfer between phases; this can be particularly difficult and significant for the gas phase. In the actual tests this mass transfer issue turned out to be significant and difficult to model. However, when all things were considered, the Humble set-up was similar to that Kerr-McGee would have offshore (live fluids, MPM, test separator), Humble was believed to be a realistic test.

Both of the Tullich meters were delivered to Humble in June 2002. NEL attended the test as Kerr-McGee representatives and were responsible for performing the data analysis, including PVT calculations[8] as well as writing a full technical report [4]. In these tests the Vx meters were located at the end of a 570m long 6" horizontal pipeline, giving the multiphase mixture a long length to mix and reach equilibrium. However, the multiphase pipe from the mixing point goes underground before climbing up an incline of approximately 45^{o} immediately before the start of the long test pipeline. This pipeline configuration induces heavy terrain slugging in the flow, as evident during the tests.

Humble Vx Testing

As per the testing at NEL, Framo were present for the duration of the test and carried out the empty pipe counts and static calibration of the meter. As we were now using live fluids the static calibration was more complex but also more realistic than that carried out at NEL. As a result of using live fluids the mass attenuation of the gas phase was now calculated from an old composition provided by Humble as opposed to actually being measured within the meter at

[7] The molar gas composition was approximately C1 77%, C2 8%, C3 6%, C4 3.5%, C5 1.2%, C6+ 0.7%, N2 0.1and CO2 3.3%. The oil and water densities were 860 and 1015kg/m^3.
[8] NEL used their PPDS physical properties software to perform the flash calculations.

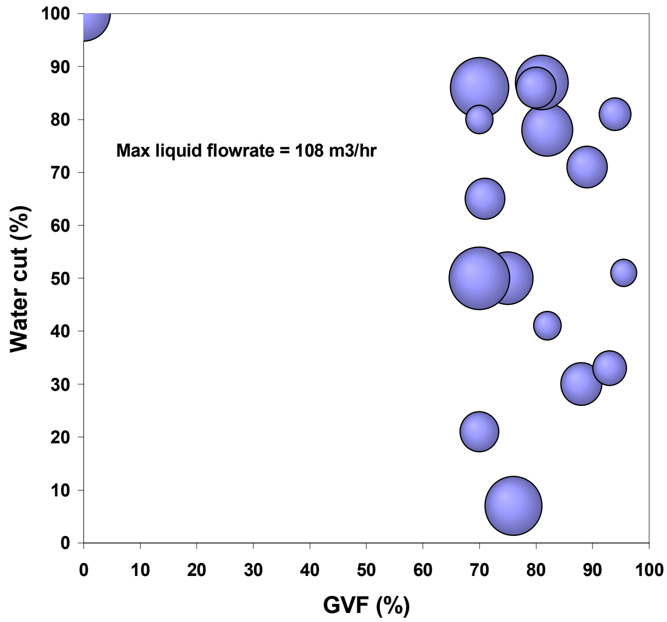

Figure 9 Actual Humble Test Matrix for 52mm

operating pressure.

During the testing of the 52mm Vx it became apparent that some of the test points could not be achieved in the Humble facility. As the GVF increased, the maximum liquid rate decreased. Furthermore, the reference meter on the liquid leg was a new 3" coriolis meter. The original meter having failed during testing. This new meter didn't have sufficient turn down to measure some of the low water rates. These two limitations and the tight timescales meant that a few of the test points had to be missed out. To ensure the testing was representative it was decided to reduce the density of the test points. Figure 9 and 10 below shows the actual completed test matrix for the 52mm and 88mmVx respectively.

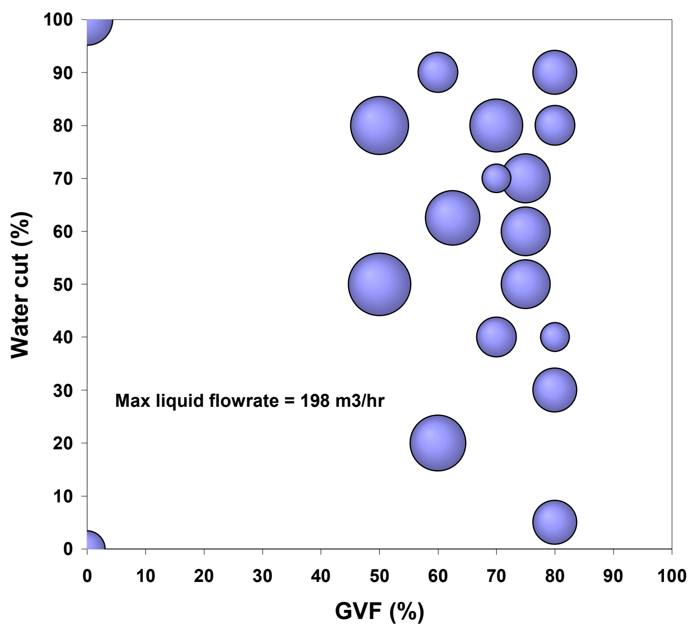

Figure 10 Actual Humble Test Matrix for 88mm

Table 1 details all the test results and errors for the 52mm Vx. However, figure 11 below shows the percentage oil error versus oil flow rate. From this graph it can be seen that the oil error increases as the oil flow rate decreases, this is similar to the NEL test results for the Maclure 52mm Vx. However, it can be seen that the Tullich meter tested at Humble appeared to perform worst although some of the low flow rate points were conducted at higher GVF's. Generally, for both the Tullich and Maclure meters if the liquid flow rates were in excess of 5000BPD (8kg/s) then the error on the oil phase would be less than 5% and thus would meet the project requirement.

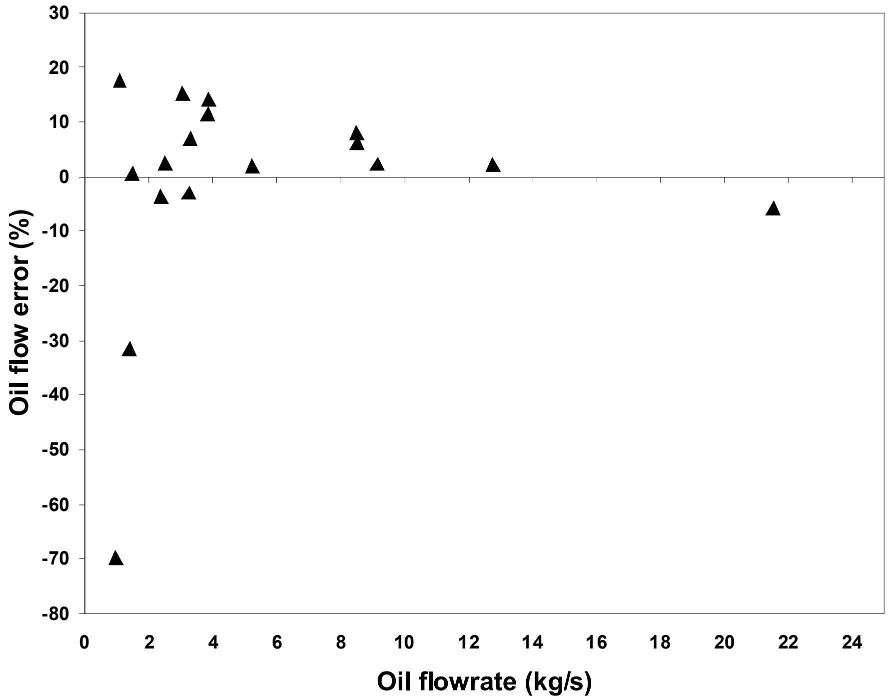

Figure 11 Humble Oil Results for 52mm

Figure 12 shows the percentage gas error versus gas flowrate, from this it can be seen that the performance of the 52mm Vx appears poor (errors between –10 to –50%). However, it is now thought likely that these errors were caused by inaccuracies in setting up the meter. Both the Maclure 52mm and Tullich 88mm were set up by the same Framo engineer however, the Tullich 52mm was set up by a different engineer. For the Tullich 52mm meter the empty pipe count check was carried out overnight and it is now thought likely that condensation formed within the meter thus causing an error in the empty pipe count checks. The Tullich 88mm had its empty pipe count check done during the middle of the day thus avoiding the likely hood of condensation forming.

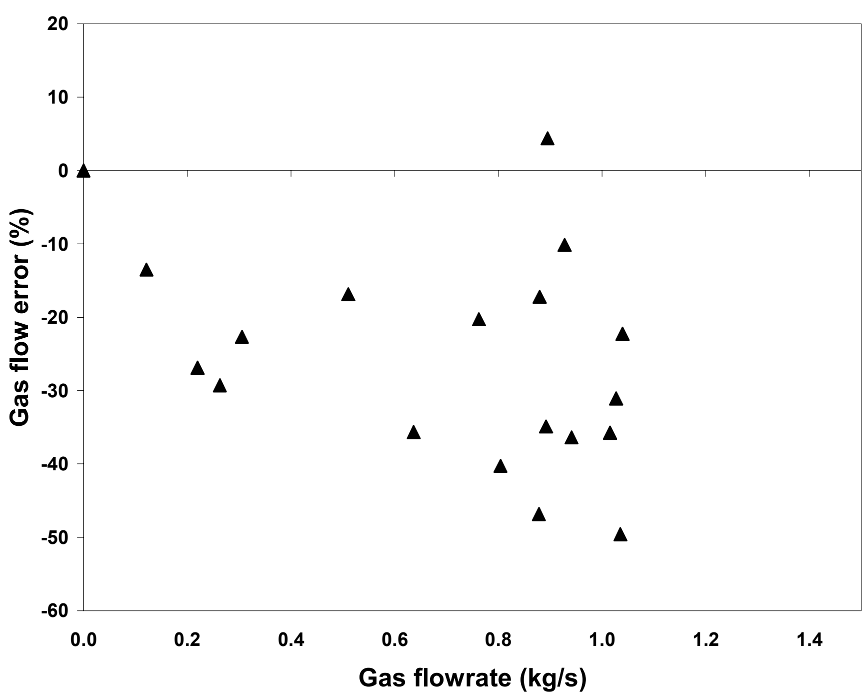

Figure 12 Humble Gas Results for 52mm

Table 3 details all the Humble test results and errors for the 88mm Vx. However, Figure 13 below shows the percentage oil error versus oil flow rate. From this graph it can be seen that yet again the oil error increases as the oil flow rate decreases. Generally, if the liquid flow rate was in excess of 8500BPD (14kg/s) then the error on the oil phase would be less than 5% and thus would meet the project requirement. Although, the 88mm Vx has a longer path length (throat diameter) and thus attenuates the gamma rays more, the meter performance did not seem to be significantly better than the 52mm.

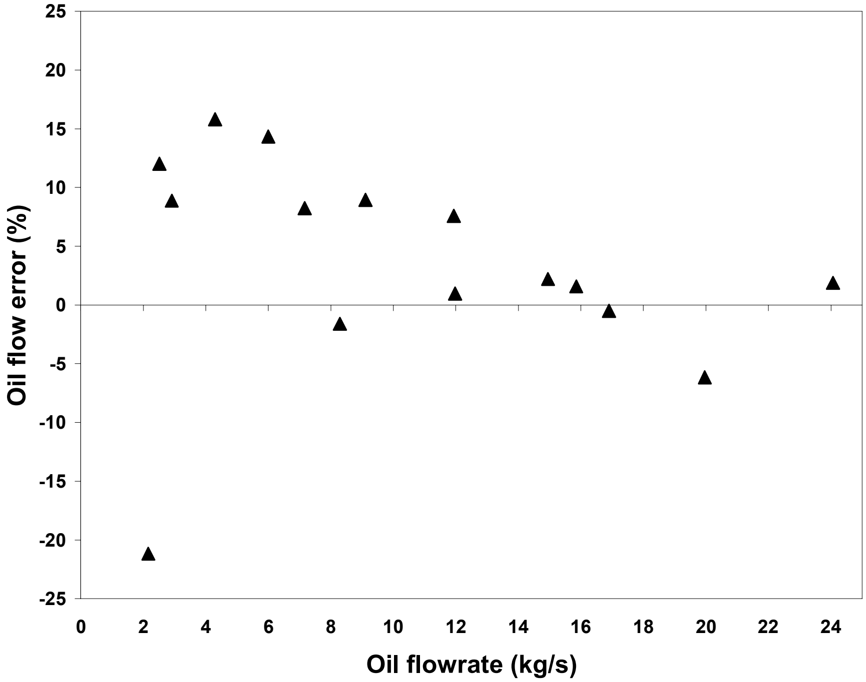

Figure 13 Humble Oil Results for 88mm

Figure 14 shows the percentage gas error versus gas flow rate, from this it can be seen that the performance of the 88mm Vx was significantly better than the either of the 52mm Vx's with typical errors within 10%. This improved accuracy may be due to the increased path length thus increased attenuation.

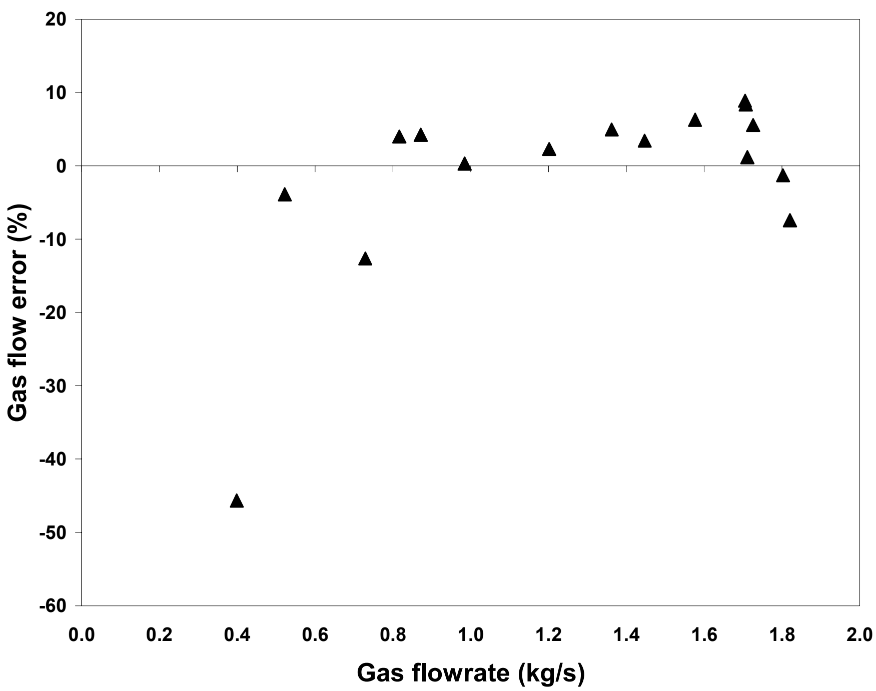

Figure 14 Humble Gas Results for 88mm

7 OFFSHORE OPERATION

Commissioning

The N2/He leak testing was completed prior to the fitting of the gamma densitometer. This was to protect the detector from premature ageing by the helium passing through the low attenuation window. Once this was complete, Framo/Schlumberger proceeded with the commissioning of all three meters. Similar to Humble the mass attenuation of the gas phase was calculated from the composition and the oil and water attenuations were measured using the actual Vx meter. The oil sample was obtained during the well drilling operations. To enable measurement of the mass attenuations of the oil and water the meter had to be removed from the line and the oil and water samples lowered into the venturi throat. The disadvantage is that each meter would need two witness joints. However, after start up larger fluid quantities would be available, and, using the drain and vent connections provided as part of the design, the static calibration could be carried out in situ. Although care would have to be taken to ensure that say during the gas calibration a thin film of oil would not be present on the gamma densitometer window.

The Maclure well was started up and routed to the test separator for one week, this enabled the well to be cleaned up and for a comparison to be made with the test separator meters. For the oil phase the test separator was equipped with new Fisher Rosemount Elite Coriolis meters (2 x 3" in parallel) however the gas orifice and magnetic water meters were existing, although the gas meter had a new orifice plate fitted. The orifice meter had an upstream straight length of approximately 30D and was of the junior carrier type; a Daniel S600 flow computer calculated the flow rate. Care had been taken with the installation of the coriolis meters to ensure that there was approximately 8m of static head to avoid gas break out. The coriolis meters were fitted with Nett Oil computers to allow detection of water carry over. All meters, including the MPM's communicated with the Daniel DMS+ system.

During the offshore testing phase, it was found that the Maclure flowing GVF was in the range 50 to 55%, and the water-cut was lower than 1%.

Verification

At the time of preparing this Paper (31 August 2002) only the Maclure MPM has been commissioned.

Although the Tullich field started up on 27 August 2002, its production is currently routed through the test separator, as the MPM calibration / set-up was delayed to allow the first oil programme to be prioritised. At this time the Tullich allocation is being calculated based on the test separator (single-phase) meters.

The Maclure MPM was successfully commissioned in late July 2002. It was routed initially through the Test Separator to allow a direct verification of the MPMs readings against the Test Separator readings. This was continued for a period of a complete week, during which a detailed verification programme was undertaken.

The following conclusions were found:

- Because of the high flow rate, low water-cut and low GVF (respectively 1% and 55%) it was found that there was an excellent correlation between the Test Separator meter and the MPM readings;
- This correlation was proved over a range of flowrates – the 'raw' multiphase reading always being a constant percentage away from the test separator readings:

Test 1	Two verification tests over a period of 8 hours At 10,000 BPD	Oil – consistently 5.6% low Gas – consistently 0.75% low
Test 2	Three verification tests over a period of 9 hours At 10,000 BPD	Oil – consistently 5.6% low Gas – consistently 0.9% low
Test 3	Using manually estimated bias values (from Tests 1 and 2) – Two tests over a period of 2 hours	Oil – consistently within ±0.2% Gas – consistently within ±0.2%
Test 4	Using manually estimated bias values (from Tests 1, 2 and 3) – Four tests over a period of 10 hours	Oil – consistently within ±0.4% Gas – consistently within ±0.75%

- The measured MPM gas quantity was consistently between 0% and 5% low, the bias increasing with increasing gas flowrate. At 9,000 BPD the bias was zero percent, this increased to 4% at 14,000 BPD.

- The measured oil quantity was consistently ca. 6% low with this bias insensitive to oil throughput – the oil, in particular, showed an excellent correlation against the test separator;

- Because of the simulation difficulties outlined in Section 4 above, it was found that the ‘corrected’ PPDS2 generated gas quantities were significantly in error and the ‘corrected’ oil quantities displayed a less robust correlation against the Test Separator

- For the above reasons it was decided, following consultation with all Partners, to adopt a simple bias correction system as opposed to using the ‘real time’ model. This was justifiable because of the excellent correlation between the MPM and Test Separator readings, thus greatly increasing confidence that metering accuracy well within the stipulated 5% on oil was being achieved. This simple approach is usable as the gas contained low quantities of condensables; the gas being 94% C1.

8 CONCLUSION

The advantage of the NEL test facility over Humble was it operated with a stabilised crude oil and nitrogen gas and thus there was no mass transfer between the phases. This enabled accurate reference measurements to be made. However, NEL can only operate at low pressures which raised concern that it could cause large errors in the MPM slip models. In addition, its maximum flow rate was limited. It must be pointed out that while the 5bar pressure limit seems low there are production facilities around the world that do operate their separators at these low pressures and thus the tests could be deemed to be realistic.

Humble had the distinct advantage that it could operate at high pressure and high flow rates. It test with live fluids and thus the requirement to use process modelling to correct for the mass transfer across phases could also be deemed realistic as this is what happens in the real world when we try and verify a MPM against a test separator.

Over the limited range of GVF’s tested it can be seen that the error in the liquid measurement at low flows becomes significant. All three tests proved that it was possible to achieve an uncertainty on the oil phase of less than 5% at moderate flow rates. The accuracy of the water cut measurement was always within 2% regardless of the GVF. The accuracy of the gas flow rate was typically within 10%.

Offshore verifications revealed that there was a positive bias of approximately 5.9% in the liquid flow rate; when this was corrected for the MPM oil measurement was typically within ±0.4% of the coriolis meters. Similarly the gas measurement exhibited a bias of 0-4% (increasing with flow) and when removed the gas rate was typically within ±0.75%.

9 ACKNOWLEDGEMENTS

The author would like to thank the U.K. National Engineering Laboratory for allowing a significant number of graphs and figures to be copied from their reports. In addition, the author would like to thank BP for their constructive input throughout the duration of the project.

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11 NOTATION

Notation	Description
BPD	Barrels per Day
GVF	Gas Volume Fraction
JIP	Joint Industry Project
MPM	Multiphase Meter
NEL	U.K. National Engineering Laboratory
PCS	Process Control System
WC	Water Cut

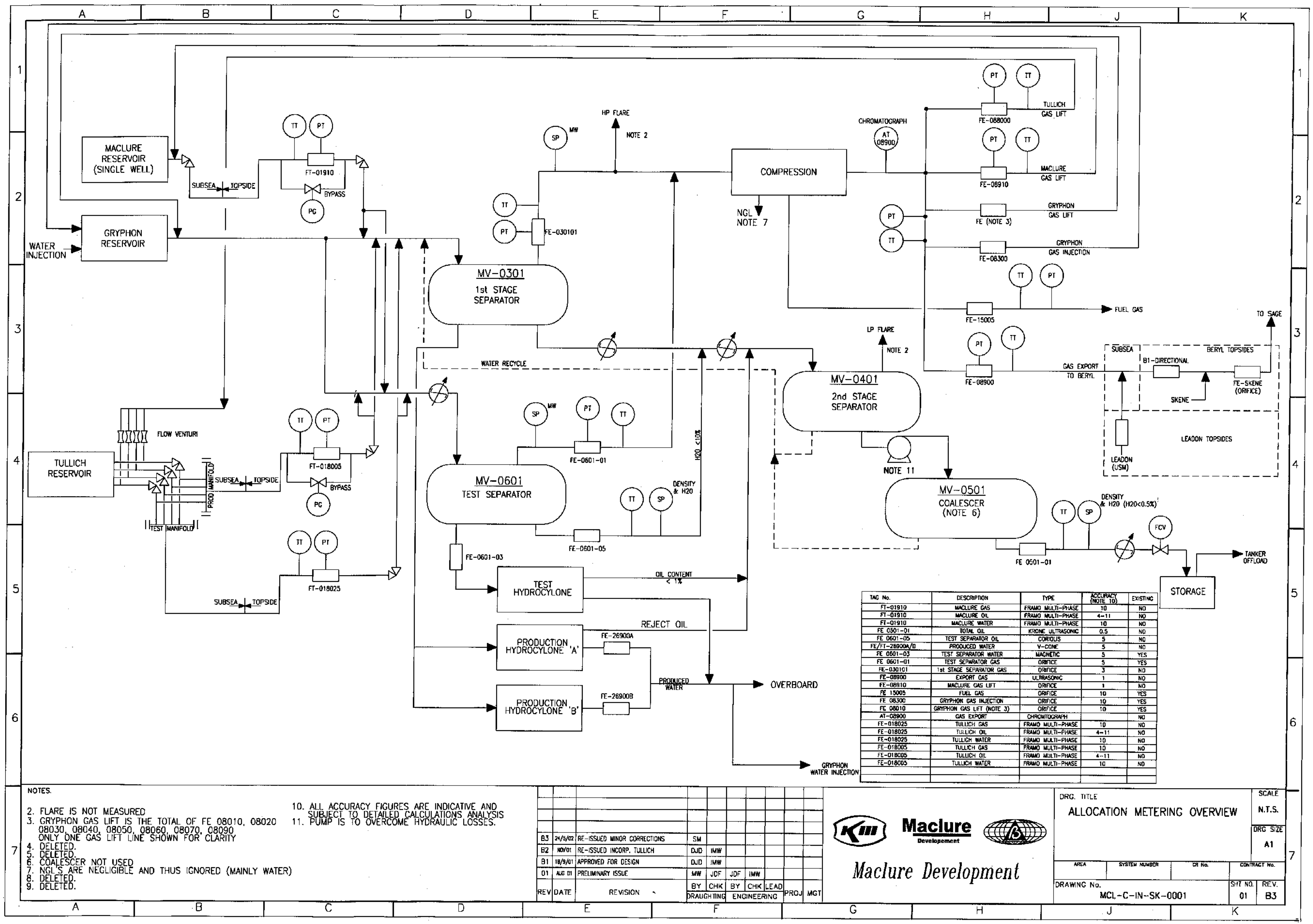
12 REFERENCES

[1] Characterisation of the Performance of Multiphase Flow Meters Tests of the 4” 3-Phase VenturiX Multiphase Flow Meter, NEL July 1999

[2] Evaluation of a 4” Phase Watcher Multiphase Meter, NEL December 2001

[3] Tullich Multiphase Meter Testing Consultancy, NEL March 2002

[4] Tullich Multiphase Meter Testing at Humble Facility, NEL June 2002



TAG No.	DESCRIPTION	TYPE	ACCURACY (NOTE 10)	EXISTING
FT-01910	MACLURE GAS	FRAMO MULTI-PHASE	10	NO
FT-01910	MACLURE OIL	FRAMO MULTI-PHASE	4-11	NO
FT-01910	MACLURE WATER	FRAMO MULTI-PHASE	10	NO
FE 0501-01	TOTAL OIL	KRONE ULTRASONIC	0.5	NO
FE 0601-05	TEST SEPARATOR OIL	CORIOLIS	5	NO
FE/FT-26900A/B	PRODUCED WATER	V-CONE	5	NO
FE 0601-03	TEST SEPARATOR WATER	MAGNETIC	5	YES
FE 0601-01	TEST SEPARATOR GAS	ORIFICE	5	YES
FE-030101	1st STAGE SEPARATOR GAS	ORIFICE	3	NO
FE-08900	EXPORT GAS	ULTRASONIC	1	NO
FE-08910	MACLURE GAS LIFT	ORIFICE	1	NO
FE 15005	FUEL GAS	ORIFICE	10	YES
FE 08300	GRYPHON GAS INJECTION	ORIFICE	10	YES
FE 08010	GRYPHON GAS LIFT (NOTE 3)	ORIFICE	10	YES
AT-08900	GAS EXPORT	CHROMTOGRAPH		NO
FE-018025	TULLICH GAS	FRAMO MULTI-PHASE	10	NO
FE-018025	TULLICH OIL	FRAMO MULTI-PHASE	4-11	NO
FE-018025	TULLICH WATER	FRAMO MULTI-PHASE	10	NO
FE-018005	TULLICH GAS	FRAMO MULTI-PHASE	10	NO
FE-018005	TULLICH OIL	FRAMO MULTI-PHASE	4-11	NO
FE-018005	TULLICH WATER	FRAMO MULTI-PHASE	10	NO

NOTES.

2. FLARE IS NOT MEASURED
3. GRYPHON GAS LIFT IS THE TOTAL OF FE 08010, 08020 08030, 08040, 08050, 08060, 08070, 08090 ONLY ONE GAS LIFT LINE SHOWN FOR CLARITY
4. DELETED.
5. DELETED.
6. COALESCER NOT USED
7. NGL'S ARE NEGLIGIBLE AND THUS IGNORED (MAINLY WATER)
8. DELETED.
9. DELETED.
10. ALL ACCURACY FIGURES ARE INDICATIVE AND SUBJECT TO DETAILED CALCULATIONS ANALYSIS
11. PUMP IS TO OVERCOME HYDRAULIC LOSSES.

Figure 15 Process Flow Diagram

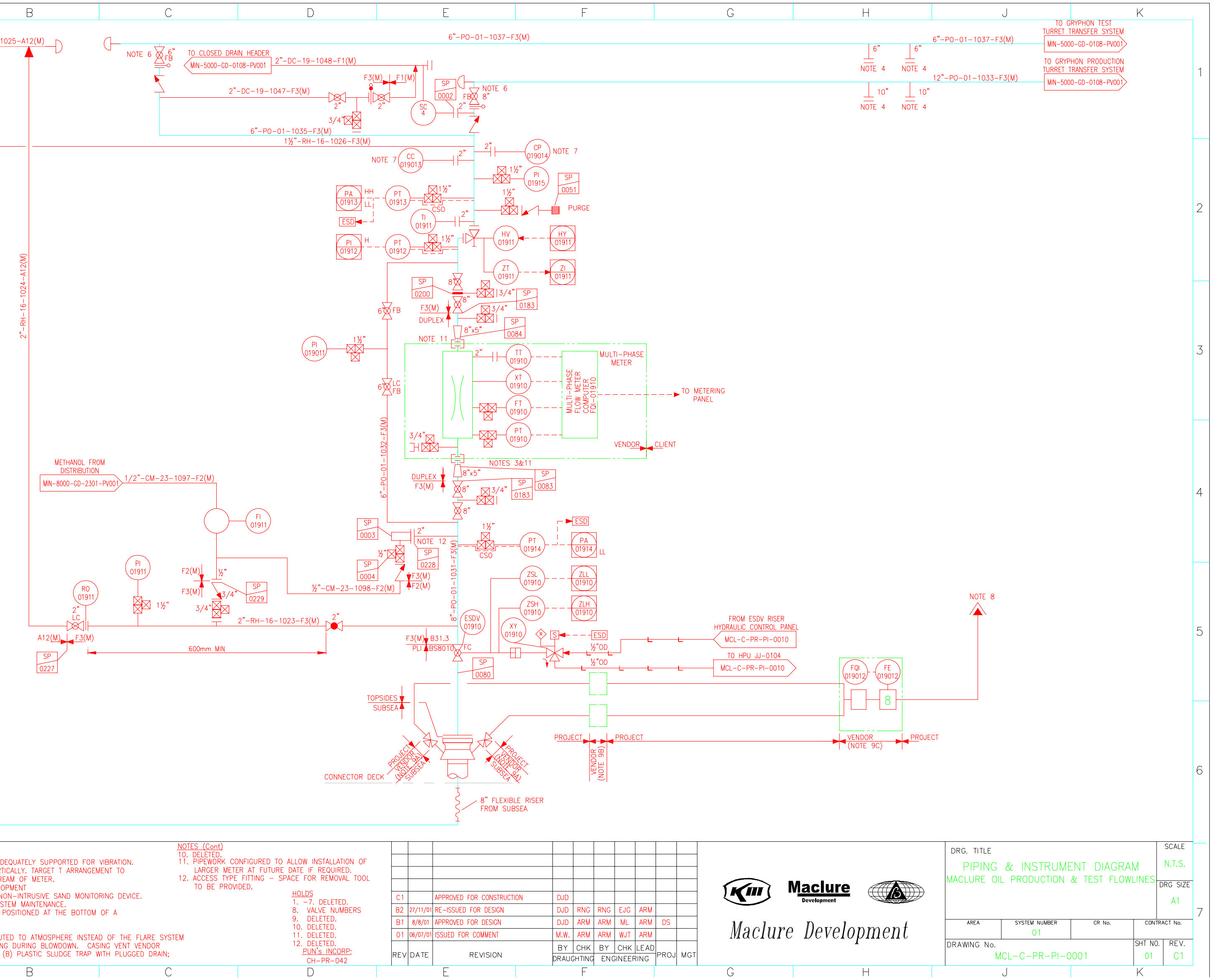
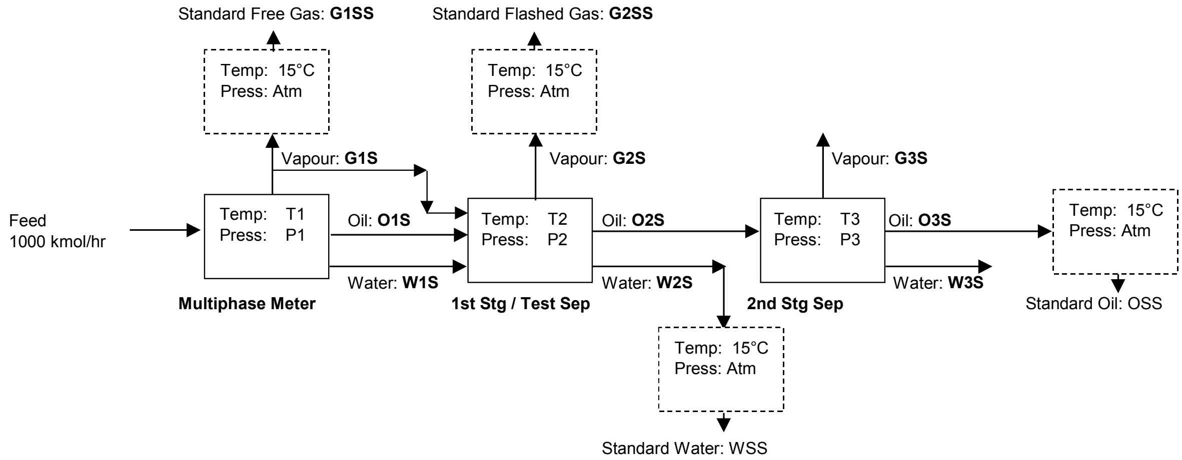


Figure 16 MPM PID

PROCESS SIMULATION (PPDS2 MODEL WITHIN THE DANIEL DMS+)

Simulated Streams



Metered Streams

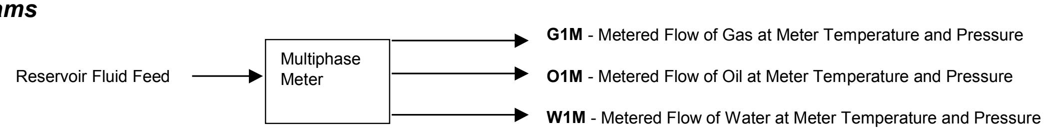


Figure 17 PPDS2 Model within DMS+

The flows at standard conditions (based on the metered readings) can be obtained using the following relationships:

- Oil Produced = $\left[\frac{OSS}{O1S}\right]\times O1M$
- Gas Produced = $\left[\frac{O1M\times(G2SS-G1SS)}{O1S}\right]+\left[G1M\times\left(\frac{G1SS}{G1S}\right)\right]$
- Water Produced = $\left[\frac{WSS}{W1S}\right]\times W1M$

The above equations are premised on the assumption that any additional associated gas generated in the 1st Stage or test Separator is produced from the oil content of the reservoir fluids.

Similarly, the multiphase meter process simulation will determine the 'oil shrinkage' and gas expansion factors

The Oil Shrinkage Factor: (OSF) = $\left[\frac{OSS}{O1S}\right]$

The Gas Expansion Factor (GEF) **=** $\left[\frac{O1M\times(G2SS-G1SS)}{O1S\times G1M}\right]+\left[\left(\frac{G1SS}{G1S}\right)\right]$

INDEPENDANT FLOW TEST RESULTS

The actual test points tested at NEL and Humble for each of the meters is detailed below:-

Table 1 Maclure NEL 52mm Test Results

Test File Information				Reference Measurements					Multiphase Meter Data			Calculated Errors		
Framo Test ID	NEL Test File	NEL Test Point	No. Records Records	Mean Pressure (bar g)	Mean Temp (degC)	Total liquid (kg/s)	Gas Flow (kg/s)	Water Cut (%)	Total liquid (kg/s)	Gas Flow (kg/s)	WLR (%)	Total liq mass flow (% rel)	Gas flow error (% rel)	WLR error (% abs)
P3	FRE001	4	86	3.40	36.99	29.06	0.00	1.50	29.02	0.00	1.28	-0.13		-0.23
P9	FRE001	5	90	5.86	35.96	0.91	0.04	1.58	1.12	0.03	1.95	23.11	-38.33	0.37
P12	FRE001	6	86	4.56	37.06	21.42	0.34	2.19	21.80	0.27	1.83	1.79	-21.58	-0.35
P5	FRE001	7	90	4.45	36.92	23.20	0.30	3.68	23.33	0.24	4.08	0.55	-20.11	0.41
P10	FRE002	1	86	5.82	37.20	4.68	0.22	12.26	4.89	0.21	12.44	4.41	-5.27	0.18
P19	FRE002	2	100	6.05	38.63	4.55	0.32	50.72	5.11	0.28	49.07	12.20	-13.41	-1.65
P16	FRE002	3	100	5.74	38.82	4.50	0.41	35.15	5.00	0.35	34.41	11.01	-13.61	-0.74
P17	FRE002	4	100	5.85	38.19	4.77	0.41	28.96	5.24	0.36	27.49	9.75	-12.28	-1.46
P15	FRE002	5	100	5.91	37.81	4.47	0.32	24.95	4.88	0.29	24.77	9.31	-9.50	-0.18
P11	FRE002	6	100	6.12	39.85	1.99	0.13	26.57	2.39	0.12	25.78	20.01	-7.18	-0.79
P4	FRE002	7	100	5.41	38.96	1.70	0.25	32.84	2.06	0.20	33.68	21.21	-20.18	0.83
P6	FRE002	8	100	5.60	37.52	12.23	0.17	9.11	12.75	0.17	9.54	4.28	2.18	0.44
P7	FRE002	9	100	6.10	37.59	6.75	0.14	8.13	7.10	0.14	7.47	5.10	-0.36	-0.67
P13	FRE002	10	100	5.70	36.86	17.33	0.22	7.34	17.46	0.21	7.75	0.77	-3.52	0.40
P18	FRE002	11	100	5.66	39.18	1.99	0.15	7.24	2.22	0.13	6.64	11.69	-10.23	-0.60
P8	FRE002	12	100	5.86	39.12	3.90	0.08	5.79	4.22	0.09	5.91	8.22	4.35	0.12
P14	FRE003	1	100	5.55	35.48	3.47	0.14	15.89	3.84	0.13	16.11	10.54	-1.49	0.23
P2	FRE003	2	100	5.11	36.68	8.66	0.38	37.16	9.06	0.30	36.46	4.61	-20.93	-0.70
P1	FRE003	3	100	5.72	38.14	17.87	0.16	14.25	18.03	0.16	14.69	0.94	-3.14	0.44
P6b	FRE003	4	100	5.95	37.57	12.55	0.17	8.41	12.73	0.17	9.11	1.50	-2.17	0.70
P9b	FRE003	5	100	5.76	38.59	3.69	0.17	5.91	3.95	0.16	6.78	7.19	-1.85	0.87
P12b	FRE003	6	100	5.46	36.96	16.91	0.27	5.57	16.94	0.25	5.87	0.14	-8.54	0.30
P8b	FRE003	7	100	5.99	39.48	4.14	0.08	5.46	4.39	0.09	5.28	6.00	3.73	-0.18
P14b	FRE003	8	100	5.95	39.37	3.43	0.17	17.69	3.71	0.16	18.23	8.25	-3.96	0.55
P20	FRE003	9	100	5.63	42.26	5.77	0.17	75.32	5.80	0.19	74.51	0.57	8.70	-0.81

Table 2 Tullich Humble 52mm Test Results

	Reference					Vx meter			Meter errors		
Point No.	Vx throat Pressure (bar a)	Vx Temp (oC)	Liquid flow (kg/s)	Gas flow (kg/s)	Water cut (%)	Liquid flow (kg/s)	Gas flow (kg/s)	Water cut (%)	Liquid flow (%)	Gas flow (%)	Water cut (% abs)
2	11.7	46.3	23.19	0.000	100.0	22.56	0.001	99.9	-2.7	n/a	-0.1
5	7.8	52.9	26.54	0.763	86.0	26.29	0.608	86.6	-0.9	-20.3	0.5
11	10.0	52.5	12.37	0.510	86.4	12.46	0.424	88.0	0.8	-16.9	1.7
13	10.1	51.9	11.97	0.306	64.7	12.28	0.236	65.2	2.6	-22.7	0.5
15	9.6	50.8	12.57	0.928	71.4	13.20	0.833	76.3	5.0	-10.2	4.9
8	8.1	50.6	21.75	1.039	87.8	22.36	0.808	89.8	2.8	-22.3	2.1
16	7.8	44.8	11.08	0.263	20.8	11.58	0.186	20.7	4.5	-29.3	-0.1
17	8.5	44.9	5.50	0.220	41.1	5.93	0.161	40.5	7.8	-26.9	-0.6
19	8.6	46.2	6.21	0.121	80.4	6.36	0.105	79.9	2.4	-13.5	-0.5
4	6.6	47.2	19.37	0.637	49.4	18.28	0.410	48.8	-5.6	-35.6	-0.6
10	5.9	48.5	27.61	0.804	50.4	25.97	0.480	49.8	-5.9	-40.3	-0.6
3	6.2	50.3	23.45	1.036	7.2	22.15	0.522	8.3	-5.5	-49.6	1.1
20	7.9	48.8	8.13	1.027	32.6	8.01	0.708	33.5	-1.5	-31.1	0.9
21	7.5	49.2	8.08	1.016	80.9	8.97	0.653	90.1	11.1	-35.7	9.2
7	6.4	50.3	20.02	0.941	78.6	20.17	0.599	78.1	0.7	-36.4	-0.5
6	6.2	49.5	12.59	0.878	29.5	12.66	0.467	28.5	0.6	-46.8	-1.0
24	6.8	46.9	5.47	0.892	51.0	5.91	0.581	57.4	8.1	-34.9	6.4
26	6.8	44.7	3.39	0.879	68.7	2.92	0.728	90.1	-13.9	-17.2	21.4
27	7.2	38.7	0.00	0.895	n/a	0.21	0.934	15.0	n/a	4.4	n/a

Table 3 Tullich Humble 88mm Test Results

Point No.	Reference: Vx throat Pressure (bar a)	Reference: Vx Temp (oC)	Reference: Liquid flow (kg/s)	Reference: Gas flow (kg/s)	Reference: Water cut (%)	Vx meter: Liquid flow (kg/s)	Vx meter: Gas flow (kg/s)	Vx meter: Water cut (%)	Meter errors: Liquid flow (%)	Meter errors: Gas flow (%)	Meter errors: Water cut (% abs)
2	15.0	50.0	38.43	0.000	100.0	37.96	0.000	104.0	-1.2	n/a	4.0
10	17.3	50.5	39.85	1.576	79.5	38.18	1.676	79.7	-4.2	6.3	0.2
9	17.2	50.7	32.93	1.711	59.9	30.97	1.731	58.5	-6.0	1.2	-1.4
8	17.1	50.7	25.49	1.820	30.2	23.48	1.685	28.4	-7.9	-7.4	-1.8
11	17.2	45.1	28.85	1.707	89.8	27.87	1.850	89.9	-3.4	8.4	0.0
12	17.8	45.0	32.89	1.705	68.8	30.81	1.856	67.8	-6.3	8.9	-1.1
15	18.4	45.4	52.20	0.984	49.6	50.30	0.987	51.3	-3.6	0.3	1.6
6	18.4	45.1	40.59	1.201	18.9	37.53	1.229	20.1	-7.5	2.3	1.1
3	17.7	44.6	27.91	1.803	7.1	25.59	1.779	4.5	-8.3	-1.3	-2.6
20	15.8	43.4	10.93	0.729	41.1	11.37	0.637	39.4	4.0	-12.6	-1.7
18	16.3	45.1	20.89	0.817	38.7	19.62	0.849	38.4	-6.1	4.0	-0.4
4	17.6	45.5	33.60	1.726	48.7	30.92	1.822	47.9	-8.0	5.6	-0.8
24	18.3	46.2	44.17	1.362	62.3	42.28	1.430	63.9	-4.3	5.0	1.6
7	18.3	47.0	47.36	0.872	79.9	46.36	0.909	82.4	-2.1	4.2	2.5
19	16.2	47.0	23.69	0.522	89.4	23.69	0.502	92.8	0.0	-3.9	3.4
22	15.5	46.6	11.14	0.399	70.6	11.21	0.217	71.8	0.6	-45.6	1.1
16	16.5	47.2	23.89	1.447	79.5	23.01	1.497	78.4	-3.7	3.4	-1.1
1	16.0	46.7	19.96	0.002	0.0	18.72	0.009	-0.1	-6.2	354.1	-0.1