Paper 5

Penguin Wet Gas Measurement

Ian M. Wood, Shell U.K. Exploration & Production, UK,
Paul Daniel, Alan Downing, Solartron ISA, UK

Penguin Dualstream II Wet Gas Measurement

Ian Wood, Shell U.K. Exploration and Production[1]
Paul Daniel, Solartron ISA

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1 INTRODUCTION

The Penguin cluster is a formation of five different reservoirs located in the UK sector of the North Sea. It is produced via a 65km subsea tie-back to the Brent Charlie platform; the world's third longest tie-back. The cluster is made up of five different reservoirs, each with significantly different gas to oil ratios. The gas volume fraction (GVF) of the arriving fluids is in the region of 85 to 95% and thus was considered to be too high for accurate (±5%) measurement of the gas and oil phases using a multiphase meter (MPM) and too low for a wet gas meter. Due to the length of the tie-back a Severe Slug Suppression Device (S^3) was installed on the platform topsides. The S^3 in effect acts as a partial separator and thus the opportunity was taken to use this device to partially separate the fluids and hence move the MPM in to a more favourable operating environment. Consequently a 14 inch Solartron ISA Dualstream II (DS II) wet gas meter was installed on the wet gas outlet of the S^3 and a Framo Vx multiphase meter on the gassy liquid outlet. The outlet of these meters is then recombined prior to being routed either to the production or test separator. Prior to the production separator the Penguin fluids are commingled with the Brent fluids. As Brent pays Petroleum Revenue Tax and Penguin does not, there is a requirement for the metering to achieve an accuracy of ±5% on gas and oil.

Following start-up it was observed that the readings from the DS II wet gas meter were out with the manufacturers specifications of ±5% for gas and ±10% for liquids. The meter was operating at a pressure of 35bar and Lockhart-Martinelli (LM) values of up to 0.5. Based on the information available it was concluded that the correction algorithms required for the Penguin meter differed significantly from those obtained with the previous much smaller 6 inch research meters (and on which the Penguin meter correlations had been based).

With a nominal pipe size of 14 inches, Penguin was by far the largest DS II meter Solartron ISA had manufactured, and unfortunately, at the time of manufacture there was no test facility that was realistically capable of testing the meter on wet gas.

However, with the commissioning of the enhanced Statoil K-Lab wet gas test facility, it was decided that the best method to ascertain the cause of the flow meter discrepancy was to manufacture a second identical meter and to test it across as much of the operating range of the Penguin meter as possible.

This paper discusses the performance of the DS II meter immediately after first oil, the changes and onshore testing required to meet the specification, and the actual offshore testing of the new algorithms.

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[1] Shell U.K. Exploration and Production (Shell Expro) operate the Penguins and Brent fields on behalf of the licensees, Shell UK Limited (50%) and Esso Exploration and Production UK Limited (50%)

2 THE PENGUIN METERING CHALLENGE

The Penguin cluster, shown in Figure 1, is located in the UK sector of the North Sea and is produced via a 65km subsea tie-back to the Brent Charlie platform. The cluster is made up of five different reservoirs, each with significantly different gas to oil ratios (ranging from 670 to 4200 scft/bbl), none of which are anticipated to produce water. The gas volume fraction of the arriving fluids is in the region of 85 to 95% and thus was considered to be too high for accurate (±5%) measurement of the gas and oil phases using a multiphase meter (MPM) and too low for a wet gas meter.

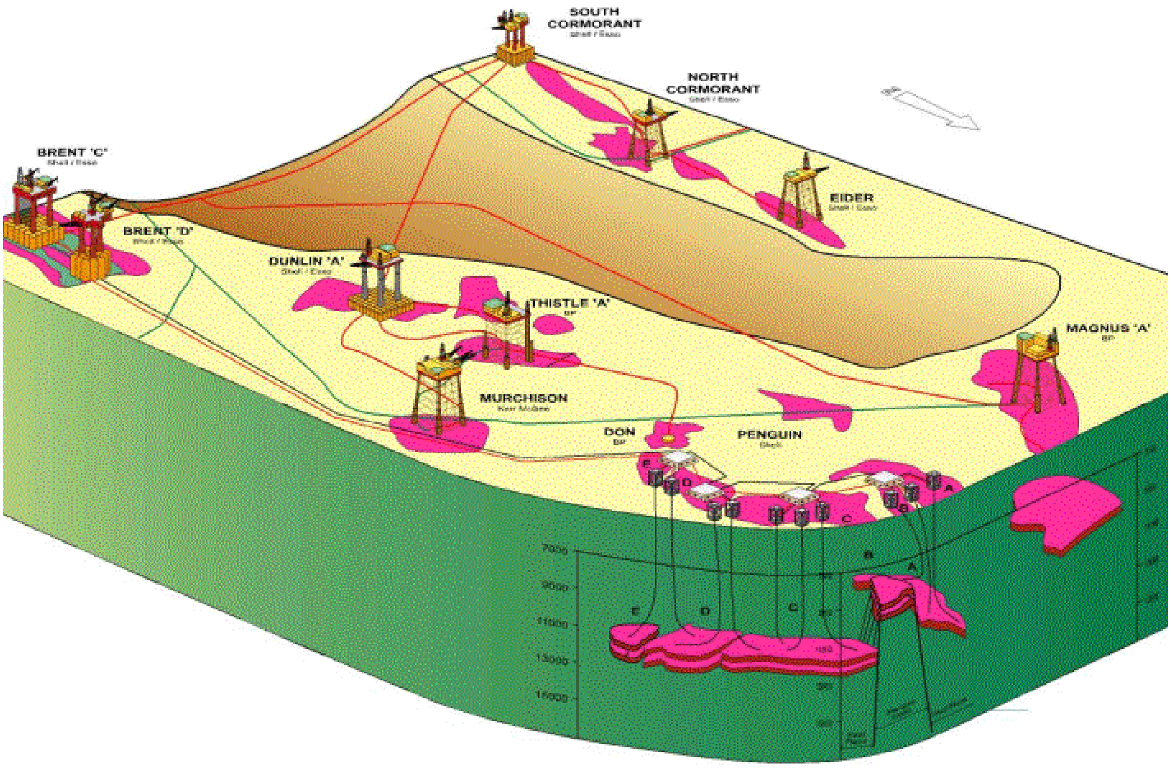

FIGURE 1:- THE PENGUIN FIELD

The cost of retrofitting a new separator would have been prohibitively expensive and was the financial driver to explore a multiphase metering solution. However, due to the length of the tie-back, a severe slug suppression device (S^3) was required. Although slug mitigation is the primary purpose of the S^3, it does in effect act like a partial separator and the opportunity was taken to use this device to partially separate the fluids and thus move the MPM in to a more favourable operating environment. Consequently a Solartron ISA DS II wet gas meter was installed on the wet gas outlet and a Framo Vx Multiphase Meter on the gassy liquid outlet. The intent was that by using the S^3 the operating envelope of the MPM could be moved from a high GVF (85% plus) to a more favourable low GVF region (<50%), as shown in Figure 2. In addition, the wet gas outlet GVF would be no lower than 98% at the worst case (15% of the total liquid being carried over) and thus within the operating range of a DS II wet gas meter. With this small quantity of liquid carry over in the gas stream the feeling was that the uncertainties of ±5% on gas and oil could be achieved, as the relative impact of the poorer DS II liquid measurement on the low liquid volume would be small (the DS II only being able to measure liquids to an uncertainty of ±10% as opposed to the required uncertainty of ±5%). In reality the GVF at the gas and liquid outlets turned out to be somewhat different.

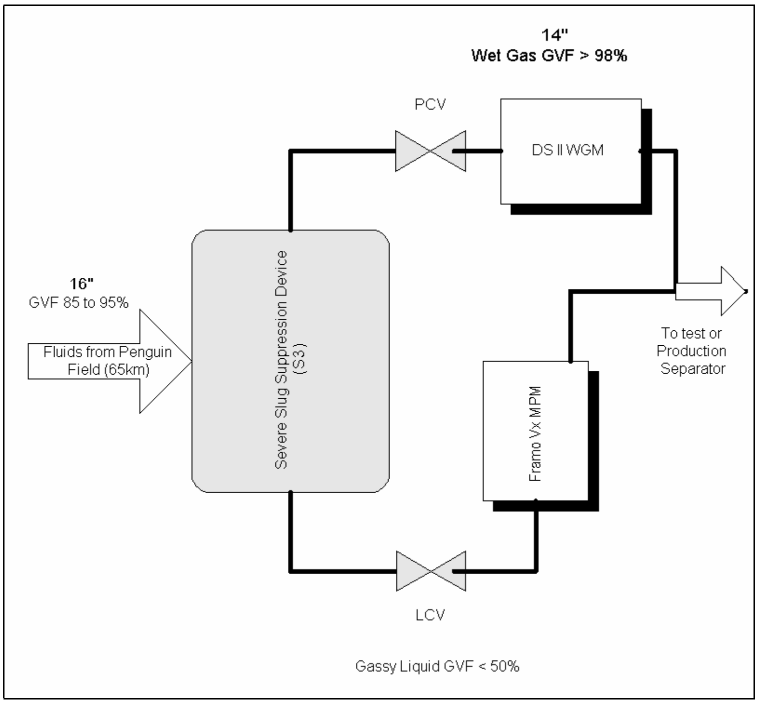

FIGURE 2:- PENGUIN METERING DESIGN INTENT.

The fluid from the Penguin reservoirs can be routed through a test separator or commingled with the Brent fluids and routed through the production separator. Because Brent pays Petroleum Revenue Tax and Penguin does not there is a requirement to meter Penguin fluids to an accuracy of ±5% on gas and oil.

3 DUALSTREAM II OPERATING PRINCIPLE

Earlier generic designs of wet gas venturi meters have the disadvantage of needing a second technique, such as tracers or a test separator to determine the liquid flow rate. As these methods are only a spot sample of the liquid flow rate, testing must be repeated at a frequency sufficient to ensure that the constant value used within the computations is representative, otherwise significant errors in the gas flow rate will occur. Tracers also have the disadvantage that skilled operators are required and they cannot be used sub-sea. The DS II meter overcomes this disadvantage by using a second type of differential pressure meter in series with the venturi to enable the liquid flow rate to be determined. The meter is designed to provide a liquid measurment in the range of approximately 90 to 99% GVF .

The DS II is a recent innovation; Advantica Technology started working on this technique in 1995 and licensed the technology to Solartron ISA in 1998, and by 1999 this meter was available commercially. Details on the development work by Advantica Technology and Solartron ISA can be found in [1] and [2]. The meter consists of a fluid conditioning element, a venturi and a wedge type meter. It relies on familiar, well proven technology and works on the principle that the first meter, the venturi, will give a different over reading to the second meter, a wedge type meter, when liquids are present. Consequently, two simultaneous equations are formed which can be solved to yield the gas and liquid flow rates[2]. The liquid loading is measured based on the readings of two differential pressure devices – nucleonic densitometry is not required.

[2] If a water cut is required then this would have to be obtained by sampling or well testing.

Because the meter is essentially two differential pressure devices, the instrumentation and operating principle is easily understood and accepted by technicians in the field.

Accuracy is a function of pressure and liquid content, however generally speaking Solartron ISA claim a relative accuracy of ±5% on gas flow rate and ±10% on liquid flow rate for Lockhart-Martinelli values between 0.1 and 0.25 and when the gas velocity is in excess of 4m/s. For Lockhart-Martinelli values between 0.05 and 0.1 the accuracy on the liquid phase was claimed to be ±20%. These accuracies had been confirmed in tests conducted at TUV NEL at the manufacturer's request [3], and this meter has also been tested as part of the Wet Gas Meters Joint Industry Project although the results of these tests are confidential.

As the liquid content in a given gas flow increases the meter's differential pressure will increase. If standard dry gas algorithms are used to compute the gas flow rate then the meter will over read. The amount of over reading is primarily influenced by liquid loading, flow regime (stratified, dispersed) and geometric meter parameters (such as beta ratio).

Wet gas correction algorithms are typically formulated in terms of the modified Lockhart-Martinelli (LM) parameter which may be defined,

$$LM = \frac{Fr_l}{Fr_g} \quad \text{where } Fr_g = \frac{v_{sg}}{\sqrt{g D}} \sqrt{\frac{\rho_g}{\rho_l - \rho_g}} \text{ and } Fr_l = \frac{v_{sl}}{\sqrt{g D}} \sqrt{\frac{\rho_l}{\rho_l - \rho_g}} .$$

Consider two devices corrected by a Murdock [4] style equation,

$$Q_g = \frac{Q_{giv}}{1 + c_v + M_v LM} = \frac{Q_{giw}}{1 + c_w + M_w LM} .$$

If we define the difference between the over-reads and the difference between the 'Murdock' coefficients,

$$\Delta Q_{gi} = Q_{giw} - Q_{giv} ,$$

$$\Delta M = M_w - M_v ,$$

$$\Delta c = c_w - c_v ,$$

then it is easily shown that the Lockhart-Martinelli parameter is given,

$$LM = \frac{\Delta Q_{gi}(1 + c_v) - Q_{giv}\Delta c}{Q_{giv}\Delta M - M_v \Delta Q_{gi}} .$$

The correction algorithm used to derive the solution is somewhat arbitrary - provided it accurately describes the over-reading characteristic observed. For example, consider the same two devices, but with a Chisholm [5] style correction algorithm,

$$Q_g = \frac{Q_{giv}}{\sqrt{1 + C_v LM + LM^2}} = \frac{Q_{giw}}{\sqrt{1 + C_w LM + LM^2}} .$$

In this case the Lockhart-Martinelli is given,

$$LM = \frac{\left(C_w - C_v \left(\frac{Q_{giw}}{Q_{giv}} \right)^2 \right) \pm \sqrt{\left(C_v \left(\frac{Q_{giw}}{Q_{giv}} \right)^2 - C_w \right) - 4 \left(\left(\frac{Q_{giw}}{Q_{giv}} \right)^2 - 1 \right)^2}}{2 \left(\left(\frac{Q_{giw}}{Q_{giv}} \right)^2 - 1 \right)}.$$

Provided that the flow meters behave differently in the presence of liquid, and that the wet gas model used is accurate over its operating envelope, the meter will function successfully. The error in the measured Lockhart-Martinelli will be a function of both the uncertainty in the wet gas models for the venturi and wedge meter and also the magnitude of the difference between the two uncorrected / indicated gas flow rates.

4 PENGUIN STARTUP

Figure 3 and Figure 4 are photographs of the Penguin metering installation. In early January 2003 first oil from the Penguin fields was achieved. By mid January it was apparent that there was a serious discrepancy between the test separator measurements and the DS II and Framo MPM combination. With the startup of new wells and the associated increased production the combined Penguin flow rate would soon exceed the capacity of the test separator. If the metering discrepancy was not identified and corrected the only method for allocation would be the test separator. The undesirable consequence of this is that the wells would have to be choked back and production deferred in order to facilitate allocation.

FIGURE 3:- PENGUIN METERING INSTALLATION – THE INSTALLED DS II METER

An investigation was instigated which quickly concluded that the Framo MPM was performing satisfactorily but the DS II readings were erroneous. Due to the simple nature of the DS II it quickly became apparent that the error was caused by one or a combination of the following three factors. i) the high level of pulsating flow[3], ii) the large amount of liquid carry over, or iii) the value used in the correction algorithms. The meter used a fixed correction constant for both the venturi and wedge meter within the algorithms. Solartron were consulted and they believed that the pulsations should not influence the meter accuracy to the extent observed, however they had some doubts about the correction constants due to the meter size and beta ratio used. Earlier work [6] concluded that the effect of changing the Beta ratio was expected to be minimal, primarily due to previous published data on orifice plates that showed little dependency on beta [7]. However, this hypothesis has subsequently been shown to be inaccurate as further work has been has been undertaken on both venturis and V-Cones [8, 9]. The initial DS II meter research had been conducted on 4 and 6" meters with a beta ratio of 0.63 for the venturi and 0.61 for the wedge. The Penguin meter had a nominal diameter

[3] To operate correctly the S^3 has to create pulsating flow / pressure during slugging conditions.

of 14 inches and with beta ratios of 0.46 for the venturi and 0.66 for the wedge was significantly different.

These problems were further compounded as the expected operating GVF of 98% at the DS II was, due to suspected foaming within the S^3 device, actually as low as 90% and thus the original design intent for the DS II to operate well within its operating envelope was not achieved. This meant that the DS II was operating at a high Lockhart-Martinelli value of approximately 0.5. In addition, due to the S^3 operating regime, significant changes in the gas and liquid velocities at the DS II could be experienced and the GVF at the MPM could be as high as 80% (this did not cause any noticeable deterioration in MPM performance).

The reality was that due to the low GVF at the DS II, approximately 70% of the liquids actually pass through this meter under steady state operation, as apposed to the design intent of 15%. Thus the relatively high manufacturer's specified uncertainty of ±10% on the DS II liquids dominated the total liquid uncertainty. It was obvious that this high level of uncertainty was unacceptable, either the S^3 separation efficiency had to be improved or the meter operating range and liquid accuracy had to be improved as well as resolving the size / beta ratio issues.

The S^3 separation efficiency is predominantly determined by the flow rate through the vessel and the level within it. The required production volumes determines the flow rate and the level is automatically allowed to vary by the S^3 control algorithms in order to build up a buffer volume for slug control. Thus to a large extent neither the S^3 vessel level or flow rate are operator changeable. Studies were carried out in order to try to improve the S^3 separation efficiency however none were thought viable to implement offshore and, as the S^3 worked well as a slug suppression device, the onus was on improving the DS II range and liquid accuracy.

FIGURE 4:- PENGUIN METERING INSATLLATION – SEVERE SLUG SUPPRESSION DEVICE

As an interim step to try to obtain accurate results from the DS II the decision was taken in February to utilize the DS II as a conventional wet gas venturi. This was a simple step as the flow computer software allowed the gas mass fraction to be keypad entered as opposed to using the value calculated using the DS II on-line algorithms. The disadvantage of this was that the test separator would have to be used to calibrate the wet gas meter (WGM) every time the gas mass fraction (GMF) changed. Unfortunately the GMF was dependant upon the S^3 level, which in order to control slugs, varied automatically. The GMF of the fluid entering the S^3 was also something that could vary quite significantly - the GOR of the individual Penguin wells varies from somewhere between 670 to 4200 scf/bbl so the amount of liquid entering the S^3 could vary quite considerably with the choke setting of the individual wells. During the time when the meter was operating as a conventional WGM the GMF had to be modified on six occasions, from February to May, to values ranging from 15% to 45%, see footnote[4]. In addition, it was also only possible to use the test separator to supply the GMF when the flow rates were low enough to ensure reliable separator operation. With additional wells being brought on line in May and June, the capacity of the separator was exceeded thereby precluding its use until the new well rates declined sufficiently. The test separator separation capacity was invariably operating near to its limit and often the oil turbine meter would go over range as either gas break out occurred or the flow rate increased as a liquid slug passed through. Due to the length of the tie back, a prolonged stabilisation period of several days was required prior to determining the GMF from the test separator. These factors highlight the operational requirements for an on-line gas mass fraction measurement from the DS II.

Figure 5 and Figure 6 show a set of results during the period when the DS II was operating as a conventional WGM.

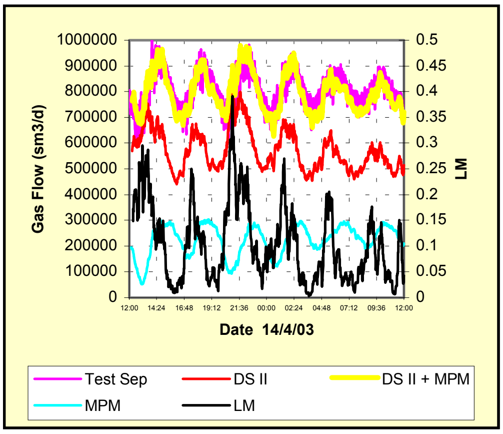

FIGURE 5:- GAS FLOW RATE DURING PERIOD WHEN DS II METER UTILISED AS CONVENTIONAL WET GAS VENTURI

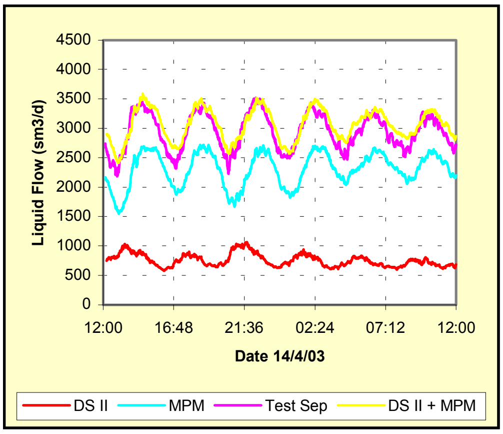

FIGURE 6:- LIQUID FLOW RATE DURING PERIOD WHEN DS II METER UTILISED AS WET GAS CONVENTIONAL VENTURI.

The dynamic nature of the flow is clearly evident. The problems associated with trying to use a fixed gas mass fraction is also apparent.

4

Date	GMF	Description
03/02 – 23/03	22	Initial manual GMF
23/03 – 27/03	43	Well bean up
27/03 – 11/05	45	Fine Adjustment
11/05 – 18/05	15	New wells brought on-line
18/05 – 28/05	20	Fine adjustment
28/05 – 12/06	23	Adjusted to account for declining well performance

As the Penguin meter was deemed to be business critical the decision was taken in early February to resolve this issue by manufacturing an identical meter and having it wet gas flow tested at the newly expanded K-Lab facilities in Norway.

5 K-LAB TESTING

The K-Lab facility is a test loop that uses live hydrocarbon fluids from the Kårstø gas terminal at high pressure (up to 120bar). With gas rates from 40-2000am^3/h and liquid rates of 0.01 to 200am^3/h, K-Lab was selected as the test site for the Penguin meter. The reference measurements are made with V-Cones on the gas and coriolis meters on the liquids. The restriction of 2000am^3/h on the gas rate meant that the maximum superficial gas velocity tested was around 7m/s. Ideally higher gas velocities would have been tested, however, previous test results have shown that the rate of change of overread decreases with increasing gas velocity and as the upstream conditioner also significantly reduces the influence of gas velocity on the overread this situation was not considered to be too detrimental. Above 7m/s the influence of the gas velocity was assumed to be negligible.

The testing was carried out on a 14” DS II meter specifically built for this purpose. The design was identical (i.e. same internal diameter and beta ratios) to that of the Penguin meter with the exception that to minimise the cost and time it was manufactured from carbon as opposed to duplex steel. Photographs of the meter installation and of the K-Lab test facility can be seen in Figure 7 and Figure 8 respectively.

FIGURE 7:- DUPLICATE DUALSTREAM II METER INSTALLED AT K-LAB

FIGURE 8:- K-LAB TEST FACILITY

The testing regime at K-Lab was specified to cover a wide operating range with nominal pressures of 20, 35 and 90bar, gas superficial velocities from 2 to 7m/s and Lockhart-Martinelli value from 0.05 to 0.6.

The carbon steel test meter was manufactured by Solartron ISA in March 2003 and shipped to K-Lab in April 2003. Testing commenced on the 2nd June 2003.

A dry gas calibration run was conducted to establish the coefficient of discharge for the meters. This was done at pressures of 20 and 33 bar. The results of this calibration can be seen in Figure 9.

The discharge coefficients were within expectations. As can be seen from the graph the venturi discharge coefficient is within the bounds for a fabricated venturi, as specified by ISO 5167.

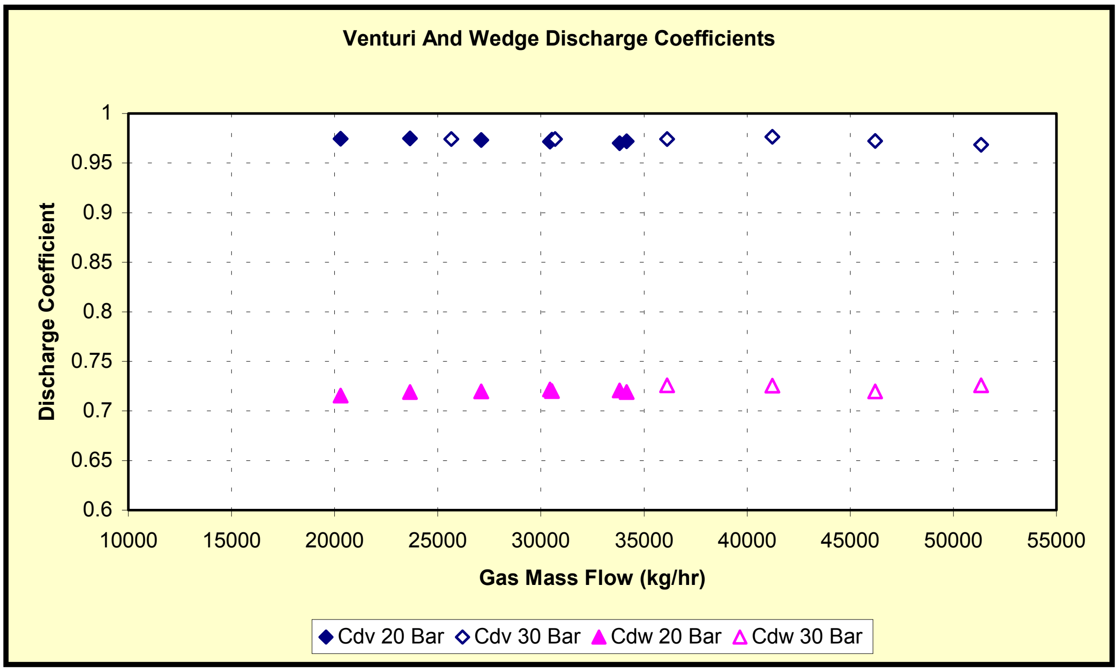

FIGURE 9:- DUALSTREAM II DISCHARGE COEFFICIENTS

A subset of the 120 wet gas test points obtained from K-Lab is displayed in Figure 10 and Figure 11. Figure 10 shows some of the 20 bar test results for three different gas velocities from 3 – 7 m/s. The upper curve on the graph depicts the overread seen on the venturi with increasing liquid content, the lower curve represents the difference between the overread on the wedge meter and venturi as defined in the previous section. Figure 11 depicts a similar set of results but for 33 bar, and, as expected the overead of the venturi can be seen to decrease with increasing pressure.

The behaviour of differential pressure devices in two-phase flow is a topic that has seen much interest. The overread characteristic of a venturi in wet gas is a function of many parameters. These include meter orientation, gas and liquid density, gas and liquid velocity, liquid droplet size, surface tension, convergent angle, beta ratio and pipe diameter [9], [10], [11], [12]. None of the wet gas correlations presently in common use take account of all these influences and interactions, although many successful installations have been reported.

These influences can be observed in the DS II test data.

- The overread of the venturi decreases with increasing pressure. The difference between the two meters also decreases with increasing pressure.
- The fluid conditioner significantly reduces the influence of the gas velocity on the overread characteristic when compared to a conventional venturi.
- As the beta ratio of the venturi decreases the overead for a given set of conditions tends to increase as the higher acceleration of the liquid leads to greater losses.

- The influence of pipe diameter is only significant at low gas velocities as the flow regime enters stratified flow. The velocity at which this occurs depends on the operating conditions.

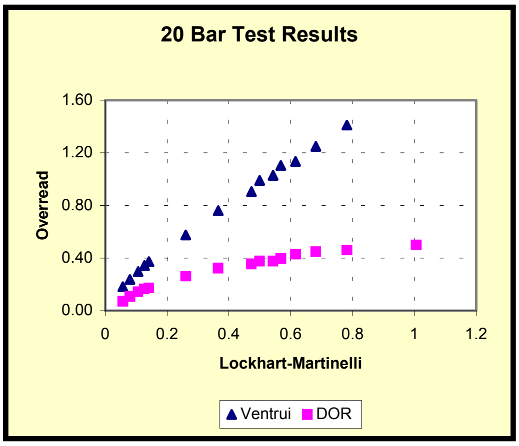

FIGURE 10:- DS II OVERREAD CHARACTERISTICS AT 20BAR

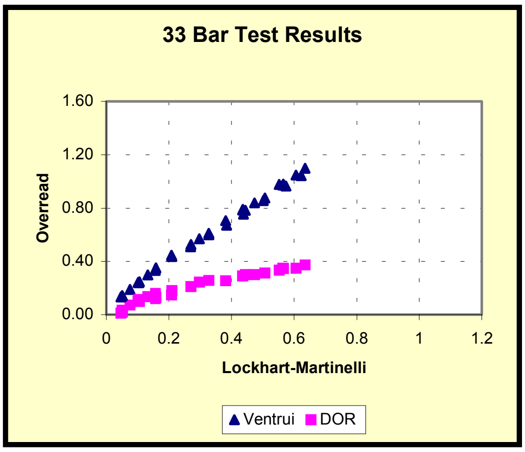

FIGURE 11:- DS II OVERREAD CHARACTERISTICS AT 33BAR

Figure 12 shows a small subset of the results obtained on the 14inch Penguin test meter on the same graph as results obtained under very similar operating conditions but on a 6inch meter with a larger venturi beta ratio at NEL. Whilst the wedge meter characteristics are very similar the overread of the venturi is significantly different for the same liquid loading.

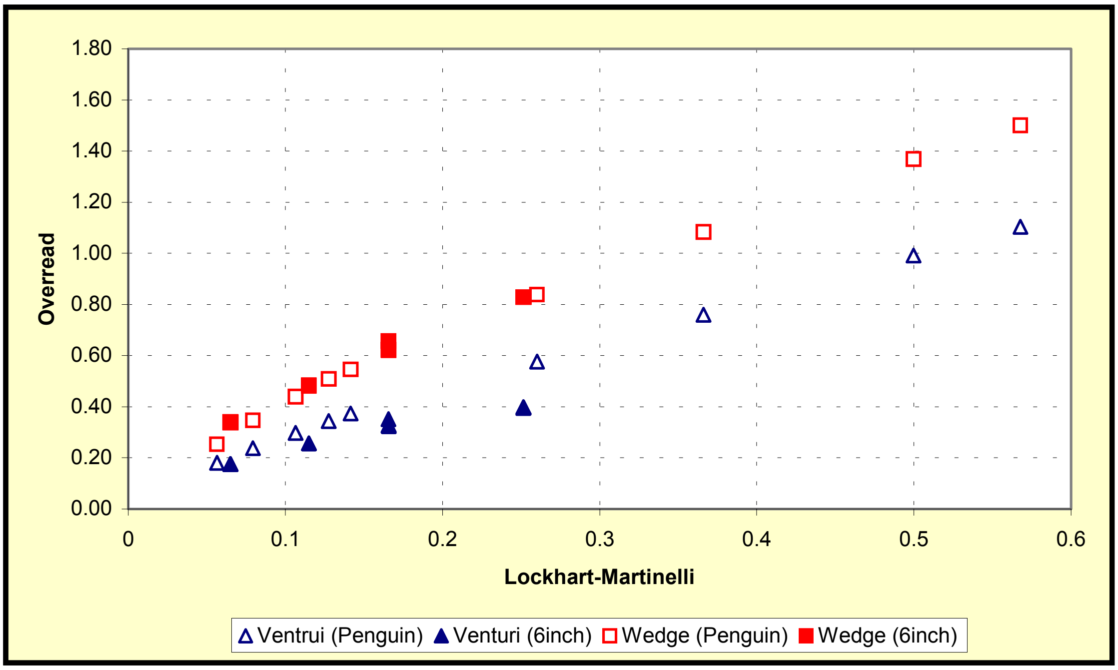

FIGURE 12:- OVERREAD CHARACTERISTIC OF 14INCH PENGUIN METER AND A 6INCH UNIT

This meant that the difference between the two meters was smaller than anticipated and, as the influence of the smaller beta ratio had not been accounted for, the liquid rate and subsequently the gas rate was incorrectly estimated.

A plot of the errors for the gas and liquid is given in Figure 13. Here it is seen that the gas flow rate is within ±5% until the LM increases above 0.5 where the gas error starts to increase. From Figure 10 it can be seen that at a LM of 0.6 the indicated/uncorrected gas flow rate from the venturi at 20 bar would be about 120% too high. For LM below 0.4 the error on the liquid rate is within 10% except for some points at low differential pressures (because of the flow rate limitation many of the test points were conducted a low velocities and low differential pressures). As the LM increases the error on the liquid rate starts to increase. This corresponds to the point where the difference between the two meters starts to flatten off.

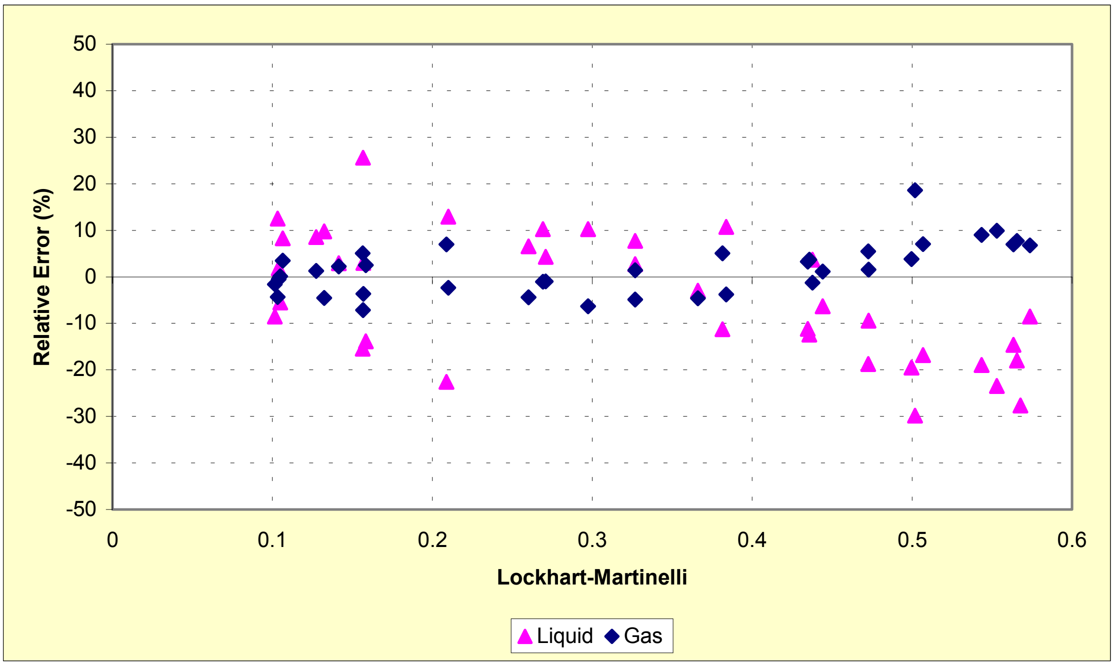

FIGURE 13:- GAS AND LIQUID ERRORS FROM K-LAB DATA

These test results enabled the 14inch meter with the smaller venturi beta ratio to be characterised. The revised algorithms were then transferred to the Penguin flow computer offshore. The revised algorithm iteratively calculates on-line the correction factors (using the gas Froude number and LM) that were previously considered to be constants.

6 FIELD RESULTS

In July the new algorithms were installed in the offshore flow computer and went live. To verify the meter performance three different types of tests were performed, these were:-

- Comparison against the test separator
- Comparison against the quantity back allocated from the Brent export oil meter and the St-Fergus terminal onshore gas meters
- S^3 Level Change “Swap Test”, this consisted of varying the level in the S^3 to force more of the gas and liquid out through the MPM as opposed to the DS II. The idea of this test is that the sum of the DS II and MPM meters should remain constant.

6.1 Comparison Against The Test Separator

6.1.1 Separator Gas Measurement

The Brent Charlie test separator gas meter consists of an orifice plate mounted between flanges with an upstream straight length of approximately 30D to the first fitting (two 90^o bend in the same plane with the separation between bends greater than 5D); there is no flow conditioner. As part of the Penguin project a new orifice plate with a beta ratio of 0.43 was fitted. Instrumentation consists of a single differential pressure transmitter. Pressure and temperature compensation is carried out within the DCS by utilizing the pressure and temperature transmitters fitted to the separator. The DCS algorithm uses a fixed value for molecular weight and gas compressibility. The accuracy of this meter is estimated as ±5%.

6.1.2 Separator Oil Measurement

As part of the Penguin project a second larger meter stream was added to the test separator oil metering. This new stream consists of a 6" Faure Herman TNZ80-110N turbine meter and a 10D upstream straight length fitted with an integral flow conditioner. This meter is connected to the DCS via a frequency to current converter. There is no pressure or temperature compensation.

The accuracy of this meter is estimated as ±5%.

6.1.3 Meter Versus Test Separator – Test 1

Figure 14 and Figure 15 illustrate the results of the meter performance, in July, against the test separator. Figure 14 has four traces, the gas rate measured by the MPM, the gas rate measured by the DS II, the summation of these two gas flow rates and finally the gas flow rate measured by the test separator. As you would expect with a meter sited on the liquid leg of the S^3, the gas measurement from the MPM is almost zero and hence the sum of the MPM and DS II gas flow rate therefore follows the DS II gas rate.

The liquid flow rates show a slightly different situation. If the S^3 device was a separator you would expect to see nearly all the liquid being measured by the MPM. This is not the case. Although the MPM is displaying a significant amount of liquid the liquid measured by the MPM only represents 20-25% of the total metered liquid. This means that the uncertainty of the total liquid measurement is not just driven by the MPM, as anticipated, but also by the DS II.

When the test separator comes on-line it is noticeable that the liquid measurement of the separator is significantly higher than the summation of the DS II and MPM, the cause of this difference was thought to be gas break out[5]. As one of the wells is choked back to reduce the production rate the liquid measurement from the separator and the liquid measurement from the combined MPM and DS II become coincident.

[5] During this test the test separator LCV postioner was found to be sticking and this may have exacerbated the gas break out problem (there is a 30 bar differential pressure across the valve so small movements can give a significant flow change which can induce increased friction losses). The test separator pipe work was the focus of a process study but this concluded that it would need a flow rate of 6,300Am3/d before gas break out, due to friction losses, would occur.

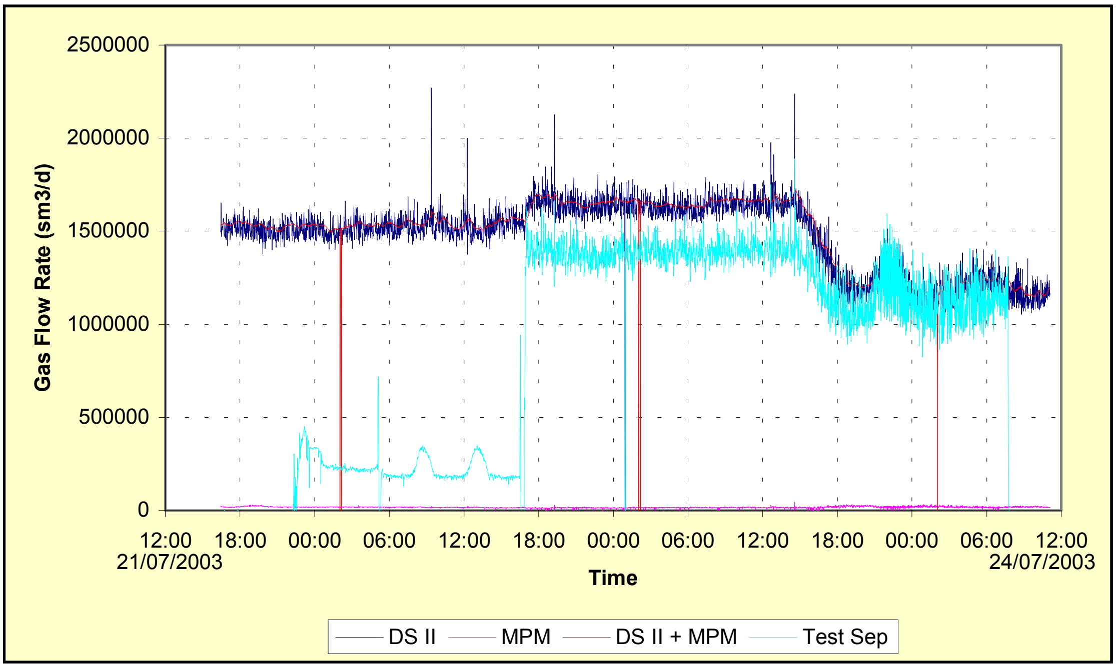

FIGURE 14:- GAS FLOW RATE OF DS II AND MPM VERSUS TEST SEPARATOR

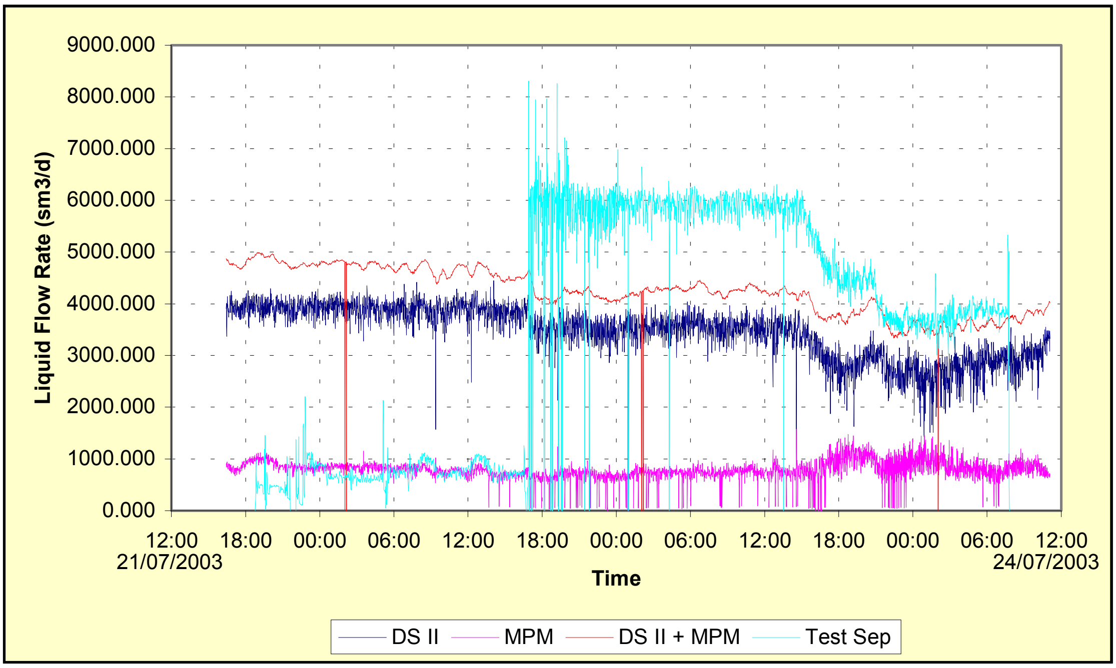

FIGURE 15:- LIQUID FLOW RATE OF DS II AND MPM VERSUS TEST SEPARATOR

When the production from Penguin is routed to the test separator there is an increased back pressure of approximately 4bar. It may be anticipated that a decrease in flow rate would accompany this increase in back pressure, however the DS II clearly indicated a slight increase in gas flow rate as the separator was aligned. Figure 16 shows a close up of the graph for the period the separator first comes on-line. In addition to the DS II and separator gas rates (and averaged version of the signals) this chart also shows the S^3 gas valve position.

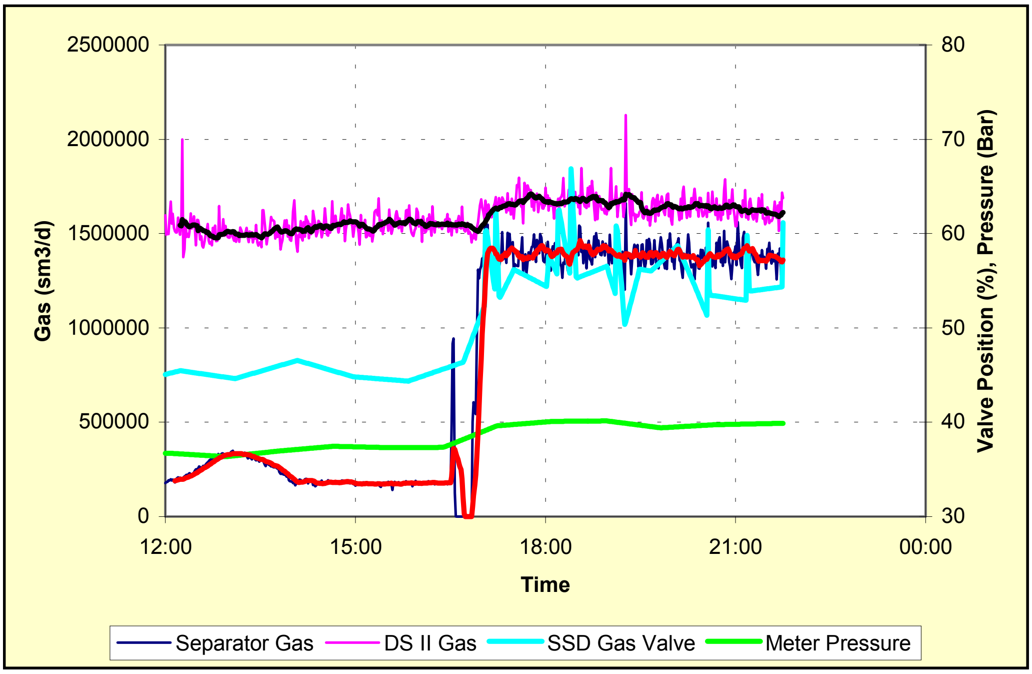

FIGURE 16:- DS II GAS RATE AND SSD GAS VALVE POSITION AS TEST SEPARATOR IS ALIGNED

The S^3 implements a control algorithm that tries to maintain the same actual total volumetric throughput. As the back pressure increased the control valve opened to try and maintain the same volumetric flow which resulted in the observed increase in gas mass flow though the DS II.

The GMF measured by the DS II was around 35% during this test. At these operating conditions this corresponds to a LM and GVF of about 0.4 and 91% respectively. The MPM was indicating a GVF of about 20%.

6.2 METER VERSUS TEST SEPARATOR – TEST 2

The results of a second later test, in September, against the separator are displayed in Figure 17 and Figure 18. These results show very close agreement between the separator and the summation of the outputs from the DS II and MPM.

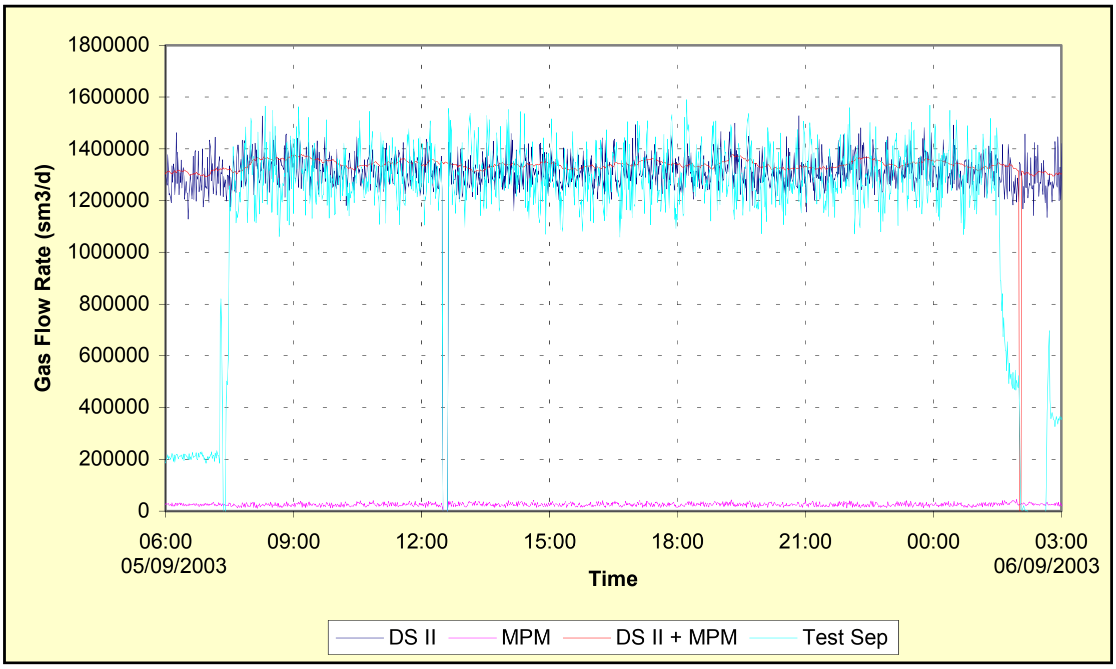

FIGURE 17:- GAS FLOW RATE OF DS II AND MPM VERSUS TEST SEPARATOR

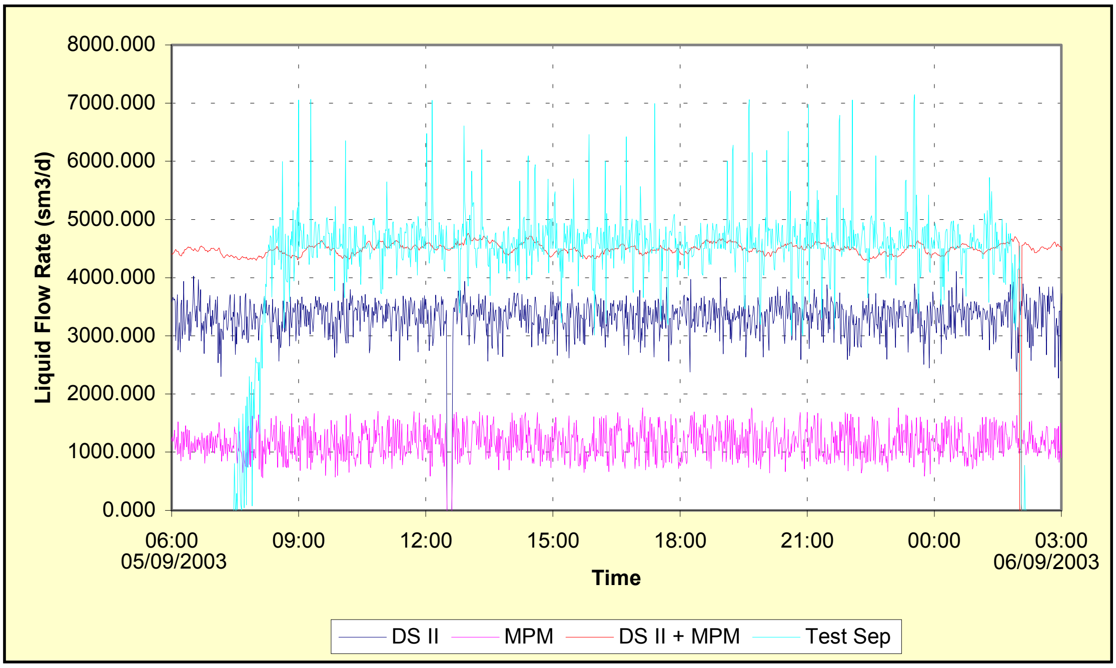

FIGURE 18:- LIQUID FLOW RATE OF DS II AND MPM VERSUS TEST SEPARATOR

These graphs are based on a historical PI database that contains data stored at 1 minute intervals. Plotting a histogram of the instantaneous difference (ie assuming steady state flow and constant separator level) between the separator and the sum of the flow rates from the DS II and MPM during the period of the test produces the results shown in Figure 19 and Figure 20. The difference between the test separator and the sum of the DS II and MPM over the duration of the test was +3.1% on gas and -0.9% on liquid.

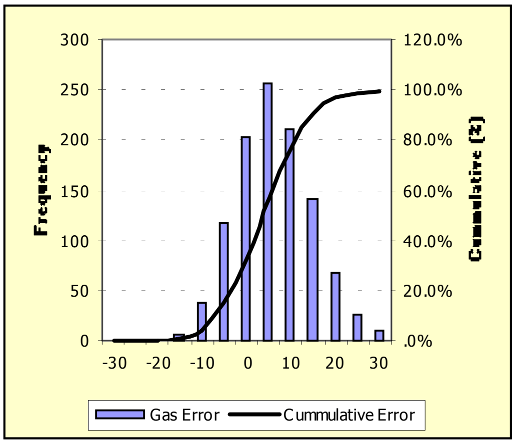

FIGURE 19:- HISTOGRAM OF DIFFERENCE IN GAS BETWEEN SEPARATOR AND DS II + MPM

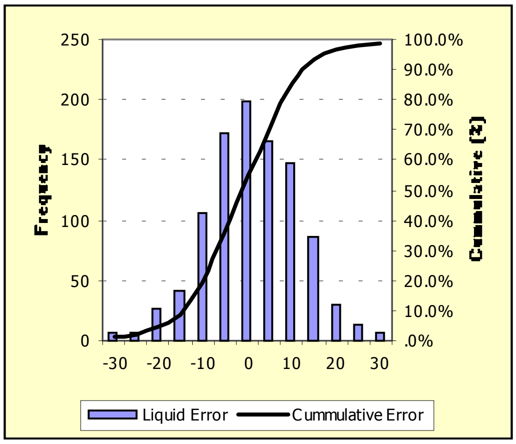

FIGURE 20:- HISTOGRAM OF DIFFERENCE IN LIQUID BETWEEN SEPARATOR AND DS II + MPM

6.3 COMPARISON WITH BACK ALLOCATION

On a day-to-day basis, Penguin oil production can be found "by difference" by using the Brent field fiscal oil export meter (which measures the combined Penguin + Brent production) and Brent reservoir well test data. Similarly, the Penguin gas quantity can be found "by difference" but this is more complex as there is no gas export meter on the Brent platforms. Instead, the combined Brent + Penguin gas production is itself determined by back allocation from the Flags/Fulmar pipeline allocation which utilizes the onshore meters located at St-Fergus in Scotland and fiscal meters located on other offshore platforms. The combined Brent / Penguin gas production is then split based on Brent reservoir well test data. This scheme is shown diagrammatically in the appendix. These back-allocated Penguin quantities can then be compared with the DS II + MPM meter readings and thus a trend of meter performance established.

It must be noted that prior to comparing the meter readings with the back-allocated quantities the metered quantities must first be corrected for the further liberation of gas from the oil as the Penguin fluids pass through the Brent Charlie process facilities. These oil shrinkage and gas expansion factors were determined using a Hysis process simulation model and have typical values of between 0.90 and 0.98 for oil and 1.07 to 1.18 for gas although these are dependant upon the separation process temperature and which wells are on-line. Usually the oil shrinkage factor is 0.95 and the gas 1.15.

The accuracy of the back allocated Penguin oil quantities is estimated at about ±5% (test separator accuracy and Hysis model) as the "metered" Brent reservoir quantity is about 50% of the total quantity passing through the fiscal export oil meter i.e. a 1:1 ratio between Brent and Penguin production. It must be borne in mind that as the oil fiscal meter is located downstream of the crude oil storage tanks, and the oil is batched in to the SVT pipeline, there can be a time lag between the Penguin meter quantity and the back allocated quantity. In the graphs below this time lag has been ignored thus the errors shown may be larger than the actual errors.

The accuracy of the back-allocated Penguin gas quantities is theoretically significantly worse than ±5% as the Penguin gas rate is only about 1:20 of the Brent gas rate. However, the trends for the gas (Figure 21) and liquid (Figure 22) show that that there is indeed a very good correlation.

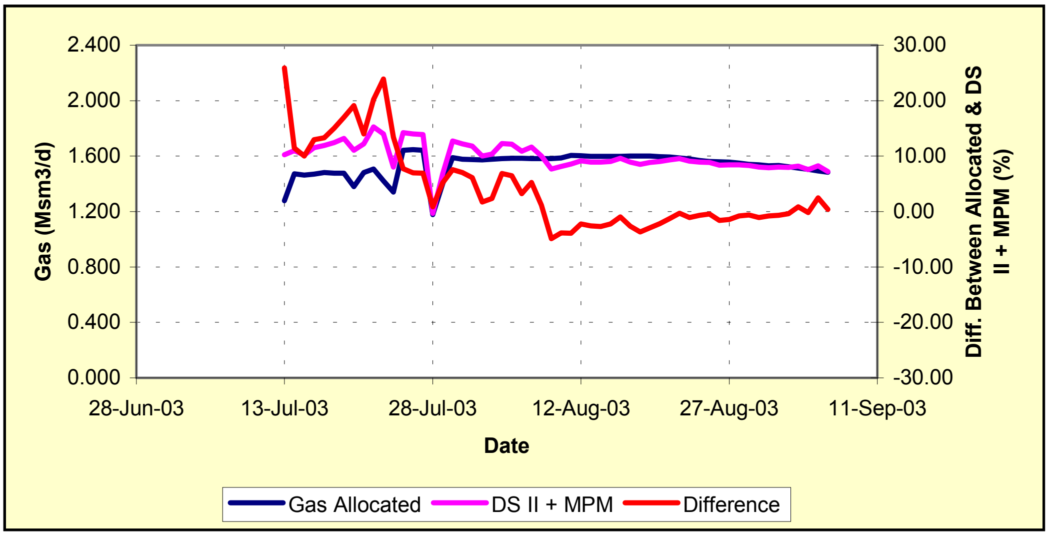

FIGURE 21:- GAS FLOW RATE OF DS II + MPM VERSUS ALLOCATED FLOW RATE

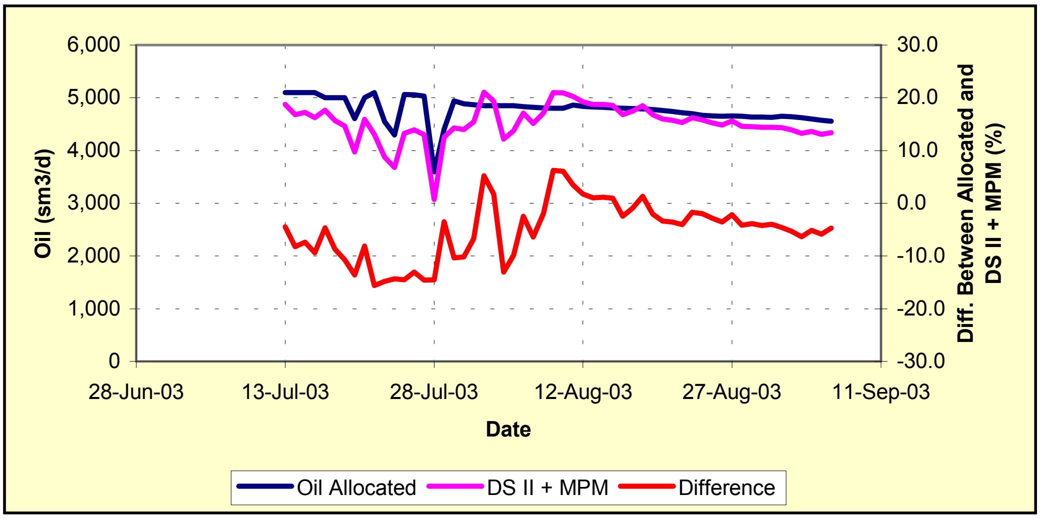

FIGURE 22:- LIQUID FLOW RATE OF DS II + MPM VERSUS ALLOCATED FLOW RATE

6.4 SSD LEVEL CHANGE (SWAP TEST)

The amount of gas that is delivered to the MPM is strongly dependent on the level within the S^3. Figure 23 and Figure 24 show the graphs of the DS II and MPM gas and liquid rates during a level change in S^3. When the level is initially reduced the gas flow rate indicated by the DS II dramatically reduces, whilst the gas flow rate from the MPM increases significantly. As the level is increased again the reverse happens, with the gas measurement of the MPM returning to almost zero. The sum of the gas flow rates remains very similar throughout the test.

The liquid flow rate chart shows a similar story. As the level is reduced, the amount of liquid seen by the MPM increases significantly, whilst the amount of liquid seen by the DS II reduces by a similar magnitude.

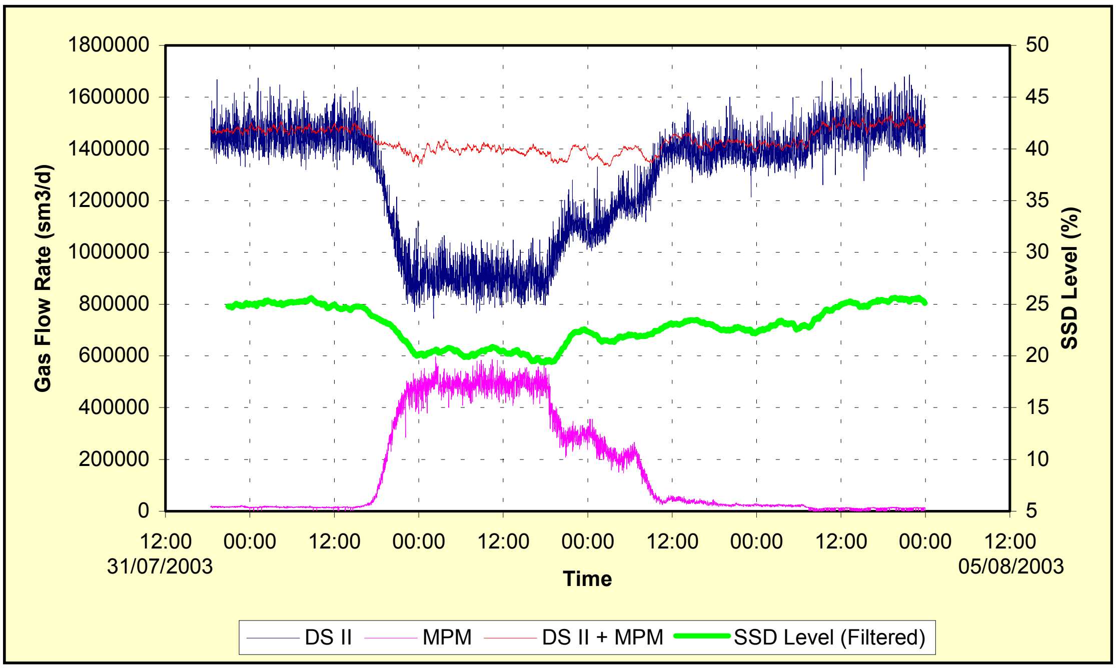

FIGURE 23:- GAS FLOW RATES FROM DS II AND MPM DURING S^3 LEVEL CHANGE

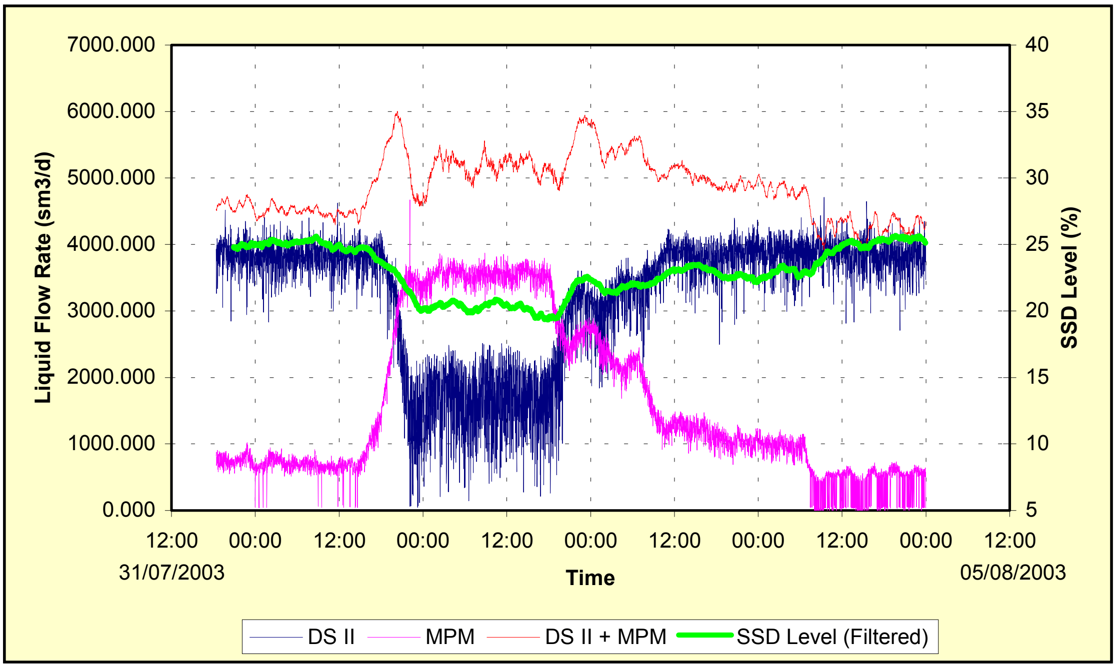

FIGURE 24:- LIQUID FLOW RATES FROM DS II AND MPM DURING S3 LEVEL CHANGE

This is a severe test for both the DS II and the MPM. Figure 25 shows the differential pressure and the measured gas mass fraction from the DS II during the test. The differential pressure of the venturi drops from 500mbar to less then 100mbar, whilst the differential pressure of the wedge meter drops to about 50mbar. At the same time the GMF increases from 30% to nearly 50%. A similar picture is seen in the MPM measurements. The differential pressure across the venturi of the MPM increases from 30mbar to 1300mbar, whilst the liquid mass fraction (LMF) decreases from almost 100% down to below 90%. This change in LMF corresponds to a GVF change of almost 0-80%

A significant change in the flow rates and operating GMF of both meters has been introduced with both meters behaving predictably.

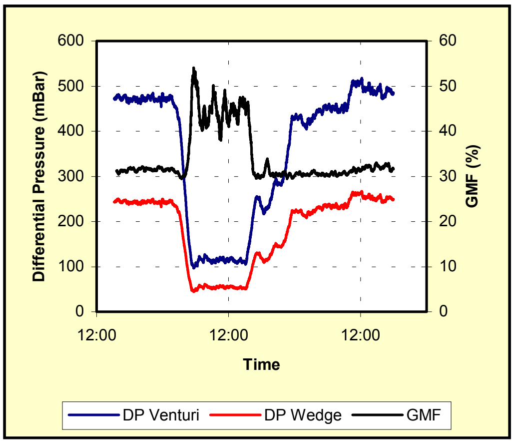

FIGURE 25:- DS II DIFFERENTIAL PRESSURE AND GMF

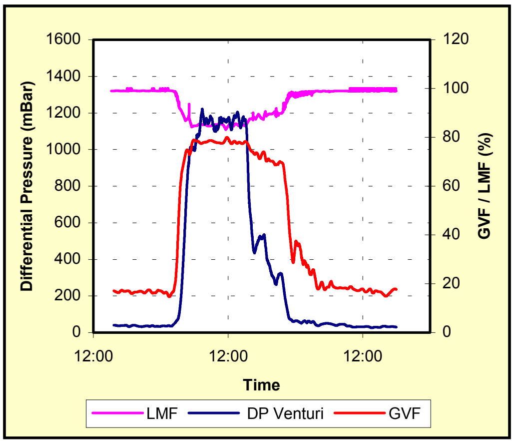

FIGURE 26:- MPM DIFFERENTIAL PRESSURE AND LMF

7 CONCLUSION

Gas is becoming an increasingly important energy source and thus to aid reservoir management and product allocation there is an increasing need to develop a simple, low cost wet gas flow meter that can be mounted on each well head. In addition, the high gas volume fraction (GVF) of many "oil" wells actually mean a wet "gas" meter could be used to measure the well head flows.

On the Penguin development the Dualstream II wet gas flow meter has been shown to be capable of measuring both gas and liquids to within the accuracy of the test separator metering system (±5%). These results have been obtained without actually calibrating the meter against the test separator.

The installed Penguin meter can see rapid fluctuations in flow rate and liquid loading and thus is operating in a harsh environment with LM values from 0.05 to 0.4 (GVF's 90 to 99%). The use of the Dualstream II wet gas meter enabled the project to remove the need for a new separator.

Initially, when first installed, the meter was in error by up to 40% on gas and 30% on liquid. However, following the test work at K-Lab this metering discrepancy was resolved and attributed primarily to changes in the venturi beta ratio between the Penguin meter and the research meters and also the use of a fixed constant within the algorithms which was actually a function of gas froude number and LM. In addition, the meter sizing has an impact during operation under stratified flow conditions. The effects of beta ratio on the over reading of venturis and V-Cone meters has been previously reported.

Often when sizing a differential based flow meter it is tempting to install a meter of the same nominal size as the upstream pipe work thus ensuring a low pressure loss. However, in wet gas measurement, particularly those using dual DP meters, this can pose a problem as the differential pressure signal is inherently noisier and at low differential pressures the signal to noise ratio will become problematic and thus make it more difficult to distinguish the difference in reading between the two meters. The vendors limit of 100mbar DP should thus be adhered to. From a process efficiency point of view it is the fully recovered pressure loss that is important and not the actual differential pressure.

Solartron have conducted wet gas flow tests with meter sizes that include 4, 6, 8, 10 and 14 inches with different beta ratios and thus now have a better understanding of the effects of changing these parameters. In addition, work is currently underway which will enable the determination of the over reading characteristic of different sizes of meters with different beta ratios from a mechanistic point of view, thus hopefully removing the need to wet-gas flow-test meters with a significantly different size or beta ratio to those previously tested. Although in reality as the beta ratio has to be chosen to minimise the venturi over reading and maximise the wedge over reading (thus maximising the difference between the meter readings) in reality there will probably be a restricted use of different beta ratios (only changing when specific projects demand). Thus the main change will be to meter size and wall thickness - a smaller pipe diameter being used to maximise the differential pressure. This smaller size also has the added advantages that the meter will operate in the dispersed flow regime, were its performance is more linear, and also removing the effect of meter size from the venturi over reading characteristic.

The successful use of the Dualstream II meter is seen as a significant step forward in fulfilling the aim of having a simple, low cost wet gas meter - particularly as it can be deployed sub-sea.

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9 AUTHOR CONTACT DETAILS

Ian Wood, email: Ian.I.Wood@Shell.com

Paul Daniel, Solartron ISA, Hackworth Industrial Park, Shildon County Durham, DL4 1LH, Tel: +44 (0) 1388 773065, email: DanielP@SolartronISA.com, www.SolartronISA.com

10 NOMENCALTURE

Q	mass flow rate
LM	Lockhart-Martinelli parameter
M	Murdock coefficient
c	Murdock offset
C	Chisholm constant
v_s	superficial velocity (m/s)
D	internal pipe diameter (m)
g	the acceleration due to gravity (m/s^2)
ρ	flowing density in kg/m^3
Fr	Froude number (dimensionless)
GMF	gas mass fraction
LMF	liquid mass fraction
GVF	gas volume fraction
DS II	Dualstream II
WGM	wet gas meter
MPM	multiphase meter
S^3	sever slug suppression device

Subscripts

g	gas
l	liquid
gi	indicated gas
v	venturi
w	wedge type meter

11 REFERENCES

[1] "A Wet Gas Meter For Gas/ Condensate Flow Measurement" JS Lund, AR Tait, S Clark, 9th International Conference on Multiphase 99, pp 303-315.

[2] "A Venturi Based Wet-Gas Meter With On-Line Gas Mass Fraction Estimation" P Daniel, M Tudge, J Lund, North Sea Flow Measurement Workshop 2000.

[3] "5106 Wet Gas Test Report." Internal Solartron ISA document.

[4] "Two Phase Flow Measurements With Orifices" JW Murdock, Journal Of Basic Engineering, December 1962, pp419-433

[5] "Flow Of Incompressible Two-Phase Mixtures Through Sharp-Edged Orifices", D Chisholm, Journal Of Mechanical Engineering Science, Vol 9, No.1, 1967

[6] "Venturi meter performance in wet gas flow" H de Leeuw. Multiphase 1997.

[7] "Orifice meter of two phase flow", Mattar, L Aziz et al, SPE paper 7411, Oct 1978.

[8] "Wet gas metering with V-Cone Meters" Stuart D, Hodges D, Steven R, North Sea Flow Measurement Workshop 2002.

[9] "Venturi Meter Performance In Wet Gas Flow" H. De Leeuw, BHR Group 1997 Multiphase 1997

[10] "Wet Gas Metering In The Upstream Area: Needs, Applications and Developments" JP Couput, North Sea Flow Measurement Workshop 2000.

[11] "Modelling Wet-Gas Annular-Dispersed Flow Though A Venturi" M van Werven, G Ooms, BJ Azzopardi, HRE van Maanen Flomeko 2003.

[12] "Wet Gas Venturi Metering", D Stewart, G Brown, D Hodges, SPE Annual Technical Conference, San Antonio September 2002. SPE 77350.

12 APPENDIX 1