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Paper 4.3

Field Installation of Smartvent Wet Gas Flow Meters at Bintang, Malaysia

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ABSTRACT

Wet gas flow measurement is increasingly gaining acceptance in replacing expensive well test separators and related infrastructure by individual wet gas meters at each wellhead. At present more than 140 Petrotech wet gas meters have been purchased by various operators world wide. Besides the significant cost savings, the availability of continuous readings of each well's production rates allow for enhanced reservoir management and production optimisation.

This paper presents a current overview of the application of wet gas flow measurement for the Bintang field developed by ExxonMobil. The Bintang development consists of permanently installed SmartVent wet gas venturi based flow meters at each well location. Special wet gas flow calculation and monitoring software for process control have been developed and installed on a separate flow computer installation interfaced to the host platform DCS system. After start up of the field on-site verification/calibration of the production measurements will be performed using the MultiTrace tracer technology method.

Prior to installation full scale wet gas flow testing of the meters have been performed at the K-Lab high pressure gas/liquid flow test facility in Norway. The test fluids used consisted of hydrocarbon natural gas and condensate, resulting in a unique set of experimental wet gas data and a valuable measurement experience. The results show that the De Leeuw gas correction correlation is capable of correcting the hydrocarbon gas flow rate to within ±2-4%, and that the De Leeuw continuous liquid flow rate measurement correlation is capable of determining the total liquid flow rate to approximately ±10-15% over the tested range. Lower uncertainties can be achieved for a corresponding smaller operating window in combination with an on-site tracer calibration measurement. In addition the tracer method will provide the individual water and condensate flow rates.

1. INTRODUCTION

Significant cost savings related to production measurement of gas/condensate wells can be realised if conventional test separators and related infrastructure are replaced by Petrotech wet gas venturi based flow meters in each well flow line, and the wetness of the flow is verified/calibrated using the non-radioactive MultiTrace tracer technique. Accurate wellstream PVT samples can be obtained in combination with the tracer technique for flash calculations and process simulation. In addition various levels of data redundancy are provided via the use of the MultiTrace gas tracer technique and the Petrotech split stream wellhead sampling technique (ISO-split).

Wet gas flow measurement was selected by ExxonMobil for the Bintang field development which is located offshore Terengganu, Malaysia. Prior to their installation, the wet gas meters have been subject to full scale wet gas testing at the high pressure natural gas/condensate test facility of K-Lab in Norway. One of the objectives was to calibrate all 15 meters in single phase flow in order to establish the actual discharge coefficients. In principle the values given in the ISO 5167 standard can not be used as the flow Reynolds number at the Bintang wellheads is much higher than the maximum value listed in the standard. The second objective was to test 3 separate 4" meters, and 3 separate 6" meters under hydrocarbon wet gas flow conditions in order to evaluate the De Leeuw gas correction correlation, and the De Leeuw continuous liquid flow rate measurement correlation.

The experiments were performed at pressures of around 35 bar and 65 bar, at various different gas velocities, and with liquid fractions up to around 4-5% by volume. The latter corresponding to a Lockhart-Martinelli parameter of up to approximately 0.125. Most importantly these experiments were conducted using hydrocarbon natural gas and condensate.

Figure 1. The Bintang-A platform under construction

2. METERING PRINCIPLE

The selected wet gas metering system for Bintang consists of the installation of SmartVent wet gas venturi based flow meters at each individual wellhead providing the continuous measurement of the gas and total liquid flow rate. The measured liquid phase will initially be split into water and condensate fractions via the use of established fluid property data and flash calculations. After start-up of the field the tracer technology method will be used to measure the water and condensate flow rates independently.

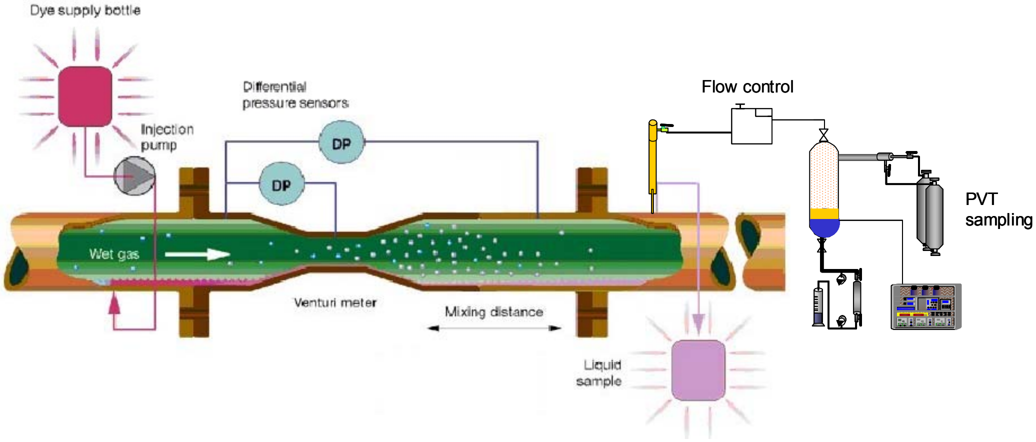


Figure 2. Schematic of the wet gas flow measurement approach.

The wet gas flow calculations, schematically shown in Figure 3, incorporate the De Leeuw gas correction correlation for correction of the gas flow rate for the free liquid content, and the De Leeuw continuous liquid flow rate measurement correlation for determining the total liquid flow rate. Both correlations do not rely on homogeneous flow conditions, nor do they require the flow to be conditioned in any other way. No obstructions are placed inside the flow line other than the wet gas venturi based meter.

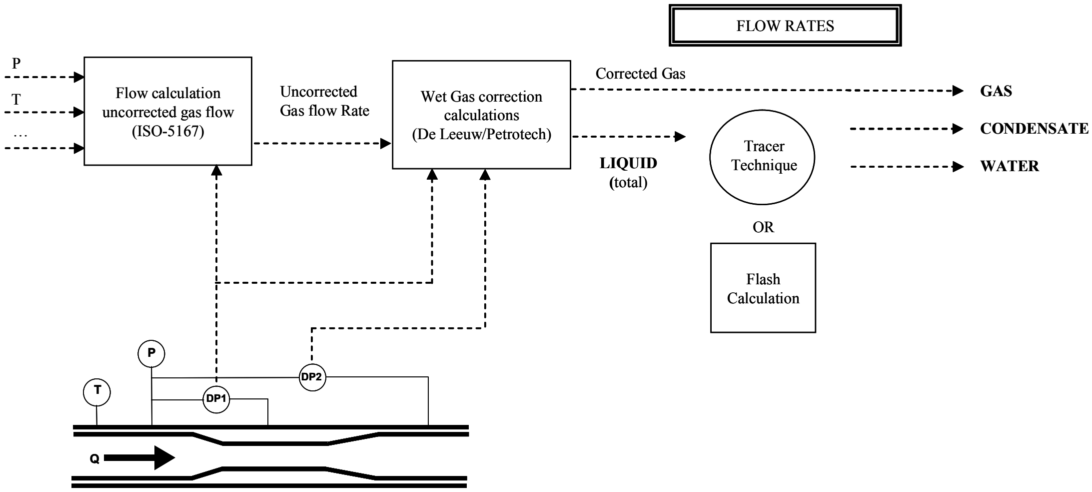


Figure 3. Typical Wet Gas Metering Calculations.

The De Leeuw continuous liquid flow rate measurement correlation is based on the sensitivity of the normalised second differential pressure measurement on the actual liquid content of the flow. The initial development of this correlation was based on the data from the Trondheim flow loop tests, from which earlier the De Leeuw gas correction correlation was developed. Typical test results are shown in Figure 4, in which the normalised second DP measurement is plotted against the Lockhart-Martinelli parameter for a range of pressures (15 and 30 bar data are not shown). Similar to the gas flow overreading behaviour, the pressure loss ratio further depend on the actual gas velocity or gas Froude number.

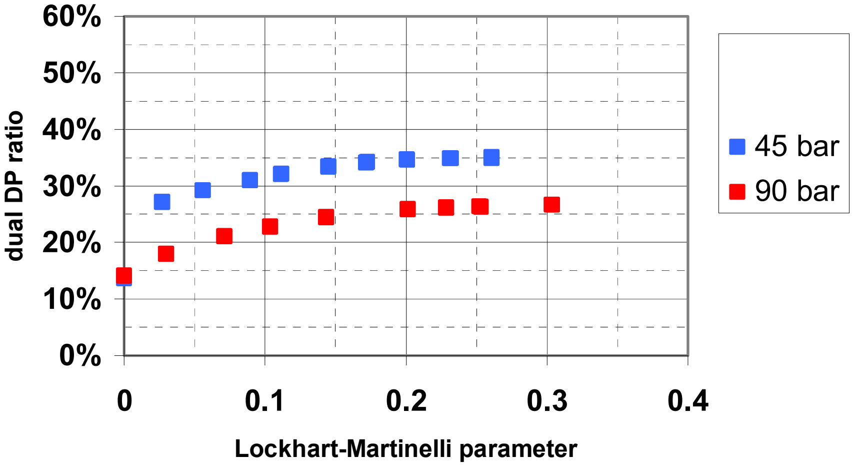


Figure 4. Trondheim flow loop results, pressure loss ratio

An overview of the accuracy of this correlation is shown in Figure 5 below. In this figure the relative error in the calculated total liquid flow rate is plotted against the reference liquid loading expressed in terms of the Lockhart-Martinelli parameter. It can be seen that the overall deviation based on the Trondheim data is of the order of ±10%.

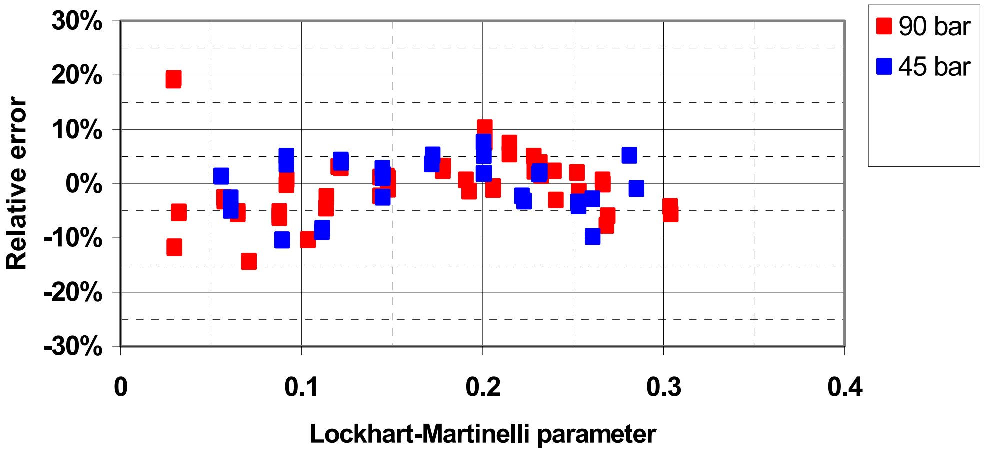


Figure 5. Potential deviation in corrected liquid flow rate from dual DP measurements

The MultiTrace tracer technique can be applied periodically to verify or calibrate the individual water and condensate flow rates. The tracer method involves injection of suitable tracers into the flow line followed by sampling of the liquids at a suitable location downstream of the injection point. Measurement of the tracer dilution ratio allows the determination of the individual water and condensate flow rates. To allow on-site verification of the Wet Gas meter performance the MultiTrace gas tracer technique can be used to verify the actual corrected gas flow rate. The accuracy of the tracer technique is better than ±5-10% relative to each phase, and is not related to the specific volumes of production.

Quality fluid samples can be obtained in combination with the tracer sampling equipment, see Figure 6. Accurate well stream compositions are normally required as gas-condensate system phase behaviour is strongly dependent on temperature and pressure variations. Equation of State behaviour often needs to be taken into account during wet gas metering calculations and process simulations.

Figure 6. Typical sampling apparatus.

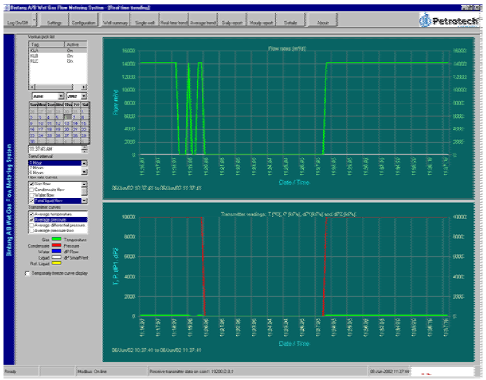


Figure 7. Real time trending.

To monitor the production of the individual wells special wet gas flow calculation software has been developed and installed on a separate flow computer interfaced to the host platform DCS system. The flow calculations incorporate the De Leeuw correlations and the software integrates the wet gas venturi meter data, tracer technology results and various options for flash calculations. All measurements can be shown in real-time trends, Figure 7, and user defined reports have been incorporated.

3. THE KARSTØ METERING AND TECHNOLOGY LABORATORY (K-LAB)

The Karstø Metering and Technology Laboratory, located near Haugesund, Norway, is a large scale test facility which operates with natural hydrocarbon gas and condensate obtained from the nearby located Karstø gas terminal. The line pressure of the facility can be varied between approximately 20 to 150 bar. The flow loop is arranged as a closed loop system. The single phase volumetric gas flow rate can be varied from approximately 40 to 2,000 actual m^3/h.

To accommodate the two-phase gas/liquid tests the test facility was extended with a condensate injection facility and the installation of 2 line separators, one installed upstream, and one installed downstream of the meter test section. The single phase volumetric condensate flow rate could be varied from approximately 0.1 to 10 m^3/h.

A schematic overview of the K-Lab facility is shown in Fgure 8, showing the situation that 3 separate meters were tested at a single time.

The reference gas flow rate is measured by a turbine meter. This turbine meter is regularly calibrated against sonic nozzles, which in turn are calibrated once a year against a weight tank system. The liquid reference flow rate was measured by a calibrated coriolis meter.

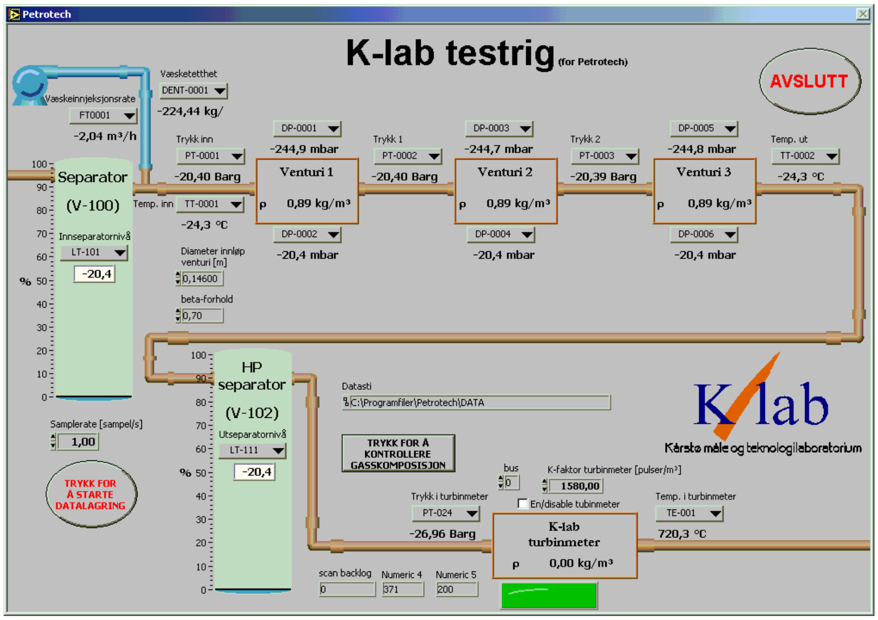
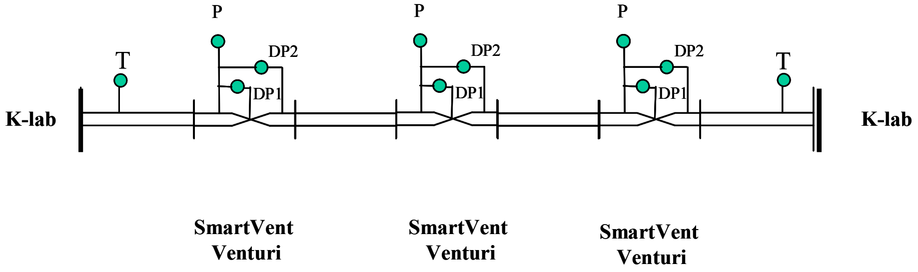


Figure 8. Schematic overview of the K-Lab test facility.

4. WET GAS VENTURI METER EXPERIMENTAL SET-UP

The meter test section layout consisted of 3 separate meters installed in series, as illustrated in Figure 9. This was done to reduce the overall testing time, and to provide the possibility to evaluate the consistency between different meters. The distance between the meters was more than 20D to prevent influences between them.

The temperature at the meters was determined by interpolation from the actual temperatures measured upstream and downstream of the test section. This is also illustrated in Figure 2 below. This approach was considered more than accurate as the temperature change over the test section was never more than 0.5ºC.



Legend
T = temperature transmitter
P = pressure transmitter
DP1 = differential pressure transmitter (flow)
DP2 = differentia pressure transmitter (LGR)

Figure 9. Layout of the meter test section.

A schematic drawing of an individual wet gas meter is given in Figure 10. As can been seen the primary measurements required are the absolute pressure, 2 differential pressures and a temperature measurement.

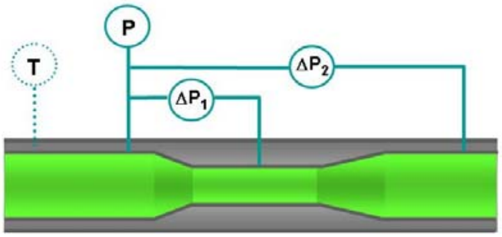


Figure 10. Schematic overview of a wet gas meter.

Figure 11. Overview of the K-Lab test site.

5. SINGLE PHASE CALIBRATION RESULTS

To determine the actual wet gas meter discharge coefficient all meters were calibrated in single phase flow. The listed discharge coefficient in the international ISO-5167 standard can in principle not be used as the corresponding flow Reynolds numbers for gas flow rates encountered at the wellhead fall outside the validity range listed in the standard.

Each meter was calibrated at 6 different gas velocities or Reynolds numbers. For each run measurements were collected for about 480 seconds (8 minutes) and averaged. A graphical overview of the 6” and the 4” meter results are given below in Figure 12 and Figure 13 respectively. For some meters a re-run was performed to verify consistency.

As can be seen from the figures below the measured discharge coefficients are in the range between 0.95 and 1.02.

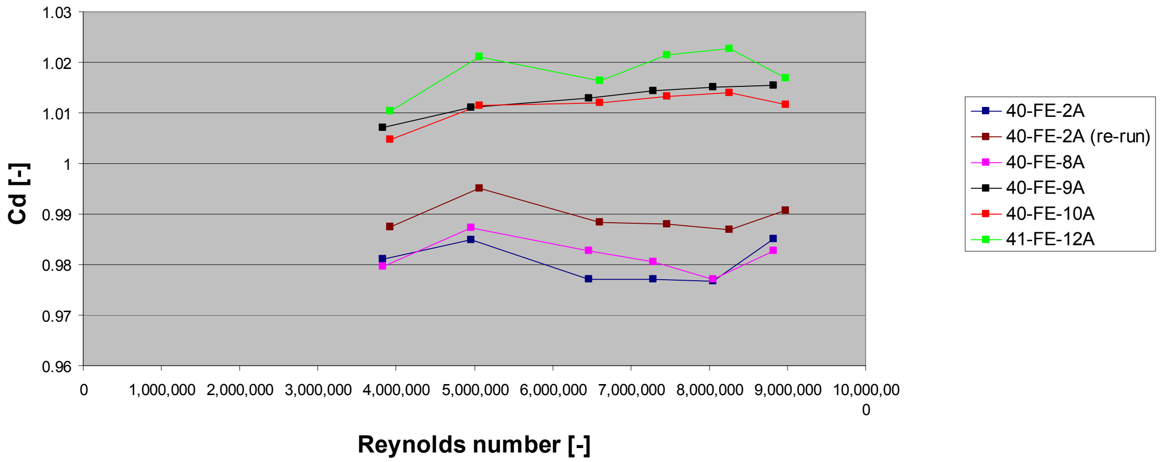


Figure 12. Single phase meter calibration (6”) - Discharge coefficients.

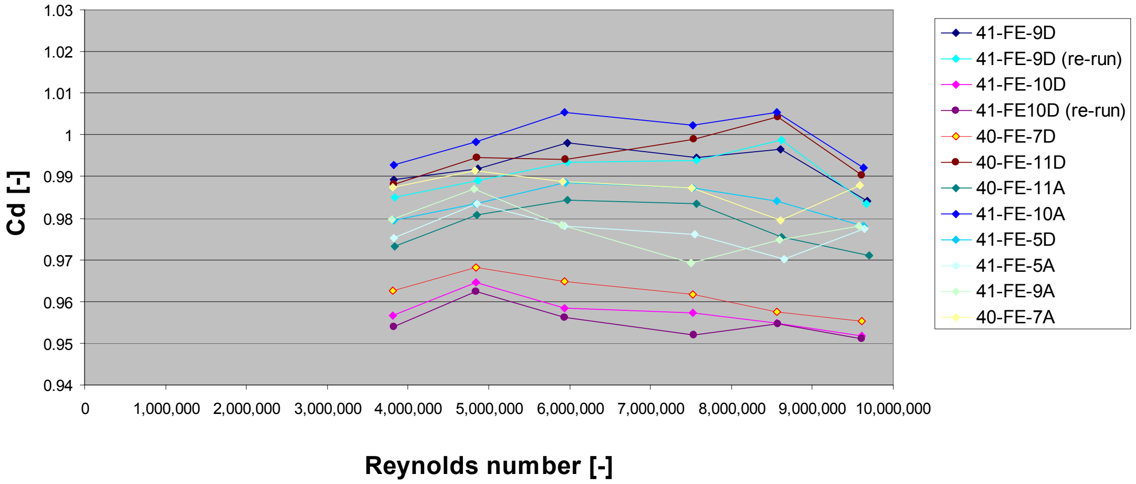


Figure 13. Single phase meter calibration (4”) - Discharge coefficients.

6. WET GAS EVALUATION TESTING

The presentation of the wet gas test results are divided in two sections. In the first section the performance of the De Leeuw gas correction correlation under hydrocarbon wet gas flow is presented. In the second section the De Leeuw correlation for the continuous liquid flow rate measurement is described.

6.1 De Leeuw gas correction correlation

The De Leeuw correlation for correcting the measured gas flow rate due to the presence of liquid in the flow was originally developed from data gathered in high pressure test facilities using typically Nitrogen as the gas phase and a refined oil as the liquid phase. Subsequent industry evaluations were based on similar test fluids.

The K-Lab evaluation tests described in this report are full scale experiments using hydrocarbon natural gas and liquid as the test fluids. There have been some limited data gathered on flowing wells, but these results were often hampered by the relatively small range in pressures and liquid loadings, and poor or no reference measurements.

The evaluation has been done by comparing the measured gas flow overreading against the calculated overreading factor. The liquid flow rate used is taken from the reference measurements, as this provides the possibility to evaluate the De Leeuw gas correction correlation without other influencing factors. As an example, the results for one of the meters is plotted in figure 14, where the gas flow rate overreading is plotted against the liquid content expressed in terms of the Lockhart-Martinelli parameter. The dotted points represent the measured values, the line graphs represent the De Leeuw relationship.

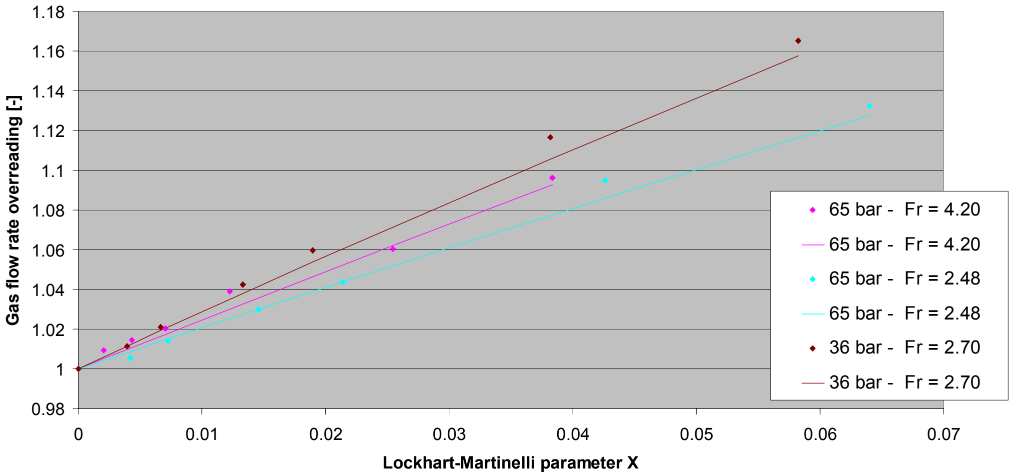


Figure 14. GAS flow rate overeading against liquid content.

The relative deviation between the reference and calculated corrected gas flow rate for all the 6 meters tested are combined in Figure 15. The results show that the De Leeuw gas correction correlation describes the overreading of the gas phase to within approximately ±2% for the majority of the conditions. It can therefore be concluded that the accurate performance of the De Leeuw gas correction correlation has been demonstrated with hydrocarbon test fluids.

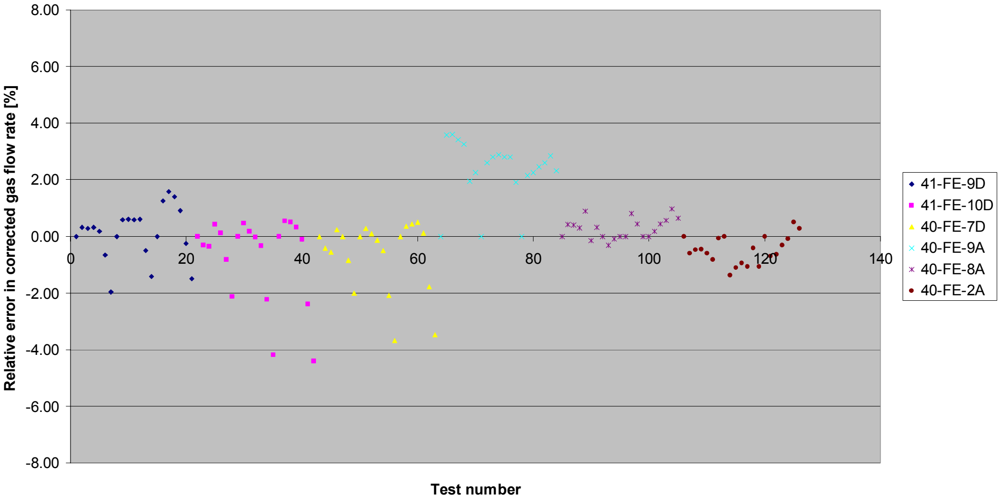


Figure 15. Relative error in the corrected GAS flow rate.

6.2 De Leeuw continuous liquid flow rate correlation

The evaluation of the De Leeuw continuous liquid flow rate correlation is presented with first the liquid flow rate results, and subsequently the final gas flow rate results. As opposed to the previous chapter the gas flow rate results are now presented using the actual liquid flow rate as determined by the De Leeuw liquid correlation.

6.2.1 Liquid flow rate results

The De Leeuw correlation for continuous liquid flow rate measurement is based on the sensitivity of the normalised additional differential pressure measurement on the total liquid content of the gas stream. This is shown in figure 16 for one of the 4” meters in which the normalised second DP is plotted against the liquid content expressed as Lockhart-Martinelli parameter. The plotted results are for 3 different flow conditions.

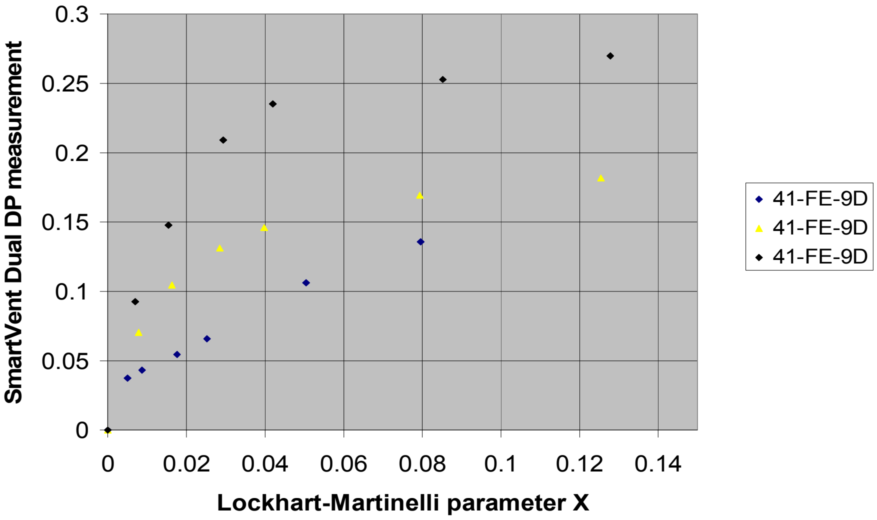


Figure 16. Dual DP plotted against the Lockhart-Martinelli parameter. (4” meter)

From the shown sensitivity the actual liquid content can be calculated. Final results for the 6” and 4” meters are shown in Figure 17 and Figure 18 respectively. The calculated liquid flow rate is plotted against the reference liquid flow rate. The 10% error bars are also indicated.

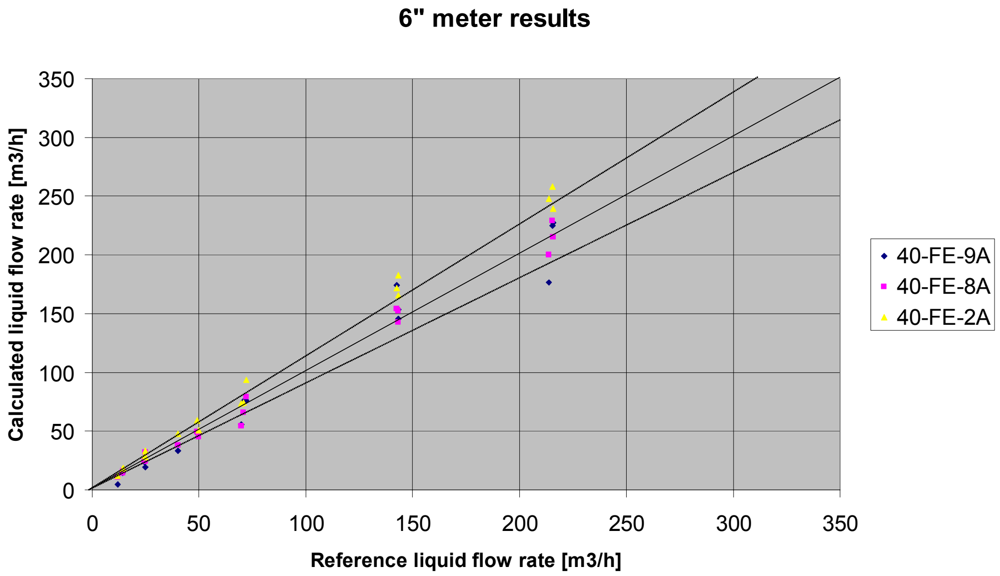


Figure 17. Calculated vs. reference LIQUID flow rate. (10% error bars)

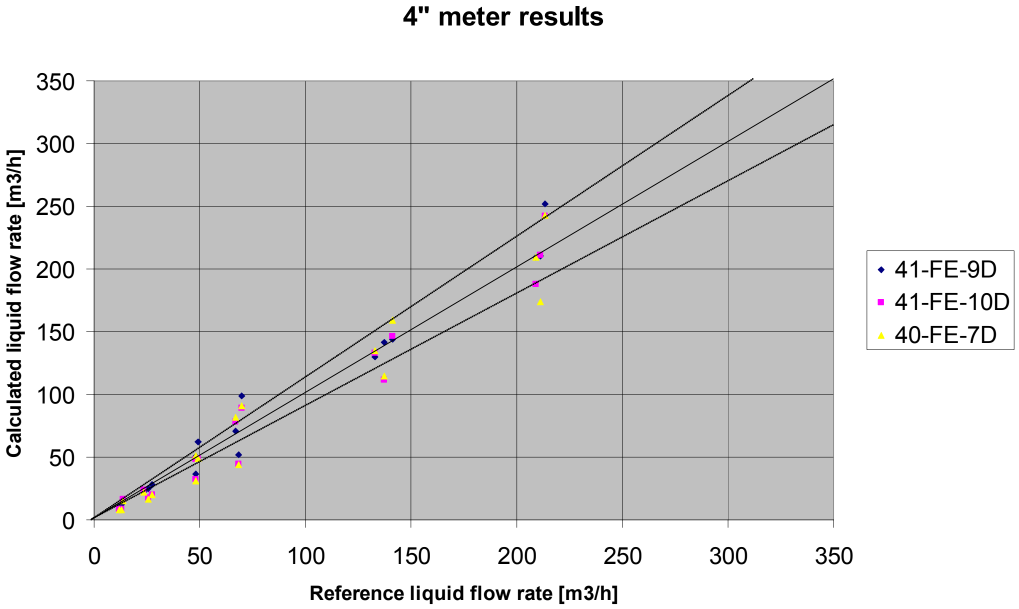


Figure 18. Calculated vs. reference LIQUID flow rate. (10% error bars)

It can be seen that the results for the 6” meters are slightly more accurate than those for the 4” meters, especially in the lower region of the liquid flow rate up to about 100 m^3/d. The reason for this is that the raw measurement data between the 3 separate 6” meters were showing less variation than the data between the separate 4” meters. This larger variation consequently results in a slightly less accurate calculation of the liquid flow rate.

6.2.2 Gas flow rate results

The final corrected gas flow rate is based on the use of the actual calculated liquid flow rate from the second DP measurement. The final resulting error in the corrected gas flow rate is shown in Figure 19. As can be seen, the overall results are still well within the target accuracy of ±5%.

One reason for the very good accuracy of the corrected gas flow rate is that the sensitivity of the gas flow overreading on the liquid content is relatively low. Basically, a 10% error in the liquid flow rate will result in an error in the corrected gas flow rate of only 0-2% maximum, depending on the actual liquid content.

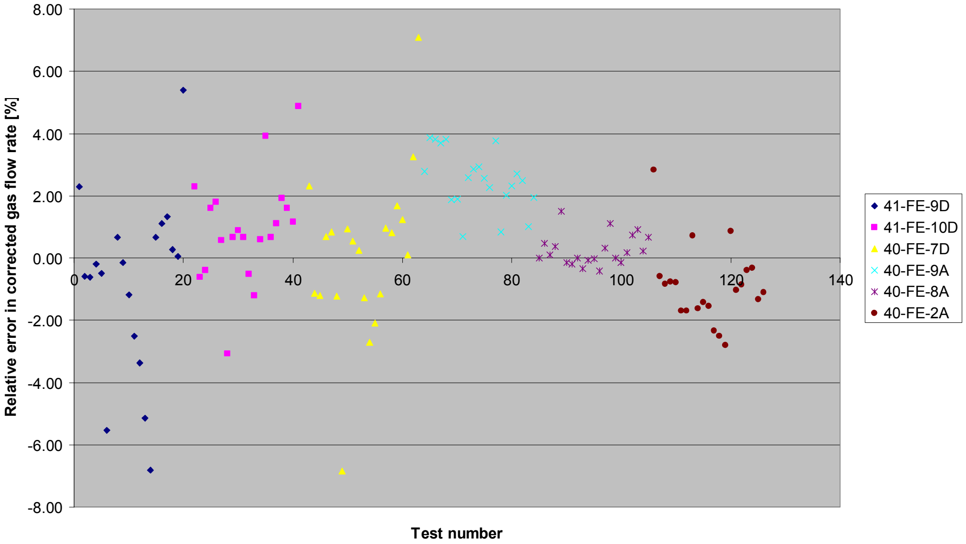


Figure 19. Relative error in the corrected GAS flow rate, using the De Leeuw continuous liquid correlation.

For illustration the results have also been plotted as corrected gas flow rate against the reference gas flow rate. This is shown in Figure 20.

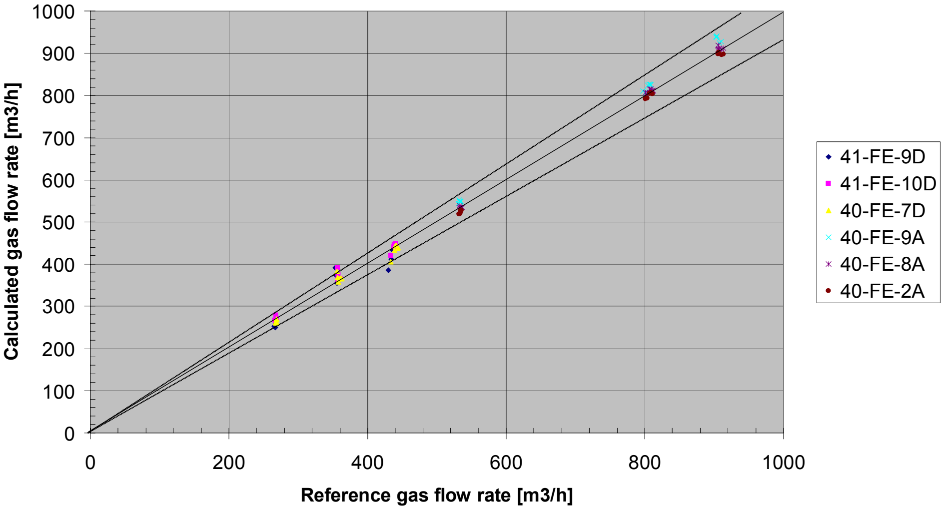


Figure 20. Corrected vs. reference GAS flow rate. (5% error bars)

7. CONCLUSIONS

Petrotech wet gas flow measurement for production monitoring has been selected by ExxonMobil for the Bintang field development, located offshore Malaysia.

Prior to the installation, full scale wet gas meter evaluation tests have been performed at the K-Lab high pressure test facility, using natural gas and condensate as the test fluids. The meter discharge coefficients as calibrated in single phase flow are in the range between 0.95 and 1.02. These values are slightly different from the values listed in the ISO-5167 standard as expected.

The De Leeuw gas correction correlation, describing the overreading of the actual gas flow rate due to the presence free liquids, has shown to be capable of correcting the gas flow rate to within ±2-4%. This result is obtained for 6 different meters tested under K-Lab conditions, and based on these results the good performance of the correlation is demonstrated.

The De Leeuw continuous liquid flow rate measurement correlation, describing the total liquid content of the stream, has shown to be capable of determining the actual liquid flow rate to approximately ±10-15%. Lower uncertainties can be achieved for a corresponding smaller operating window in combination with an on-site tracer calibration measurement. The tracer method will also provide a measurement of the individual water and condensate flow rates.

8. REFERENCES

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