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LONG TERM USE AND EXPERIENCE OF MULTIPHASE FLOW METERING

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TRIAL OF THE PROTOTYPE KVAERNER DUET MULTIPHASE FLOW METER

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ABSTRACT

The Kvaerner DUET multiphase flow meter (MFM) determines the flow rates of oil, water and gas in pipelines from oil wells. The MFM consists of two specialised gamma-ray transmission gauges, and pressure and temperature sensors, which are mounted on a pipe spool carrying the full flow of the well stream, and processing electronics which are located in a control room.

The prototype MFM has recently completed, what the authors believe to be, the longest ever operational period of an MFM anywhere in the world: from November 1994 to September 1998. This paper details the associated testing and method of using the MFM to reduce load on the facilities offshore. A description of the condition of the MFM at removal, including the physical condition of the composite windows, MFM electronics and the flow tube, and to the state of the head electronics is given. Also, the flow rate algorithms for the production MFM have been tested on existing MFM data and comparisons made between each trial result.

1 INTRODUCTION

The Kvaerner DUET MFM originally was developed by CSIRO (Commonwealth Scientific Industrial Research Organisation). In 1997 Kvaerner Oilfield Products signed an exclusive licence agreement with CSIRO for production and further development of the DUET MFM.

The field trial of the prototype MFM occurred on the West Kingfish offshore oil platform from November 1994 – September 98. The platform is located in the Bass Strait off the South Eastern Australian coast and is operated by Esso Australia. This installation was chosen as test site because of the quality of flow measurements available from an up-rated test separator and metering skid

During the trial, well streams were sequentially routed past the MFM which was mounted on a pipeline between the test manifold and the test separator. The bore of the test pipeline is 139.7 mm. The typical test pressure is about 15 bar, and fluid temperatures up to 96°C.

This paper describes the MFM installation and use over the almost four years of continuous operation. A detailed description of the excellent condition which the MFM was found to be in after removal is given and the flow algorithms are tested on existing MFM data.

2 THE DUET MFM

2.1 Principles

The DUET MFM consists of two specialised gamma-ray transmission gauges, and pressure and temperature sensors, which are mounted on a pipe spool carrying the full flow of the well stream. In the prototypes the processing electronics were located in a control room. The first gauge, a density gauge, measures the intensity of 662 keV gamma-rays (^{137}Cs) transmitted through the fluids in the pipeline. The second, a dual energy gamma-ray transmission (DUET) gauge, measures the transmitted intensities of 59.5 and 662 keV gamma-rays from ^{241}Am and ^{137}Cs.

All flow rates are calculated from separate determinations of water cut (WC) and flow rates of liquids and gas. Water cut is determined by dual energy gamma-ray transmission. The flow rates of liquids and gas are determined mainly from measurements of mass per unit area of liquids across a diameter of the pipeline by the density gauge; flow velocity from cross-correlation of the outputs of the two gamma-ray transmission gauges; and operating pressure and temperature in the pipeline. Gas volume fraction is calculated from the internal diameter (I.D.) of the pipe, the densities of oil and formation water at the line operating pressure and temperature, and the combined thickness of oil and water in the gamma-ray beam. In calculation of liquids and gas flow rates from these measurements, corrections are applied to make an allowance for slip between the liquid and gas phases in different flow regimes. Oil and water flow are respectively determined by multiplying liquids flow by (1-WC) and by WC.

The DUET gauge determines the mass fractions of oil and water in the liquids. The basis of this determination is the difference in atomic number of the oil and the formation water. The intensity of the transmitted 59.5 keV gamma-rays depends both on the atomic number of the fluid constituents and the mass per unit area of the fluids in the gamma-ray beam. The intensity of the transmitted 662 keV gamma-rays depends on the mass per unit area of fluids in the gamma-ray beam. Water cut is determined by combining these two measurements and the densities of the oil and formation water at the pressure and temperature of the flowing stream of multiphase mixture.

2.2 Hardware and Software

The DUET gauge requires low atomic number windows to ensure adequate transmission of the low energy (59.5 keV) gamma-rays. Thick windows of carbon fibre reinforced epoxy composite are incorporated into the DUET MFM. The inside surface of the carbon fibre epoxy window, exposed to the multiphase fluid, is shaped to match the curvature of the cylindrical inner walls of the ring, which has the same I.D. as that of the production pipeline. These windows are sealed with O rings to contain the process fluids [pressure tests at up to 10,000 psi have proved the integrity of the system], and, for the production version, a fully metal-to-metal sealed containment system surrounds the windows to prevent escape of production fluids in the unlikely event of leakage.

The very narrow beam of gamma-rays emerging from the radioisotope source containers traverse a diameter of the pipeline. The transmitted gamma-rays are absorbed in the NaI crystal of the scintillation detector. For the DUET gauge, the intensities of the ^{241}Am and ^{137}Cs gamma-rays are separately determined using pulse height analysis. The detector systems are mounted in explosion proof housings. The electrical signals from the detectors are carried via armoured cables, first to a flameproof junction box and from there to the processing electronics. Power is carried by the same armoured cable. The processing is undertaken by a fast nuclear counting system, and the outputs, in the form of counts, are processed by an industrial computer. The computer outputs the flow rates, water cut, and various other parameters which are displayed in computer graphics. The MFM presents the flow rates of oil, water and gas to the platform control system by a serial interface.

3 WEST KINGFISH PLATFORM

Esso Australia Ltd. operates, for the Esso/BHP Joint Venture, all the oil platforms and gas production facilities in the Bass Strait, Australia. The MFM trials were undertaken on the West Kingfish oil platform which lies 70 km from the coast in 80 m depth of water.

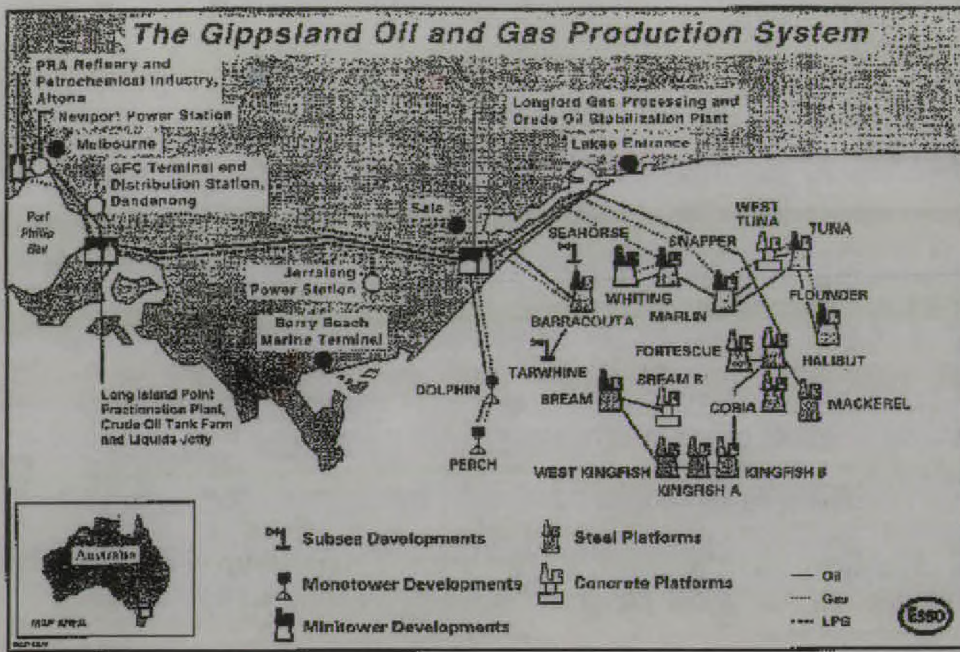

Figure 1 - Oil and Gas production systems in the Bass Strait, operated by Esso Australia Ltd

There are about 20 wells in production on the platform. The densities of stabilised oil and formation water are respectively 0.802 and 1.023 g cm^{-3} at STP. The flows from each of the 20 production wells are measured by the test separator twice a month.

Figure 2 shows the MFM was mounted on a vertical upflow section (ID: 139.7 mm) of the test pipeline which carries the full flow of the multiphase mixture from the test manifold to the test separator. The length of straight vertical pipe upstream of the density gauge was 1500 mm (11 pipe bores).

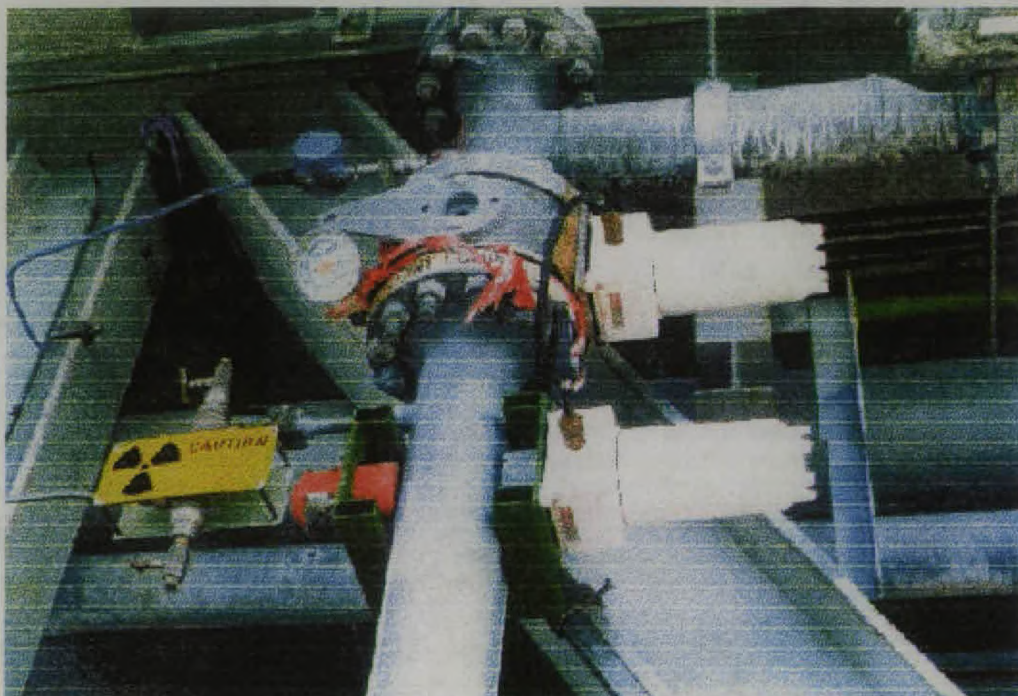

Figure 2 - The West Kingfish MFM about one month after installation

3.1 Eighteen Week Trial

The eighteen week trial of the MFM on the West Kingfish platform was undertaken from November 1994 and March 1995. Prior to start of trial, all meters at the separator outputs were upgraded/replaced to ensure the best accuracy and reliability possible. Sand is produced from some wells and so the test separator was cleaned out to ensure good water/oil/gas interface control.

3.2 Routine Use on Platform

Esso has continued to use the MFM on the WKF platform since the eighteen week trial. The MFM has been in routine operation, 24 hours per day, until its recent removal. After the initial 18 week trial, it soon became apparent that, for a good assessment of the MFM, a continuous record, over the one hour period of each well test, of the flows measured by the test separator output meters was required. This recording of separator flows was achieved in February 1996, with 30 second updates fed to the MFM computer.

The experience from the comparison of MFM and test separator flow determinations from March to the present date is that the MFM and separator determinations of liquids, water and gas flow rates generally agreed well. The accuracies for the MFM were maintained as for the 18 week trial throughout the remainder of the four year deployment.

The Texaco Humble field trial (1996) and subsequent ten month laboratory stability test (1997-1998) of an identical MFM as on West Kingfish, led to further development of hardware and software. The most important changes involved the use of lower capacitance cable and the development of new algorithms for water cut calculation. These changes improved the accuracy and stability of water cut determination, especially over a period of years. The ESSO MFM had approximately quarterly 'health' checks of the MFM performance compared with the test separator to maintain confidence in the DUET MFM performance. The hardware changes and the updated algorithms for water cut determination have been incorporated into the production versions of the DUET MFM. Trials of 6-inch and 4-inch production versions of the Kvaerner DUET MFM have been carried out subsequently using the NEL multiphase flow facility and have affirmed the performance improvements.

3.3 Condition of MFM Ring Gauge after Removal

The prototype DUET MFM was removed from the West Kingfish Platform during September 1998. This intervention provides the opportunity to determine the condition of the hardware following a demanding four year installation, in conditions which included large variations in environmental conditions and flows containing sand. The physical condition of the ring gauge and CFRE (Carbon Fiber Reinforced Epoxy) windows was of particular interest. No inspection of the windows had been carried out since the MFM was installed. Although health monitoring by regular checks of empty pipe gamma-ray intensities had indicated that there was no wear of the CFRE windows in the gamma-ray beam it is important to confirm this by inspection.

The MFM was installed near the eastern side of the platform, with only a walkway between the MFM and the edge of the platform. The walkway consisted of metal grating with the ocean visible directly below. The main deck overhead extended about 3m past the MFM and provided some shelter from the weather. However, the MFM was mostly open to the elements and as a result, after almost 4 years, and absolutely no maintenance, the surface of the MFM was coated with salt and other foreign material. After removing the MFM from the pipe, it was dismantled into its three basic components: source pots, electronic head units, and the ring itself, and then packed into a sea container and shipped back to CSIRO Sydney for complete dismantling.

Figure 3 - Inside bore of the ring gauge.
The white spots are dried salt

Figure 4 - CFRE window after removal.
Note the lack of wear

Figure 3 shows the inside bore of the ring with one of the CFRE windows still in place. The ring was forged from low corrosion carbon steel. The inside of the ring showed no evidence of erosion, nor was there any scaling or buildup of wax. The small white spots are salt. The CFRE window extended slightly in to the pipe after installation. No wear was apparent on the outer face or edge of the window.

The window galleries were sealed from the weather by an outer O-ring joining the ring gauge to source pot or head unit electronics. The seals were unbroken. The oil used during installation of the collimators and threaded parts provided further protection, and each part showed very little evidence of aging.

Figure 4 shows a CFRE window after removal and cleaning in soapy water. Inspection of the O-ring sealing surface of both windows revealed no corrosion or damage to the seal surface. There was no evidence of any wear, corrosion or damage to the front window surfaces. Neither was there any evidence of hydrocarbon or production water seepage into the epoxy. Similarly, the window mating surface of the steel body, Figure 3, was completely intact and showed no sign of any corrosion or wear. Put quite simply, in CSIRO's opinion, the O-rings could have been replaced and the original windows (except for the chip caused by the removal tool) put back into the ring, and the whole MFM reinstalled for another 4 years!

Figure 5 - Window mating surface in the
metal ring

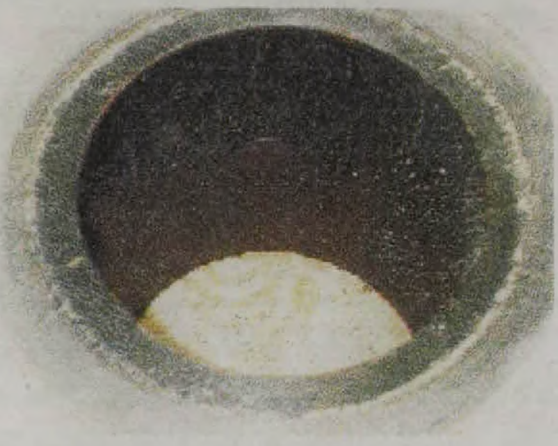

Figure 6 - O-ring after removal

The O-rings were slightly flattened, and in parts were plastically deformed to conform with the slight irregularities of the window sealing surface. However, the rubber remained smooth and flexible and showed no other signs of damage or wear, including the inside surface of the O-rings which were in contact with the produced well fluids and gas.

3.4 Condition of MFM External Head Unit Electronics

Both of the external head unit electronic containers have never been opened since the day they were installed. The NaI crystals, photomultipliers and pre-amplifiers of both units have operated without any faults at all. This is a remarkable achievement, especially considering that the initial specification was for the eighteen week trial only, with the possibility of an approximately one year extension if the MFM was found to be successful. The electronics has been powered continuously, interrupted only occasionally by power resets typical of offshore platforms.

The greatest concern upon receiving the head units back at CSIRO was that the Aluminium housing, used for the prototype, may have seized closed. As it turned out there was no need to worry: a little tight, but not unduly so. Upon opening the vessels, the electronics was found to be in near perfect condition. The only faults were a burnt out neon indicator light in the DUET head unit, and seized air circulation fans in both units. The indicator light has no effect on the meter and the fans were found to be unnecessary in 1996 and are not incorporated in the production DUET MFM.

4 DISCUSSION

Comments are now made on various aspects of the DUET MFM based on CSIRO and Kvaerner experience in its use, particularly in field trials. All data collected during field and laboratory trials is processed through the flow rate algorithms.

4.1 Comparison of Trials

4.1.1 Determination of water cut

The accurate determination of water cut is a consistent feature of the Kvaerner DUET MFM. The determination of water cut by the DUET gauge is independent of flow regime, water cut, and emulsion. Sand and corrosion inhibitor at levels normally occurring in well streams do not affect water cut measurement. The water cut has been consistently measured during field and laboratory trials to better than ±2% at up to 70% GVF and ±4% at up to 95% GVF (Figure 7).

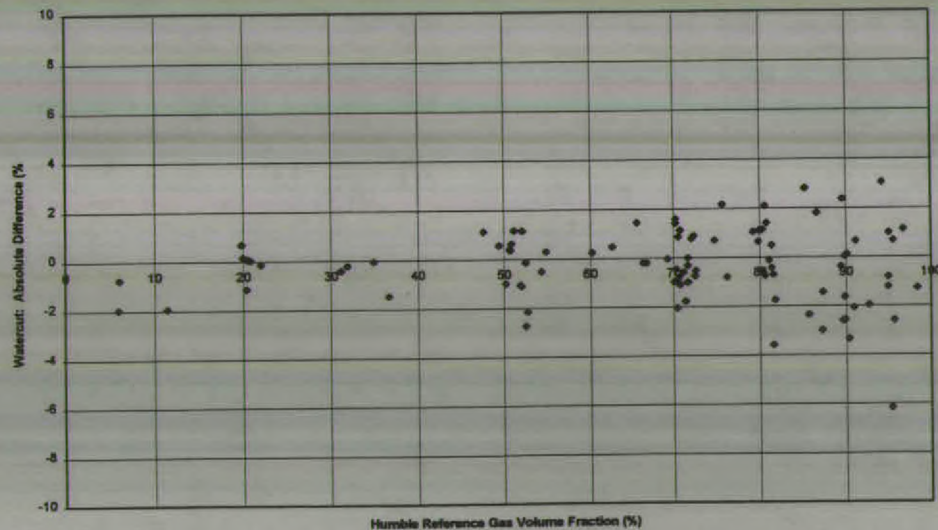

Figure 7 - Watercut results

4.1.2 Determination of liquids and gas flow rates

The algorithms used to calculate the gas and liquids flow rates from the parameters measured by the DUET MFM have been developed progressively. The same algorithms have been applied to data gathered during all trials, using physically different flowmeters and different trial sites. The results from a trial at the Humble test facility are illustrated in Figures 8 and 9 below.

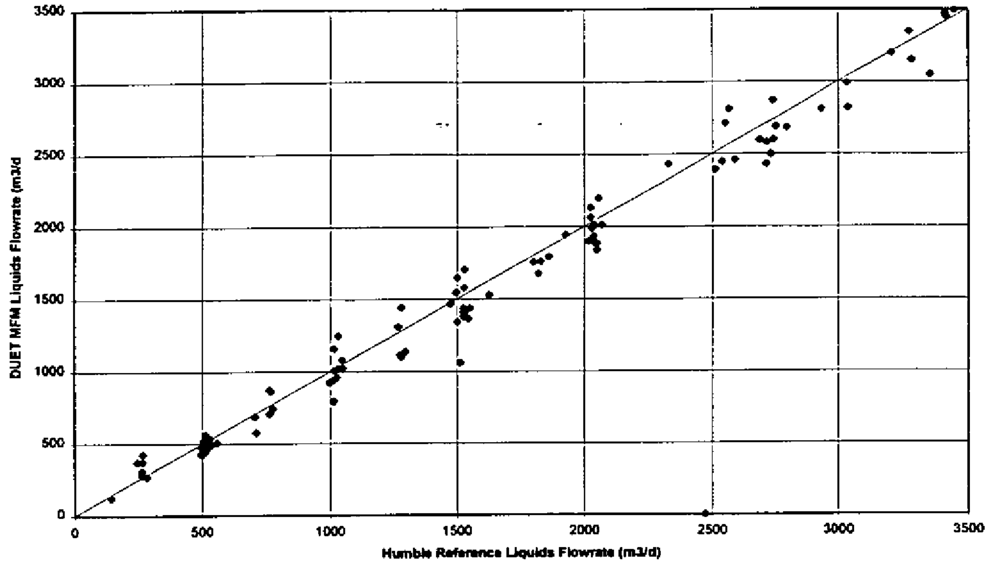

Figure 8 - Liquid flowrate results

These sample data are indicative of the results from all DUET field trials and show that liquids and gas flow rates are determined to accuracies of ±10%, independent of whether the flow regimes in the DUET MFM are dispersed, intermittent or separated.

Differences between the fluids used in the different trials have not caused systematic offsets in the flow rates determined by the MFM and have shown that the measurement accuracy is not dependent on the pipeline fluids.

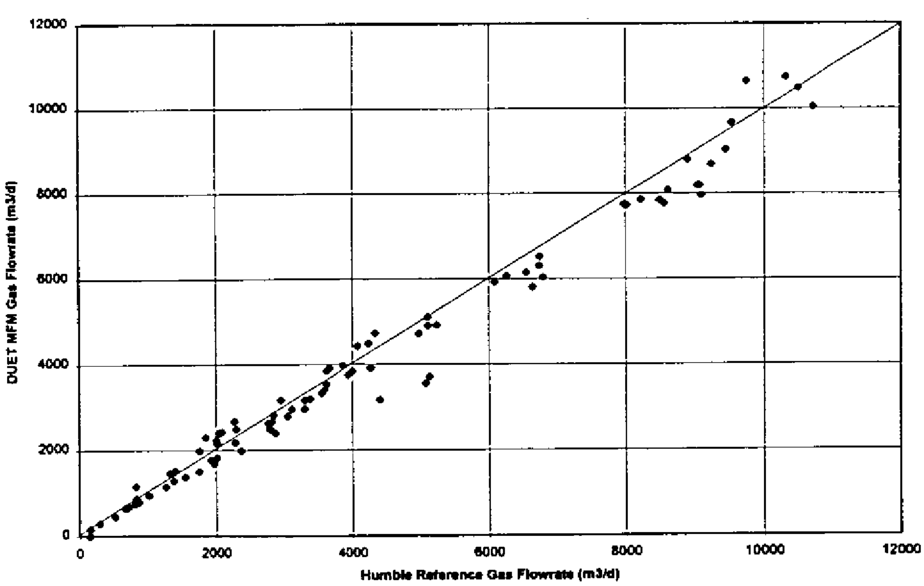

Figure 9 - Gas flowrate results

4.2 Reliability

The DUET MFM has proved to be reliable on the West Kingfish platform. The carbon fibre epoxy windows in DUET gauge ring have been demonstrated successful, with the windows showing no detectable wear over 43 months on-line. There have been five failures of the MFM equipment over the extended period of its operation on the platform: a hard disk crashed irretrievably within 2 weeks of installation, a fan in the processor box failed after 7 months of operation and again after almost 3 years. The heater control circuit needed modification after 2 years. Both the fan and heater unit have been phased out of the production versions of the Kvaerner DUET MFM. A modem also failed after one of the lads used it as a saw bench! All of these breakdowns occurred in the processing electronics in the control room where access and repair were simple, and none have occurred in the head units mounted on the pipeline. In fact, the two electronic head units in the field have never been opened, and have operated without incident since installation. These head units remained installed at all times, without maintenance intervention, during the four year trial.

One reason for the reliable operation of the MFM is that it is non-intrusive and does not depend on use of moving parts as with, say, turbine meters. The West Kingfish trial has demonstrated that the DUET MFM is highly suited to unattended operation on offshore oil platforms.

4.3 Calibration

The determination of water cut is now well understood, and calibration has now been simplified to making sequential measurements with the pipe filled with (static samples) oil, formation water and gas, and knowledge of the densities of oil and formation water, and the solubility of the gas in the fluids, as a function of pressure and temperature. The gamma-ray measurements required for calibration on static samples can be undertaken on-line at the field site, using samples at factory calibration or by calculation from fluid composition data.

4.4 Operational Advantages

The Kvaerner DUET MFM has important operational advantages over the test separator/output meters system. The DUET is more reliable and requires far less operator support and time for determination of the well flows than test separator systems. The MFM operates continuously with operator intervention only being required to switch the appropriate stream through the pipe on which the MFM is mounted.

Since the DUET MFM can be mounted on the pipeline between the manifold and the production separator, there is no need for stabilisation of the well flow prior to the MFM measurement. An Esso operator explains; "There can be a bottleneck which can lead to back pressure on the well. It can take up to two hours to stabilise the well flow before testing. On top of this the separator's turbine meters are prone to blockages which can lead to delays for hours as well as wear and tear." (The Tiger, 1995)

Operator intervention is also required with the test separator when there is a considerable change in flow rates of oil or water or gas to ensure that the single phase output streams are routed to the appropriate output meter. For example, on the West Kingfish platform, the output oil and water streams are monitored by turbine meters, with both high and low flow meters on each stream. The gas flow output is metered by a high range orifice plate and a low range vortex meter. The one DUET MFM on the West Kingfish platform measures all the component flow rates from all the wells fed to the platform; six single phase flow meters are required for use with the separator. The MFM has been shown to operate over a much wider range of flow rates of liquids, oil, water and gas than can be handled by the test separator and its output meters.

4.5 Engineering and Other Developments

The MFM can be adapted for use on a wide range of pipe diameters simply by adapting the design of DUET meter body. The DUET gauge with the ^{241}Am and ^{137}Cs radioisotope pair is suitable for use on pipelines with diameters between 4 and 12 inches.

The current limits of the DUET MFM operating range have been extended to up to 95% GVF, with velocity up to 25 m/s. It is expected that further development of the MFM will extend the operational envelope up to 98% GVF in the very near future.

5 CONCLUSION

The DUET MFM has been successfully demonstrated in the almost four years of continuous operation on the West Kingfish platform. Further concurrent trials of prototype and production standard DUET flowmeters at the Humble and NEL multiphase flow facilities have demonstrated that the performance of the flowmeter is transportable across physically different hardware and to different sites with differences in the composition of the hydrocarbons and produced water. Each of these trials has demonstrated reliable and consistent operation and measurement performance of the DUET MFM.

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