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BP MULTIPHASE METER APPLICATION EXPERIENCE

W J Priddy, BP Exploration Operating Co. Ltd.

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1 INVOLVEMENT HISTORY

BP, like other oil majors, commenced funding of research activity in the early 1980s aimed at developing multiphase meters. The objective was to provide low cost, compact, in-line metering as an alternative to well test systems using separator vessels and single phase flow meters.

Several research programmes have been funded by BP. Principal among these, (and emerging commercially in the industry today) were the Christian Michelsen Research (CMR)/Fluenta, Framo and MFI JIPs and an in-house development which was licensed to ISA Controls Ltd in 1995.

BP conducted a series of field and flow loop test programmes involving the CMR/Fluenta and in-house technologies. These included substantial evaluations at the Wytch Farm (UK) and Prudhoe Bay (Alaska) oil fields from 1989 to 1993 [1, 2, 3].

In 1994, the emphasis was switched owing to concern about the high cost of these programmes and lack of clarity on foreseeable business benefit. The level of funding on hardware development and test was reduced and effort concentrated more on understanding the benefits the technology could offer to BP's business assets.

As part of this, BP explored dialogue with Shell and Statoil and continues now to share the leadership of a multiphase meter users' forum with these companies which provides a useful vehicle for exchanging experience.

Through these efforts, two applications have so far emerged where multiphase metering offers significant benefits: in the ETAP field - subsea; and on land in the Cusiana oil field and Cupiagua gas condensate field in Colombia. The purpose of this paper is to report the latest status of these applications now that multiphase meters are in the early stages of operation.

Some funding of test and development activity on multiphase metering continues. BP is a participant in the Multiflow JIP run at the UK National Engineering Laboratory (NEL). This is a valuable benchmarking exercise which is one of the ways in which knowledge of technology status is maintained. It can also be one of a number of contributory sources of guidance for selecting multiphase meters for application.

Multiphase meter technology is not "proven", as some in the industry misleadingly claim. For example, the capability to measure water cut continuously, on-line at the wellhead, to acceptable accuracy and cost (1% - 2% absolute; one meter on every well) has still to be demonstrated, particularly for mature oil fields producing gas-prone wells with high water cut. BP continues to support research on this aspect. The current applications are another substantial phase in bringing the industry multiphase production measurement capability forward. This will be developed as a contribution to an acknowledged key role of technology in allowing BP to strive for competitive edge.

2 ETAP (EASTERN TROUGH AREA PROJECT)

The Eastern Trough Area Project (ETAP) integrated development in the North Sea comprises seven separate oil and gas fields (Monan, Mungo, Machar, Marnock, Skua, Heron and Egret), Figure 1. The development consists of a two-platform Central Processing Facility (CPF) located at Marnock and a smaller Normally Unattended Installation (NUI) at Mungo. The other fields have been developed as subsea satellites and flow, via multiphase production lines, back to the CPF which also provides oil and gas export facilities.

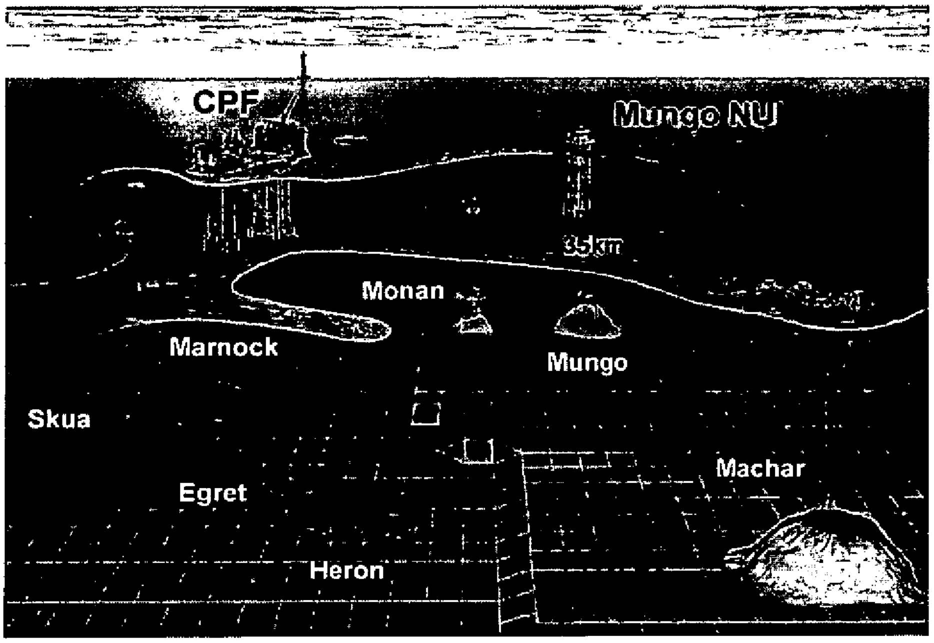

Figure 1 - ETAP Overview - Topside, Sub-Sea and Sub-Surface

The operator for the "M" fields; Marnock, Monan, Mungo, and Machar, is BP. Shell is the operator of the Heron, Egret and Skua fields. BP is the operator for the combined ETAP development. BP's partners are Shell, Esso, Agip, Murphy, Total and Mitsubishi.

Over the last decade or so, a number of feasibility studies have shown that, when considered in isolation, the economic viability of each of the fields was marginal. In 1992, BP Exploration proposed to group together a number of fields into a single development which, when developed together, would deliver a sufficiently robust economic solution. The number of fields has gone through a number of iterations but has finally been refined into what is now known as ETAP.

2.1 Well Production Measurement Needs

There is a requirement to test each of the ETAP wells at a frequency of approximately once per month. The reason behind the well tests and the information required differs between the ETAP fields but in all cases is for reservoir management. These measurements are not required for allocation between the partners.

Multiphase metering was selected for two of the subsea fields, Machar and Monan. The development team studies and processes to establish that these subsea multiphase meters would provide acceptable well testing for these two fields were described in [4]. That paper discussed the criteria used to select the meters.

2.2 Benefits and Service Duty

The Machar and Monan subsea satellite fields are connected to the CPF from a distance of 35 km and 15 km respectively. Conventional test separation metering over these tie-back distances would have been expensive although the CAPEX in each case was not a sole distinctive influence when comparing against the cost of multiphase meters installed subsea.

Considering through-life costs (CAPEX, OPEX and lost production), the case was heavily influenced by the income lost (or deferred) as a result of shutting wells for test by difference. Also, operational difficulties were expected with long test lines. There were concerns about wax and hydrates, compounded by the fact that the test pipelines would have been of smaller diameter than the production pipelines. Control of flow switchovers would be difficult over such distances in view of the multiphase flow dynamics, would have required unacceptable levels of manning, and would also carry some risk of process upsets and deferral of production. Test line metering over these long distances would require excessive purge and stabilisation periods and would alter the wellhead pressure thereby compromising accuracy in terms of representing the flow rates to the production pipeline.

It was concluded that well testing either using a test line or by difference over such distances would not be practical or accurate, especially given the drive towards minimum manning for the operation of the ETAP facilities.

The most cost-effective solution for Machar and Monan uses a single multiphase meter installed in a subsea test manifold with actuated divert valves. This was felt to offer the additional advantage that systematic measurement errors should, to some extent, be compensated in comparing the relative performance of wells.

Multiphase meters were also evaluated as an option for topsides service on the CPF at Marnock and Mungo NUI. For Marnock, they could provide continuous monitoring for two particular "rich" gas condensate wells to allow close control of condensate banking. The most economic (and the original) design case for Mungo was based on topside multiphase metering for reservoir management. For Mungo, the flow measurements are needed to optimise production (on the basis of relative GORs) from eight wells producing with drive from water and gas injection schemes. The control of the injection systems on the basis of the well test measurements is critical.

In both cases, the decision not to install multiphase meters was strongly influenced by lack of confidence that multiphase metering was sufficiently developed for application. Accurate CGR (condensate-gas-ratio) readings are required in the Marnock application (for which a test separator is available).

In view of the relative high value of the Mungo field, and the number of wells and nature of the scheme for recovery, the multiphase meter option posed an unacceptable level of risk. A relatively late decision was made to install a test separator on Mungo, at some additional cost to the project and increase in the level of maintenance presence required on the platform. The decision was also influenced by the requirement to provide a proppant receptacle.

This is in contrast to the Machar and Monan subsea fields which will produce from five and two wells respectively. For the former field, the primary function of the multiphase meter will be to monitor for water break-through during a water injection phase. In the Monan case, the intention is to be able to optimise production from the two wells on the basis of GOR. Monan production ties into the production pipeline from the Mungo field before reaching the CPF. The Monan multiphase meter readings will be judged against the rates of the eight producers in the Mungo field metered by test separator.

In both subsea cases, the project had little alternative to well-site multiphase metering for well testing. This, coupled with an underlying philosophy of the ETAP project to use and advance new technology (of which multiphase metering is just one example being deployed) convinced the project team (BP/Brown and Root) of the argument to proceed. The Machar and Monan subsea multiphase meters are not production critical.

2.3 Selection of the ETAP Subsea Meters

The selection process is described in more detail in [4]. The choice incorporated an analysis of the responses from a number of vendors to a formal questionnaire incorporating a listing of carefully considered criteria.

Framo Engineering A.S. were successful in winning the order for the supply of the two subsea meters in June 1996. This multiphase meter has been described previously on numerous occasions. In brief, it uses a Venturi and dual energy gamma ray flow sensor combination downstream of a novel mixer vessel.

A key factor in making the selection was established experience in designing and supplying subsea engineering hardware. Fluenta were the only other supplier with a subsea sensor package at that time.

It is important to point out that latest flow loop data available to BP from the NEL facility and the high pressure (live hydrocarbon) multiphase flow loop operated by Norsk-Hydro at Porsgrunn from recent JIP test programmes were consulted to the extent made possible by references to them in the vendor answers to the questionnaire. These test data did not present unambiguous evidence in support of the selection process.

The Framo meters are designed for retrieval by ROV and for rapid change-out with a spare sensor cartridge should the need arise. Ideally, remote subsea flow meters should require minimum requirement for calibration adjustment. The subsea engineering team of the ETAP project preferred the Framo mixer technique compared to other systems which attempt to model flow behaviour and rely on in-service factoring.

The selection questionnaire included a key behavioural criterion emphasising the requirement for willingness to work openly with BP ETAP.

2.4 Operating Experience - Start-Up

Test Loop

Prior to delivery, the Machar multiphase meter was subjected to a BP witnessed 3-day test matrix using the Framo three-phase flow test loop at Flatøy, Bergen. Following set up and checking by Framo during the preceding week, this test confirmed the functioning of this particular meter. The extra expense incurred by BP in taking this option and tight project schedule prevented a similar test of the Monan meter.

Comparing against single phase reference flow measurements obtained by calibrated V-cone meters, the measurements by the multiphase meter for bulk liquid and gas rate were mostly within ±10% relative and for water cut within ±7% absolute under conditions of GVF expected in the Machar application, ranging 60% - 80%. The test points covered nominal water cuts of 0%, 50% and 80%. This included some repeats at the end of the period. This level of performance in service, if repeatable, is considered adequate for the management of the Machar reservoir. The loop does not use hydrocarbons under pressure and clearly could not simulate the length or topography of the subsea pipework (multiphase meter 40 to 100 metres from wellheads).

The Monan meter is expected to 'see' GVFs reaching 97% during service. The detail of its mixer internals differ to those of the Machar meter. Both meters use a 65 mm Venturi throat which offered economies of manufacture. Both are designed as nominal 6" units to class 1500 rating.

Onshore

Functional checks were made in the UK at the various stages of integration testing within the subsea manifolds and transport offshore. These included communication links and sensor signals such as the empty pipe gamma photon count readings.

Prior to load-out off-shore, the gamma detector in the Machar meter was found to be suffering degradation with loss of signal. It was necessary to change out the sensor cartridge with the spare insert purchased by BP as a back-up for the Monan and Machar multiphase meters.

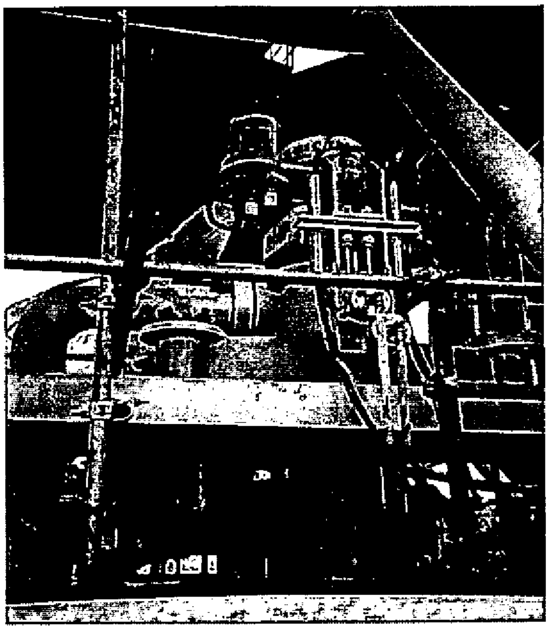

Figure 2 - Multiphase Meter - Monan Manifold

The replacement insert is fitted with a gamma detector manufactured by a new supplier to Framo. It emerged, after detailed questioning, that work had been in progress for some time with the previous supplier to improve detector reliability. The difficulties encountered did not become apparent before the Monan meter, with the earlier detector design, was installed on the seabed. This is regrettable.

Partnership and co-operation in order to ensure the earliest opportunity to address technical challenges in the course of commercial applications (and to assist vendors to overcome them) are to be encouraged in the best interests of all parties.

The ETAP subsea multiphase metering schemes were designed with the intention of little need for intervention during field life (sixteen years for Machar and nine years for Monan). Theoretically, in the Machar case, the decayed Barium gamma source of the Framo meter may require change-out after ten years.

Following installation of the replacement insert in the Machar meter, two of its components failed. The multi-channel signal analysis card failed. This component is not duplicated in the meters so any further failure, in service, would result in loss of meter use. The DP cell also needed replacement owing to erratic signal fluctuations and, in service, such failure would have affected the total volume reading from the Venturi.

BP ETAP is now aware of the possibility of the need for an intervention and retrieval of a subsea meter early in service. Some expectation and budget for this is in place in the context of other equipment installed on the subsea manifolds. It could be argued, in a positive sense, that this early intervention, if it arises, will be an opportunity as part of the technology advance and learning which has underpinned the ETAP philosophy. It would test the capability to change-out multiphase metering hardware subsea in an operational setting.

Offshore

After installation of the Machar manifold subsea, function tests showed that all elements of its multiphase meter were working and that the meter was communicating with the host facilities. At the time of writing, after several months since installation on the sea-bed, commissioning of the Monan meter was in progress.

3 COLOMBIA (CUSIANA/CUPIAGUA)

The Cusiana oil field and Cupiagua gas condensate field are operated by BP Exploration on behalf of a consortium including Ecopetrol, BP, Total and Triton. hey are located in the Casanare province in the eastern foothills of the Andes mountains. The discovery of these fields in the early 1990s doubled Colombia's oil reserves by adding over 1.5 billion barrels.

The development of these fields has proceeded in two phases. Phase I involved a first stage of development of the Cusiana field and peaked at a production rate of over 190 mbpd. During the current Phase II expansion of Cusiana and start-up of Cupiagua, oil production is being increased to 500 mbpd.

A combination of hilly and difficult terrain coupled with a complex and unstable geological structure has necessitated the use of geographically dispersed wells. Drilling is relatively expensive in these areas and scope for deviated well-bores is limited. The multiphase production fluids are transported through a flow-line/trunk-line system to central processing facilities (CPF), Figure 3. The multiphase fluid dynamic behaviour through the pipelines over the hilly terrain has needed special study by BP Exploration including field trials using clamp-on gamma densitometers.

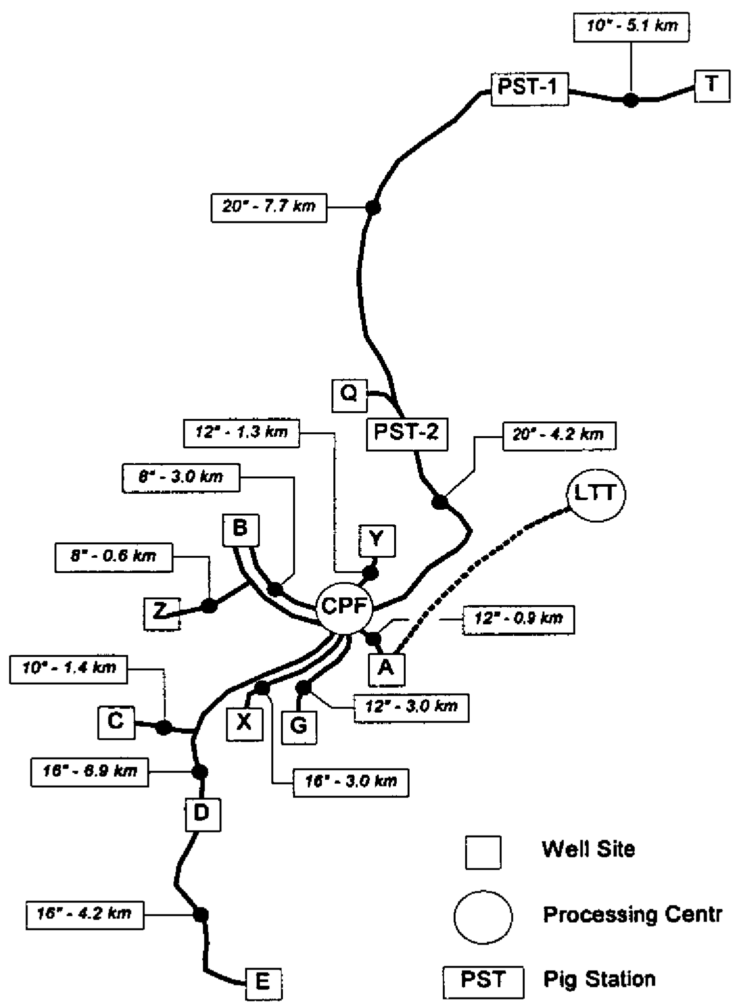

Figure 3 - Cusiana Oilfield Multiphase Production Flowline Network (June 1995)

3.1 Well Production Measurement Needs

Tests of every well are required once per month as a minimum. The production data are critical to effective management of the reservoirs but are also needed for allocation. It is a requirement of the Colombian regulatory authorities that these monthly data are obtained accurately to the best standards expected of a good test separator system. Local royalty and ownership interests vary depending on well location.

3.2 Benefits and Service Duty

Conventional fixed well testing infrastructure including test lines, for the majority of wells, which are remote, would be too expensive and difficult to operate. The well tests during phase one production from the Cusiana field used portable conventional metering systems to cover the more remote of twenty four early production wells. A permanent test separator has been used at the CPF for wells in closer proximity and where a dedicated test line was available. The truck-mounted test separators require choke-back for the high potential wells due to their limited flow capacity. They are expensive and cumbersome (logistics include additional truck mounted auxiliary equipment): in 1996, a total of seventy five well tests was achieved at a significant service cost (~$30,000/test) and with production losses.

During Phase 2 - (full field expansion) - the number of wells for Cusiana and Cupiagua fields combined will exceed ninety. For the Cupiagua field, which sits in more elevated terrain and vegetation, a well test using the portable test separation equipment can take four days minimum to complete and as for Cusiana, in some cases, requires the use of two test sets in parallel to achieve useful flow range, with potential operational difficulties.

Multiphase metering offers substantial benefit in these circumstances, both economic and logistical. Cost savings in furnishing well test equipment, for a five year period, have been estimated at levels comparable to those expected of remote offshore applications. Each meter would permit up to sixty well tests per month. On the basis of Cusiana experience in 1996, this compares to six tests achievable per month for each of three portable conventional equipment sets. In addition to these considerations, there is a significant revenue implication in being able to test to full well capacity. Multiphase metering permits this. Furthermore, the limitation on test capacity to date, imposed by the conventional equipment, has led to some uncertainty in production rates under normal operation and has deprived the asset of important information on, for example, variation of GOR with rate.

The strategy with regard to the deployment scheme using multiphase meters is being developed following field tests and as further experience is gained from operation with the portable multiphase meters used for the trial.

3.3 Field Trials

Recognising the significant benefit potential of multiphase metering, BP Exploration Colombia begun planning field trials in 1996 with assistance from the BP Multiphase Production Technology group. Further confidence was needed before committing to commercial orders for full field deployment. For example, the technology needed to be demonstrated using large meters capable of operating to the full capacity of the high potential wells. BP had substantial experience from across its test and development participation but all involving meters and test facilities restricted to 4" nominal pipe and below. The wells in Colombia typically need 8" multiphase meters.

Furthermore, the viscosity of the Cupiagua condensate (41° API) is 0.3 cP under line conditions, lower than anything experienced previously. Cusiana oil is also light: 35° API; 0.7 cP at line conditions typically.

A short-list of manufacturers was screened in order to select a metering principle which could deliver the required accuracy, repeatability and functional reliability. On the basis of fundamental metering principle, demonstrated and consistent track record and performance, and BP's considerable trials experience at Wytch Farm and Prudhoe Bay [1, 2, 3], the ISA "Multistream" meter was selected for the trial. The positive displacement principle of this technique has been detailed in the above references. An order for two 8" meters was placed in January 1997.

Cupiagua production is dry (apart from water of condensation). Some Cusiana wells are beginning to cut water (up to 20% in a few cases). At the time of order, the ISA system did not include an in-line water cut monitor. Current multiphase meters with this capability have not demonstrated the required accuracy on flow rate. Furthermore, particularly at gas void fractions (GVFs) approaching and exceeding 90%, which is the case for both Cusiana and Cupiagua well streams, they do not exhibit the required accuracy in measuring water cut.

Test separator equipment will remain for well clean-up and related work. This equipment will also provide one means of periodic verification. It can be used to measure water although the companies currently providing the portable well testing service typically route total liquids through the oil leg and resort to samples taken from the multiphase well stream to determine water cut. BP Exploration Colombia also purchased a "WellComp" unit in 1995 for service in the Cusiana field. Some reliability problems have recurred with this unit, but it remains in use. It has not been subjected to a rigorous systematic evaluation but experience in Colombia and sparse data available external to BP show that accurate water cut measurements can be made with this equipment.

The sampling approach was recommended for use with the ISA multiphase meter. As already noted, research to develop water cut sensors of the required accuracy and acceptable cost is ongoing.

In July, 1997, ISA delivered two 8" multiphase meters designed for up to 20 mbopd and 80 mmscfd at Cupiagua wellhead conditions (approximately 1000 psi). The delivery comprised truck mountable skids including: by-pass piping, valves, 8" meters, flow computers, flexible connection hoses and spares, to ANSI 900 rating.

UK National Engineering Laboratory (NEL)

A trials meter was tested at the NEL as a functional check prior to despatch to Colombia. This also facilitated training of Colombian personnel in the form of a one-day programme of lectures and flow loop tours designed in co-operation with the NEL. The NEL has subsequently developed a course and offered it to the industry at large. The NEL resource has been of value in helping BP take multiphase metering into application.

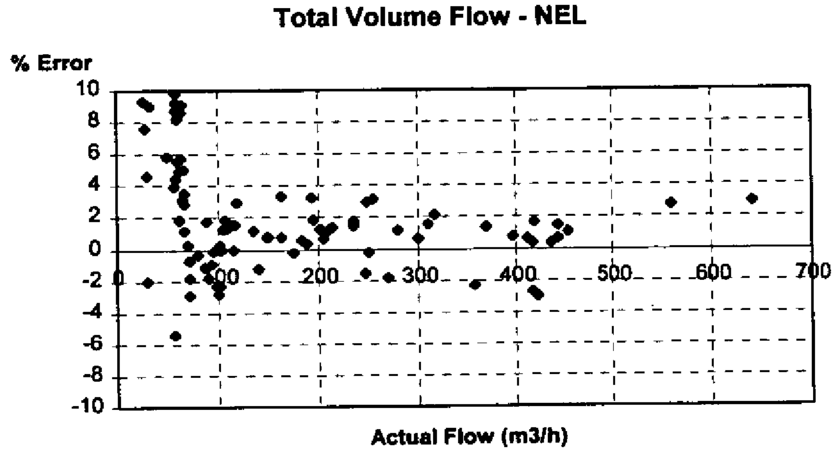

Figure 4 - Relative Error in Total Volume Flow Rate - 8" ISA Meter

Figure 4 shows the relative deviation between the total volumetric flow stream measurement by the multiphase meter and the reference measurements of the NEL test loop. These data cover GVFs ranging from 0% to 99%. The increased scatter below 60 m3/h is associated with frictional drag of the rotor-bearing system of the 8" test meter and is below design range of flow. The meter could be tested over the lower half of its flow rate range using full blow-down of the NEL facility to atmospheric pressure. It exhibits a flat characteristic within ±3%, - close to the NEL reference system uncertainty (up to ± 2.5% estimated by the author, with allowance for pressure differences which must be measured by transducers at the reference station and the test section to correct reference gas volume; and using NEL quoted uncertainties for the single phase reference streams). The multiphase meter is calibrated on single phase water. This was performed against a turbine meter in the ISA factory using the manufacturer's calibration.

The agreement in the comparison concurs with the absence of solubility effects of the NEL test fluids (dead crude oil, Nitrogen and simulated brine - test pressure a few bar at most).

<u>Cusiana Central Processing Facility (CPF)</u>

For an initial phase of testing, a meter was installed in a purpose-built by-pass loop tied into the test pipeline in the manifold area of the CPF. This allowed direct comparisons with a fixed test separator and relatively close proximity to workshop facilities during commissioning.

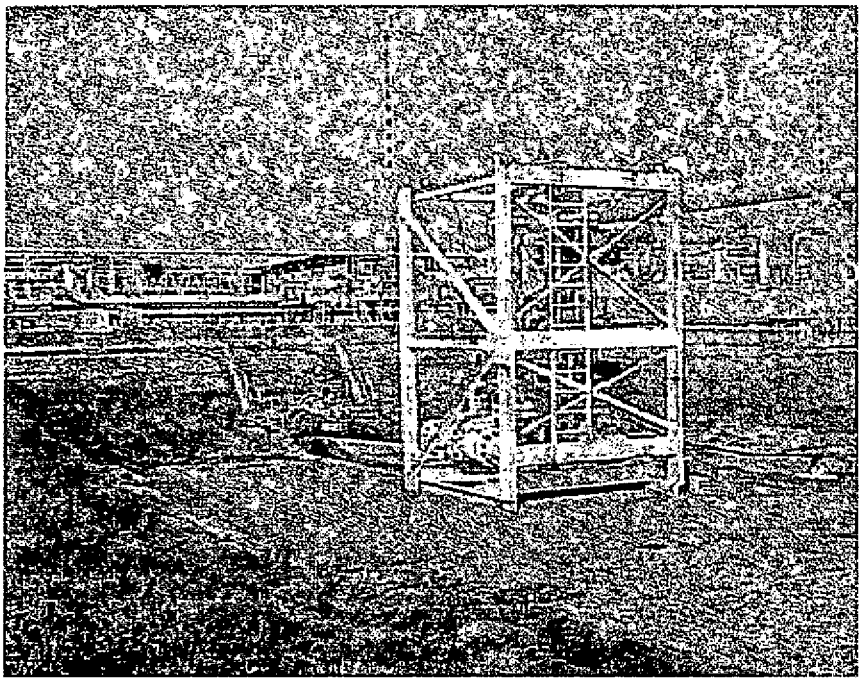

Figure 5 - Multiphase Meter Skid at Cusiana CPF

After two months of difficulties and delays, partly associated with the site, a series of well tests was conducted and some good comparisons emerged, Figure 6. These data were limited in the selection of wells but demonstrated the repeatability of the meter whilst the trials team gained in confidence in the operation of the equipment. These good comparisons were obtained only after the turbine meters in the liquid legs of the test separator were replaced. This followed the discovery of damage to those meters during investigations to assess if larger deviations initially observed were attributable to the multiphase meter.

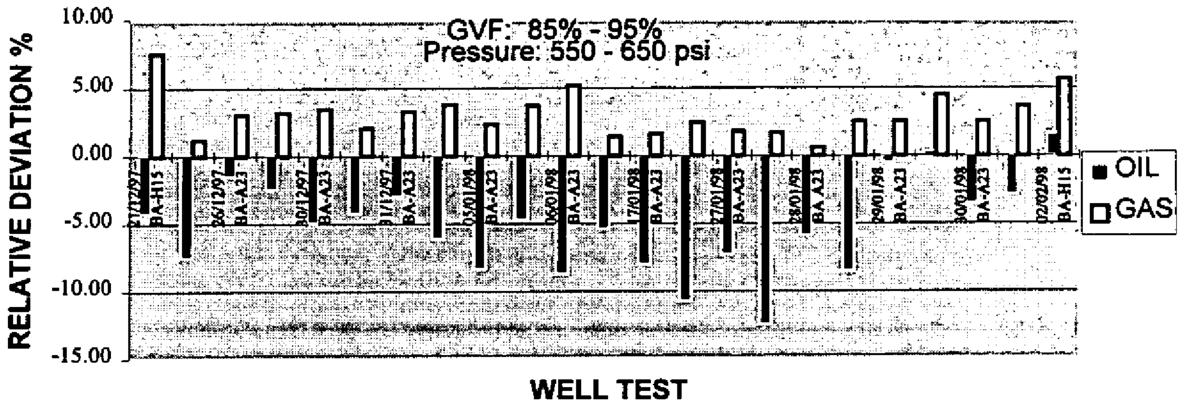

Figure 6 - Multiphase Meter Versus CPF Test Separator - Cusiana Field

(The deviation bars are labelled alternately for clarity. The tests are repeats using wells BA-A23 and BA-H15).

Tests using other wells were attempted early in the trial at the nominal maximum flow range of the meter. Two attempts were made but on both occasions mechanical failures occurred after several hours of operation. One rotor set was returned to the ISA factory for examination and the trials were continued with the second meter to obtain the above results but restricted to half intended full rate. It was concluded that the journal bearings were breaking down under excessive lateral loading at high flow rates.

During factory experimentation and a fast-track study of rotor dynamics lasting four months, ISA established that the rotor design was mechanically unstable owing to an inherent static out-of-balance. This factor had not been understood by the original design team responsible for developing the smaller prototype prior to ISA's involvement. As a result of the factory studies, ISA successfully developed the manufacturing process to compensate for out-of-balance rotor dynamics. Good vibration characteristics have now been demonstrated across range.

<u>Well Pad Tests.</u>

In parallel with the factory investigations, field tests were continued using the second meter (restricted to half range) to assess the accuracy and repeatability of the measurements at different well locations in the Cusiana oil field. This allowed some assessment of reliability, not only by accumulating run-hours in various well streams (with the meter rotors in an out-of-balance state) but additionally by subjecting the equipment to transport on the poor track surfaces in the oil field. As well as having a poor surface in some places (including river crossings), the tracks are narrow with sharp bends around hilly terrain. The ISA skid pivots on a base frame which enables it to lay low on the back of the truck during transport.

At first, poor results were obtained from comparisons with the portable test separation equipment (errors of up to -40% on liquid phase flow rate; up to 20% on gas flow rate). The explanation for this was clouded by the fact that simultaneous testing with the multiphase meter and test separator connected in series was not attempted. Significant differences in wellhead pressure between the two cases (up to 100 psi) could result owing to large pressure drops associated with the test separation equipment and the measurements by the two systems were typically separated by a few days. Nevertheless, it was felt that the errors were too large.

Tests were repeated against the CPF fixed test separator on a well previously used for the earlier successful phase of testing. The errors were unacceptably high with the meter located at the well pad. The meter was then relocated at the CPF manifold area test loop site but the earlier good agreement was not repeated with the multiphase meter reading a low oil rate and high gas rate relative to the CPF test separator. The magnitude of the deviations was not repeatable as tests were repeated.

Thorough investigation of the multiphase meter on site revealed no faults. Its readings indicated well behaviour not inconsistent with that observed earlier when good agreement between systems had been seen. In view of the volumetric accuracy of the multiphase meter observed against the traceable references of the NEL, site operational personnel were advised to check the test separation facilities. In particular, the system consisted of a number of branches with single block valves, between the multiphase meter and the test separator, which could pass fluid.

Thinking had become polarised at several levels of the BP organisation in Colombia that the multiphase meter did not work. The reluctance to question the existing (and familiar) systems was rapidly dissolved on the discovery of a number of leaking valves, both within the CPF manifold area and some by-pass legs of the portable and well pad facilities. There was some evidence that this problem had been aggravated by operational debris, including proppant ("frac" sand).

The testing campaign was renewed with the return of the rotor set from ISA incorporating the improved state of balance. A further series of well tests was conducted, including some at maximum nominal total volume rate. These were more rigorous, using the service company test separation sets coupled directly in series with the multiphase meter at the well pads. Careful attention was paid to valve integrity, reference meter condition and calibration (which included local gauge tank facilities, dead weight tester, etc), and regular hourly sampling for carry-over in the separator gas leg streams in addition to monitoring of level and pressure controls. In some cases, two parallel test separators were needed in series with the multiphase meter to cope with capacity. Good comparisons followed as shown in Figure 7.

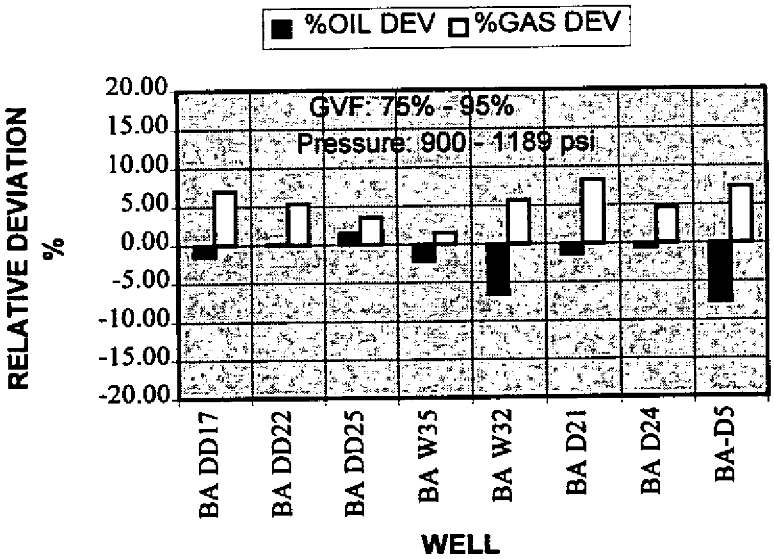

Figure 7 - Multiphase Meter Versus Portable Test Separators - Well Pads - June/July 1998

This follows on from the good earlier results obtained at the Cusiana CPF. There, the meter was located approximately half a mile downhill from (and upstream of) the test separator and a few kilometres, over terrain, from the wellheads. Eight hour test periods, with a preceding purge, were typically used. This was needed to allow for liquid hold-up effects in the flow-lines. Generally, the trial has demonstrated to site operations how, with the meter located at the well pad, a reduced test time can be used, allowing considerable logistical benefits.

Increasing attention was paid to the test separator equipment. The high gas fractions of the well streams, 75% to 95%, dominate the total volumetric reading of the multiphase meter, which, being of a positive displacement design, could be expected to show some under-read of gas flow rate. On average, the opposite has been observed. Sampling and purging from the test separator gas metering runs, which use Daniel senior orifice plate fittings, has revealed instances of liquid carry-over. In some cases, buckling and slight wear of plate edges has been noted. Such effects may have caused these reference gas meters to read low.

Persistence has been needed to ensure consistency between the different metering systems in the use of PVT equations. The specialist equation of state methods employed for the trial and supporting fluid property measurement data are beyond the scope of this paper. The pre-existing equations used for the various test separator systems were all different. Both these systems and the multiphase meter rely on fluid property data as input in order to derive phase volume flow rates and report in standard units. Analysis of the sample data and equation of state correlation on which this input depends continues for meter testing on the Cupiagua gas condensate fluids.

Site operational engineers are using the multiphase meters as stand-alone units on the basis of the results obtained and having demonstrated benefits in their use. The evaluation of reliability continues in service. Questions remain regarding the conventional test separation metering systems, including the liquid (turbine) meter gauge tank systems. These aspects will be pursued further as opportunities arise within operational schedules (including more in-series comparisons with the multiphase meters) in order to tighten the understanding of the comparisons further.

It is important to re-emphasise that the multiphase meter was factory calibrated on single phase water. Apart from repeatability checks of the gamma densitometer counts during commissioning operations in the field, no adjustment or re-calibration has occurred at any stage through the testing at the NEL and in Colombia. The accuracy and repeatability of this metering principle, demonstrated during previous field trials of the 4" prototype [2, 3], is now being confirmed for larger designs. The insensitivity of its calibration to flow conditions and installation sites is key to the practical use of multiphase meters, particularly for applications such as in Colombia.

4 CONCLUDING STATEMENTS

The purpose of this paper was to present the current status of BP's first applications of multiphase metering. These applications are the next major step in taking development of the technology from the research and test phase towards confident commercial deployment.

A key part of this early phase of deployment is the process of verification. One of the main ways in which multiphase meters will gain acceptance is by comparing measurements at operational sites with those from separation metering systems; - commonly, test separators. During technical forums on multiphase metering, much has been said about the accuracy (or lack of it) of test separator metering systems.

Provided the test separator and associated equipment are correctly designed, operated and maintained, meaningful evaluations of multiphase meters are possible. The failings of separation measurements across the industry, where they occur, often result from a lack of adequate attention to these areas, particularly with today's pressures of reduced manpower. Clearly, the verification process can be more difficult over long tie-backs off-shore, such as with the ETAP subsea meters. The field trial experiences presented here have highlighted the importance of a rigorous approach.

Simple, transparent and reliable multiphase metering techniques will greatly diminish the quality assurance burden. Through its development of such multiphase metering methods, incorporating sound fundamental physical principles, BP Exploration can substantiate these concluding statements with a series of consistent and repeatable field data, both recent, from fields in Colombia, and from earlier trials at Prudhoe Bay [2].

With a willingness of the meter manufacturer to co-operate in an open way to ensure successful operation, BP is already realising some business benefit in its first applications of multiphase meters. Demonstration of reliability will now be important to the evolution of multiphase metering in BP's ETAP and Colombian oil fields.

5 ACKNOWLEDGEMENTS

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