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OIL COMPANIES NEEDS IN MULTIPHASE FLOW METERING

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Oil companies' needs in multiphase flow metering

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ABSTRACT

In the last year BP, Statoil, Saga, Norsk Hydro and Shell have established a multiphase metering forum. The objectives of this is to identify common needs and interests for possible co-operation between the oil companies. The aim of this paper is to broadcast key areas of need so far identified by this forum.

The participants in the forum have reviewed a number of potential multiphase metering applications for each oil company. The review clearly showed that there is a widespread need for systems that provide adequate oil, water and gas measurements at gas volume fractions (GVF) between 50% and 99% and that can handle high volumetric throughputs (exceeding 60,000 m^3/day in some cases). The determination of water cut in a range from zero to above 90% is also needed in many applications.

The reservoir and petroleum engineering needs were also addressed, yielding some general ranges for a multiphase meter's accuracy: 5% to 10% error (relative to the individual phases) for both the total liquid flow rate and the gas flow rate, and no more than 2% absolute error in water cut. (This paper calls for the specification of accuracy in such terms.) The specific demands for a meter's accuracy, of course, ultimately depend on its envisaged application; they sometimes can be relaxed in favour of the meter's consistency of performance. Finally, the forum underscored the importance of calibrating meters particularly under conditions of varying produced-water salinity.

INTRODUCTION

The availability of multiphase metering systems is seen by the oil companies as a major cost saver in the development of hydrocarbon reservoirs. Many oil companies have been actively pursuing the development of such metering systems, either through Joint Industry Projects or through their own research and by making test facilities available. These efforts, together with the expertise and the perseverance of the equipment suppliers, have led to the appearance of first-generation multiphase metering systems on the market. It is now up to the industry to successfully implement the current generation of meters and to set new development targets so that the technology matures in the coming years.

In the last year, BP, Statoil, Saga, Norsk Hydro and Shell established a multiphase metering forum to identify common needs and to see what opportunities there were for possible co-operation between the oil companies. So far, the participants in the forum have had four meetings. In these, many aspects of the development, performance, testing and implementation of multiphase metering systems were addressed. The participants felt it appropriate to communicate to the industry, by means of this paper, the common needs that they have uncovered. These needs can be grouped into four aspects of multiphase metering: flow ranges; user requirements; performance specification; and calibration methods.

POTENTIAL MULTIPHASE METERING APPLICATIONS

Each of the participating oil companies has analysed their potential multiphase metering applications. Selected applications were reviewed by the forum, and some of their typical characteristics are presented in Figs 1 and 2.

BP Application

This four-well satellite field will be tied back to a processing platform in the North Sea through a 35-km multiphase pipeline. Conventional well-test facilities relying on a test pipeline would be uneconomic and are unworkable within the metering scheme. This example (Figs. 1a and 2a) illustrates the wide range of flow rates with which the metering scheme will operate over the field life, including high gas volume fractions. The design case is for a subsea installation, in water 95 m deep, that handles fluids flowing under natural reservoir pressure. An alternative production scheme is based on water injection, which would result in higher water cuts. The capability to determine water cut over its full range will be required in many BP Exploration applications around the world.

BP's global multiphase metering perspective ranges from low-rate heavy-oil wells (as low as 32 m^3 liquid per day) to high-volume producers (4000 m^3 liquid per day at 75% - 90% GVF). Some gas-condensate applications will require shut-in pressure ratings of up to 1000 bar.

Statoil applications

The prospect consists of two neighbouring fields in the northern part of the North Sea at a water depth of 135 metres. The field development will be based on a subsea production system. The first field has four producers; their commingled flow will be transported 25 km for processing. The production time for the field is estimated to be 15 years. Reservoir pressure will be maintained through gas injection. The second field will produce hydrocarbons from two different reservoirs. The first year's production will come from five wells in one reservoir and three in the other; ultimately there will be a total of 13 producers. The total productive lifetime of the field is estimated to be 16 years. The entire production will be transported to an existing processing facility, some 8 km away. Figures 1b and 2b show the expected production for a typical well in the first reservoir. Multiphase meters will be needed both topside, for measuring the total flow, and on the subsea template, for measuring individual wells.

Shell Expro applications

Field 1:

This is a small gas field in the central North Sea for which four subsea wells are planned. A floating production, storage and offtake (FPSO) unit is being designed for this field, and a multiphase meter is being considered for well testing. The meter is to be installed inside the turret of this FPSO, resulting in savings on the use of swivels, flowlines and deck space. The FPSO will be used for several other fields later on. The multiphase flowmeter must be suitable for the other fields; otherwise, a test separator would need to be retrofitted. The field is due to start up in 1997, and a decision to use a multiphase flowmeter system will have to be taken by the end of 1995.

Field 2:

This field is one of the high-pressure and high-temperature fields in the central North Sea. It is most likely to be developed around a Not Normally Manned satellite installation. The

Figure 1: Two phase flow maps

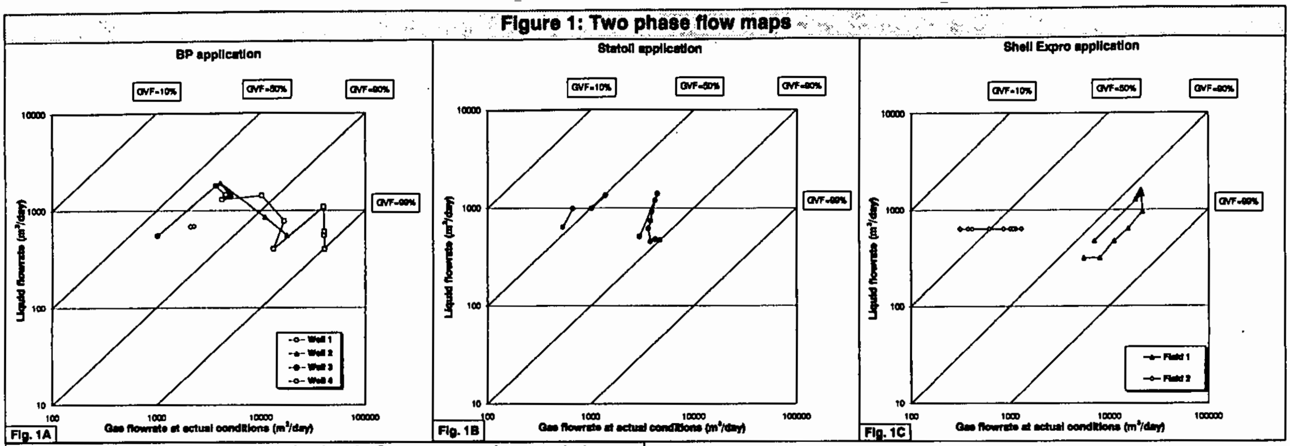

Fig. 1A

Fig. 1B

Fig. 1C

Fig. 1 Collection of two phase flowmaps showing the flowrate ranges of some typical multiphase metering applications. Each point represents a consecutive year.

Figure 2 Multiphase composition maps

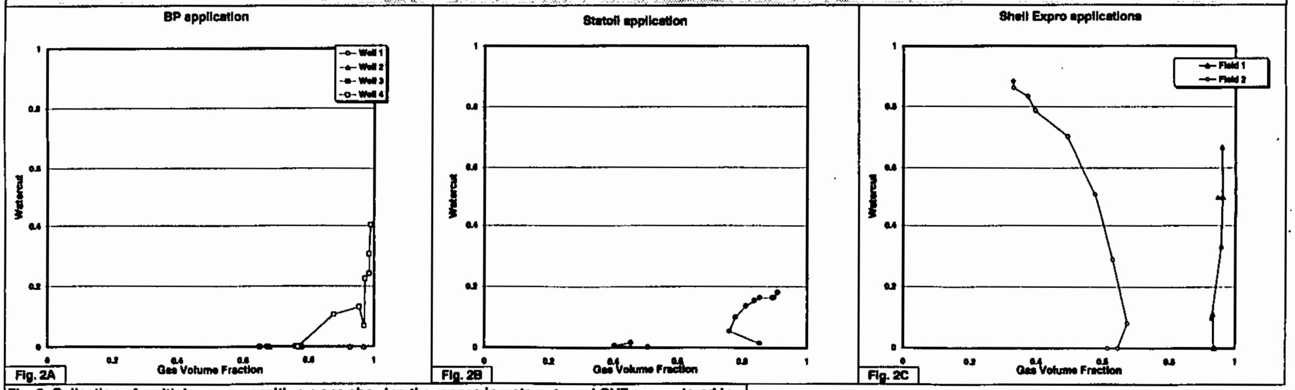

Fig. 2A

Fig. 2B

Fig. 2C

Fig. 2 Collection of multiphase composition maps showing the ranges in watercuts and GVF encountered in some typical multiphase metering applications. Each point represents a consecutive year.

processing will thus take place at central processing facilities nearby. Owing to the chemistry of the field, very heavy scaling is expected. Before it is installed in this field, a multiphase flowmeter will therefore have to be assessed as to its susceptibility to scaling. Also, the high pressure (15,000-pound class) and high temperature will require special meter designs. Field start-up is planned for 1998. The decision to employ a multiphase flowmeter is required before the end of 1995.

Common characteristics of well streams

Having reviewed a number of applications of the forum oil companies, the participants could straightforwardly deduce a number of common characteristics: Large well stream throughputs of up to 5000 m^3 of liquids per day and 60,000 m^3 of gas per day at line conditions are not uncommon. These are likely to require 6- to 12-inch meters. Evidently, for total satellite allocation even higher flow rates have to be metered. High GVF (exceeding 70%) is commonly seen. In many cases wells have a water cut that ranges from 0 to over 90% over their life. Conditions of high pressure and high temperature are also found, particularly in the North Sea area.

RESERVOIR/PETROLEUM ENGINEERING NEEDS

Surveys of the accuracy specifications that would be needed for multiphase flow measurement within the forum oil companies have revealed the following general requirements:

- 5% to 10% relative accuracy in total liquid flow rate;
- 5% to 10% relative accuracy in gas flow rate;
- 2% absolute error in water-cut measurement.

Specific accuracy requirements, of course, will depend on the application. If a multiphase meter is used as a means of allocating production amongst different equity holders using shared processing and export facilities, then the lower limit of ±5% of oil and gas flow rate is more likely to apply—indeed, an even tighter specification might be desirable in some cases.

For reservoir management, on the other hand, the well-test data has several possible uses, and the accuracy and repeatability requirements vary accordingly. Historical well-test data are used for production forecasting and reserves determination. Well workover decisions depend on up-to-date well tests, and—as soon as they are worked over—the wells are usually re-tested. Decisions about expensive development or in-fill drilling programmes are also based on well-test results. The performance of a gas-lift system or an electric submersible pump can be optimised on the basis of well-flow measurements.

Production optimisation similarly relies on well testing to determine the gas/oil ratio (GOR), water cut and oil-rate data for each well so that the well rates may be "tuned" to achieve maximum revenue under given processing-facility constraints. A survey of reservoir-engineering requirements for a range of applications revealed that the desired accuracy in the GOR measurement varied widely, from between 1.5% and 3% in one case to 15% in another. The more stringent tolerance for GOR error is perhaps indicative of a reservoir engineering ideal, given the capabilities of conventional well-test equipment. The looser specification is for a case where well chokes are to be adjusted for maximum oil production through gas-constrained facilities. (A similar requirement may exist when gas production from a gas cap above an oil rim is to be avoided.) Realising that the GOR is the ratio of average gas flow rate to average oil flow rate from the well, one should nonetheless carefully assess the phase flow rate error specification. In the worst case, the GOR may be derived from gas and oil rates whose errors are additive. Each phase, if equally uncertain, would then have to fall within a 7.5% relative error tolerance band in order to satisfy the overall 15% accuracy in the GOR. Moreover, one should not forget that flow rate quantities and ratios are usually required in standard or stock-tank units. Near-wellhead measurement systems therefore will have to be corrected on the basis of fluid state (PVT) data, which present an additional source of measurement error.

Still, it is not difficult to envisage potential applications where the accuracy requirements of multiphase meters can be relaxed. If, for example, the revenues from particular well streams are relatively low, then obviously the accuracy tolerances could be at the loose end of the ranges given above. In some cases the lesser accuracy of multiphase meters could be offset by the fact that well-stream measurements could be taken much more often than conventional test-separator measurements.

Multiphase meters that have been combined with test separators so as to allow more frequent measurements could also afford to be less accurate, but then they must exhibit a high level of repeatability: they must have a "stable" response. To date, most available data from multiphase-meter tests has been collected in flow loops and field trials covering different flow conditions. Attention now needs to be focused on the furnishing of repeatability or response-stability data, which are acquired from multiple readings under closely reproduced flow conditions.

Just as a relaxation of accuracy requirements does not apply to all fields neither does it apply to all measurements. Oil companies are increasingly operating in fields where wells can economically produce significant reserves even at water cuts above 90%. In such circumstances accurate monitoring of the water cut (given by the ratio of the average water flow rate to the average total liquid flow rate) is critical for making shut-in decisions. Because a measurement error can significantly influence the amount of recovered oil and the length of the field life, an accuracy to within ±2% absolute or better is demanded.

Given the variation in requirements across applications, it is essential that facilities designers, engineering contractors and meter vendors have an open dialogue with reservoir and petroleum engineers, who must establish user needs on the basis of the reservoir depletion strategy. Further, metering system specifications must fully account for flow rate ranges over its service life, including an allowance for reservoir uncertainty. Consultants, contractors and their clients must realise, in turn, the substantial investment of time and effort needed by the vendor to tender a proper multiphase meter quotation. Co-operation will be necessary to allow vendors, intermediaries and end users to properly assess and qualify the multiphase metering system.

PRESENTATION AND SPECIFICATION OF METER PERFORMANCE

The forum discussions have revealed likes—and definite dislikes—regarding the presentation and specification of meter performance. Two-phase flow maps and multiphase composition maps (see Figs. 1 and 2) are preferred for presenting flow-rate ranges and indicating the location of test data. Furthermore, errors in phase flow rate should be presented as a percentage of phase flow rate. The forum also prefers the presentation of the accuracy in the water-cut determination to be in terms of absolute error. The forum found it unhelpful and even confusing when errors in flow rates were expressed as a percentage of total volume flow rate. The same applies for quoting relative errors as a root-mean-square average over a number of wells or test points. The vendor should in any case be able to demonstrate the performance of his product with traceable test data.

(IN-SITU) CALIBRATION OF METERS

An important aspect of a multiphase flowmeter is its calibration. Once the meter is physically installed, initial calibration and set-up procedures need to be carried out to arrive at the claimed accuracy and repeatability, regardless of whether these have been derived for production-allocation or for reservoir-management purposes. Yet this essential metering support function has received relatively minor attention over the last 10 years or so of metering hardware development. It is unclear, for example, how remote stand-alone multiphase meters will be calibrated in situ. Depending on the application, such calibration will not only be required initially but also at subsequent intervals.

Hence, multiphase metering systems should incorporate means for in-situ checking or calibration, both of compositions and of rates. Facilities designers should be aware of the sub-systems required for such purposes. For example, purge systems or valve arrangements could be used to introduce single-phase fluids of known properties into composition-sensing cells. Procedures might also be drawn up for summing the total mass of fluids from metered wells and comparing that with the measurement of total production. Alternatively, one could consider deploying more than one multiphase meter for cross-checking purposes.

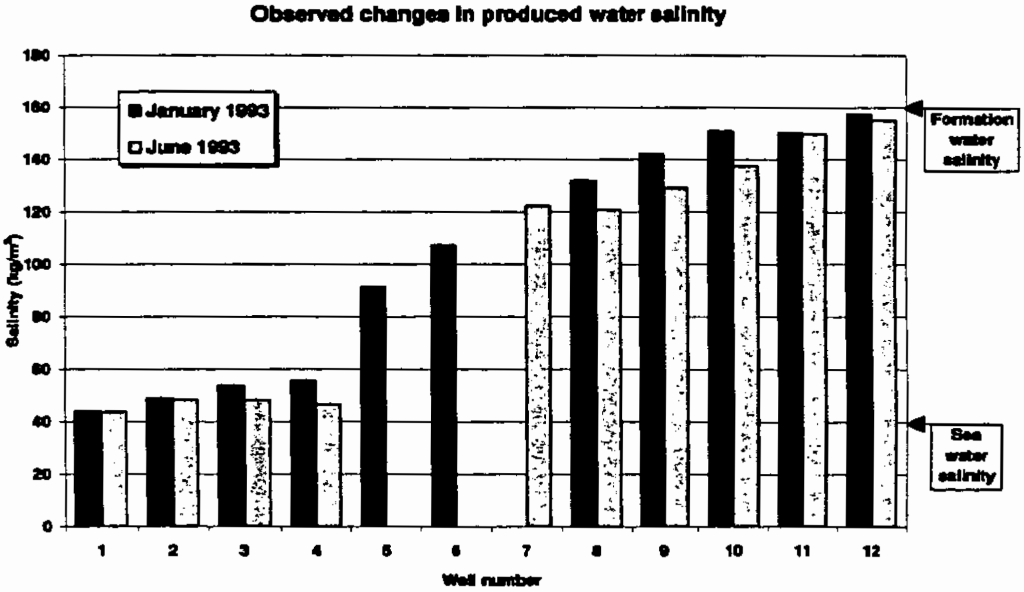

Figure 3 **Produced-water salinities for a North Sea reservoir as measured in January and June 1993.**

Composition-measurement devices must also be capable of compensating for fluid-property variations (e.g. fluid densities). In many potential multiphase-meter applications, for instance, the salinity of the produced water—a key calibration parameter—will not be constant in time. In water-injected reservoirs the salinity will change from the original formation-water salinity to the injection-water salinity. As an example of this, Fig. 3 shows the produced-water salinities for the wells of a North Sea reservoir as measured in January and June 1993. It is seen that salinity is different for each well in the same reservoir and that in a six-month period the salinity for some wells changed by more than 10 kg/m³. Indeed, horizontal and/or vertical gradients in formation-water salinity amounting to salinity variations much larger than 10 kg/m³ across the reservoir may occur [1].

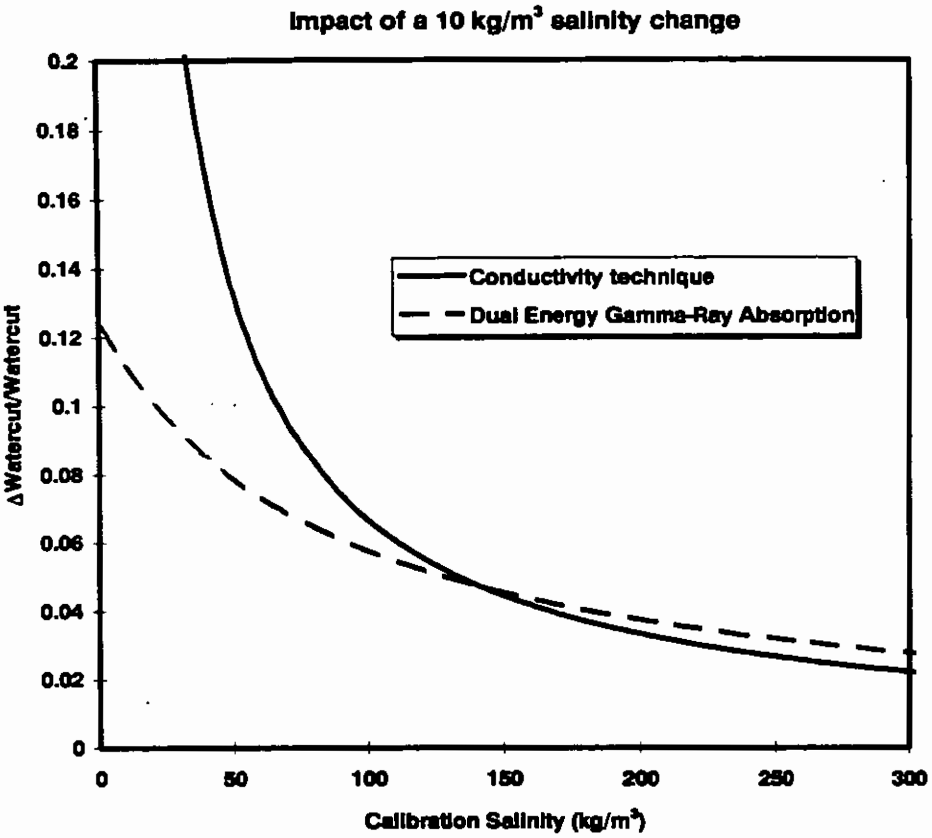

Figure 4 **The relative error in water cut, as a function of calibration salinity, due to a change in salinity of 10 kg/m³.**

Figure 4 demonstrates the sensitivity of two water-cut measurement techniques to a deviation of 10 kg/m³ from a given water-salinity calibration level. (The curve in Fig. 4 for the conductivity technique was computed under the assumption that water conductivity is linearly dependent on salinity [2] and that a Bruggeman-Hanai model was used for the calculation of water cut from conductivity [3,4]. The curve in Fig. 4 for gamma-ray absorption is a re-worked version of Fig. 6 in Ref. [5]. The nature of this problem is such that the relative error in water cut [ΔWatercut/Watercut]is the parameter to plot. This implies that the larger the water cut, the larger the impact of changing salinity will be.) From Fig. 4 it is concluded that a systematic <u>relative</u> error in water cut of at least 5% is to be expected for a 10 kg/m³ change in salinity, corresponding to an <u>absolute</u> error in water cut of more than 2% when the water cut exceeds 40%.

It is thus necessary for the manufacturer or supplier of a multiphase meter to specify the device's tolerance to changing fluid properties and to estimate on that basis a calibration frequency for a given application. In addition, the manufacturer or supplier should specify the exact procedure for in-situ re-calibration of the meter.

CONCLUSIONS

Multiphase metering hardware has been under development for over 10 years, culminating in the emergence of the first commercial products. The applications where this technology has the potential to deliver benefits have started to arise and are expected to increase. As the emphasis of oil companies' attention now switches from the development of equipment to its application, key needs have been reviewed.

These needs include the building of confidence in metering high fluid flow rates with units larger than current prototypes. In many cases, this coincides with high gas volume fractions and the requirement of accurate full-range water-cut measurements. Some applications will also involve pressures and temperatures higher than those experienced by anything built and tested to date. In this context, the accuracy levels that oil companies generally require of multiphase flowmeters have been reviewed. Although the specific requirements vary widely from application to application, they fall within the range of between 5% and 10% relative error for both the total liquid flow rate and the gas flow rate and a 2% absolute error in water cut. In certain cases, accuracy can be traded off for stability of performance. In every case, however, a manufacturer should express the error in phase flow rates relative to the phase flow rate, not to the total volume flow rate. The accuracy of water-cut measurements, in contrast, should always be expressed in terms of absolute error. In view of the confusion that currently exists, the specification and presentation of the performance of a multiphase metering system need to be standardised. Last but certainly not least, the calibration of multiphase meters also demands far greater attention.

Although the technology is admittedly immature, we believe that sufficient confidence now exists to design multiphase meter systems that will add value to emerging applications. With due attention to the needs articulated in this paper and with a general appreciation of the technical challenge and capabilities of multiphase metering, equipment developers, vendors, consultants, contractors, government agencies and field operators can all speed the technology's maturity. Further, we wish to encourage the industry to continue to strive for the ultimate target of low-cost meter-per-well systems.

REFERENCES

[1] McCoy, D.D., Warner, H.R., and Fisher, T.E.: "Water salinity variations in the Ivishak and Sag River Reservoirs, Prudhoe Bay Field", *SPE 28577* (1994).

[2] DIN 746-part 3 : "Angabe des Betriebsverhaltens von elektrochemischen Analysatoren".

[3] Lim, K.-H. and Smith, D.H.: "Electrical conductivities of concentrated emulsions and their fit by conductivity models", *J. Dispersion Science and Technology*, 11(5) (1990) 529-545.

[4] Hanai, T.: "Theory of the Dielectric Dispersion due to the interfacial Polarization and its application to emulsions", *Kolloid Zeitschrift*, 23 (1960) 171.

[5] van Santen, H. and Kolar, Z.I.: "Using a third photon energy for gamma-ray and/or X-ray Composition Measurements in Oil-Water-Gas Mixtures", *Nucl. Geophysics*, to be published.

Figure 1: Two phase flow maps

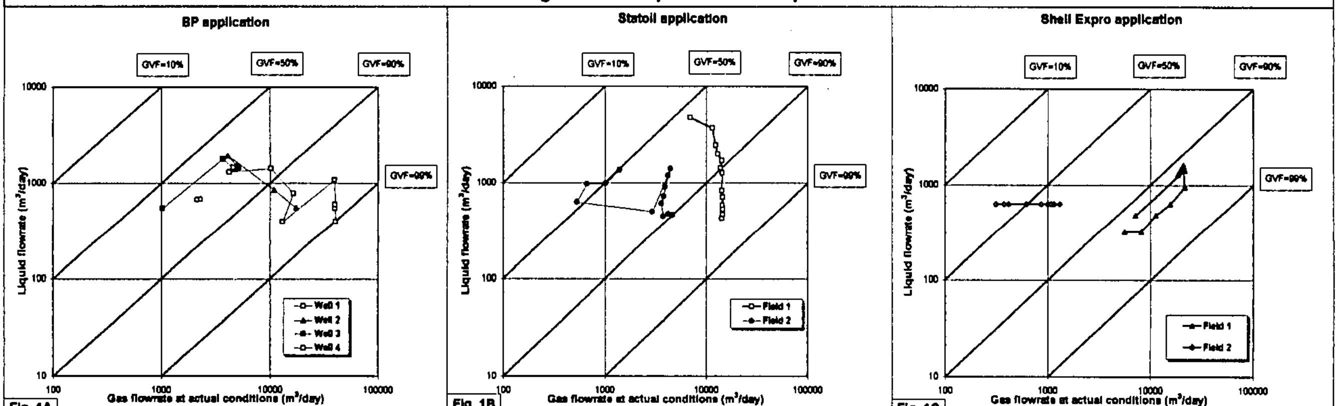

Fig. 1A Fig. 1B Fig. 1C

Fig. 1 Collection of two phase flowmaps showing the flowrate ranges of some typical multiphase metering applications. Each point represents a consecutive year.

Figure 2 Multiphase composition maps

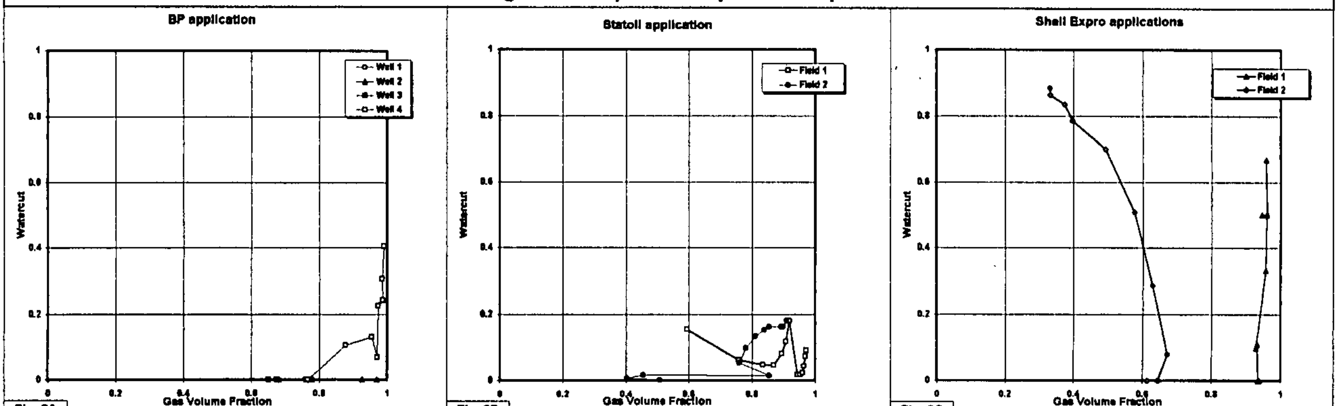

Fig. 2A Fig. 2B Fig. 2C

Fig. 2 Collection of multiphase composition maps showing the ranges in watercuts and GVF encountered in some typical multiphase metering applications. Each point represents a consecutive year.