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MULTIPHASE METERING - THE CHALLENGE OF IMPLEMENTATION

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1 INTRODUCTION

"Multiphase flow measurement" is a term that has been increasingly heard since about 1980 amongst operators in oil companies and designers of oilfield facilities. For some, it promised measurement capabilities under new and trying conditions. They saw a need to simplify the design and improve the control of production facilities. They considered that, unless multiphase measurement techniques were improved, it would be virtually impossible to know what was happening in the advanced subsea systems or on the unmanned satellite platforms that were being planned. In addition they could not see how future enhanced oil recovery systems could be operated effectively without these measurements. For others, multiphase flow measurement was less appealing. They envisaged even more intricate measuring systems, which would be difficult to maintain, and which would only complicate the design and operation of the facilities – without producing a single extra barrel of oil.

It is now clear that the first view is being confirmed. After a long gestation period, reflecting the technical difficulties involved, multiphase meters with adequate performance for selected applications are now commercially available. Oil companies are keen to deploy them. At present Shell Expro has operational multiphase meters on four facilities in the North Sea and can show savings in capital expenditure of about £40 million through their use. The second view must not be ignored however. As multiphase meters are deployed in our operations unexpected difficulties will appear, as with any new technology. If these are not addressed promptly and effectively, multiphase metering will get a bad name, operator confidence will be lost and full implementation of the technology could easily be delayed for, say, five to ten years.

Multiphase flow measurement is not new. Indeed, such measurements are made routinely at most production facilities: a test separator combined with its instrumentation in fact forms a multiphase flowmeter. What is new is the changed attitude towards these measurements. Oil companies have decided on detailed requirements for such measurements, and together with scientific and industrial instrumentation specialists are working towards satisfactory multi-disciplinary solutions for specific applications. The long-term aim is a low cost multiphase meter per well.

Shell Expro has been proactive in the development of this technology, supporting development at Shell laboratories, Universities, and in Joint Industry Projects. The areas of application are varied and include wet gas metering, well testing, optimising production to delay abandonment, and allocation metering. The biggest savings come when it is possible to deploy subsea meters and performance is good enough to allocate production to third parties. By 2010 Capex savings totalling £180-280 million should have been made. Large savings in operating costs over field lifetimes should also be achieved.

None of this will happen by itself. Currently expertise in multiphase flow measurement resides in a few specialists in oil companies, manufacturers and testing laboratories. Know-how must be transferred to project teams, metering consultants; design contractors and operating staff before this technique can realise its full potential.

In this paper, I will outline the types of multiphase meters now available to the oil industry and consider a variety of applications. I think that this is the best way of illustrating the challenges that face the oil industry in implementing multiphase metering in a reasonable time scale, and also of illustrating the opportunities that multiphase metering will continue to open up for well into the new millennium.

2 OVERVIEW OF MULTIPHASE METERING

The oil industry began to take a serious interest in developing multiphase meters around 1980. The problem is simple to state: we want to obtain the gas, oil, and water volume flowrates at line conditions. (At present there is a strong preference for volume rather than mass flowrates, but this preference may change.) These are the measurements that are in principle obtainable from a test separator, the oldest type of multiphase meter. Today I would identify four general approaches to multiphase metering, all of which are being actively developed and are being applied in the field.

Compact separation systems

These devices perform a rough separation of the well flow into liquid and gas streams. These are then metered using meters that can tolerate small amounts of the other phase. The liquid must be further split up into oil and water. These systems are being applied worldwide, but are bulky and do not bring the full benefits of multiphase metering with them. Typical cost £100 – 200k.

Phase fraction and velocity measurement

These meters attempt to identify the fractions of oil, water and gas and measure the phase velocities, which are not usually the same. In practice manufacturers try to condition the flow so that the phase velocities are similar, and the differences in velocity are corrected using multiphase and slip models. Most of the multiphase meters deployed in the North Sea are of this type. Typical cost £100 – 200k surface, £200 – 400k subsea.

Tracers

Multiphase flow is measured by injecting at known rates tracers (e.g. fluorescent dyes) that mix with the individual phases. By analysing a sample of the multiphase fluid taken sufficiently far downstream of the injection point, and combining this with the injection rate, the individual flows can be determined. Currently tracers are only available for oil and water. The technique is particularly suited for wet gas measurement. Costs are closely related to day rate for work and hire of equipment, say £1500 per day.

Pattern recognition

These systems are characterised by their use of simple sensors combined with complex signal processing. Potentially they offer the cheapest hardware combined with the highest metering performance. A major benefit from this approach will be targeting low cost solutions for specific applications. Cost is more variable, but within the range £20 – 60k, depending on the number and type of sensors used.

I believe that any multiphase meter can be fitted without much difficulty into one of these four categories or a combination of them. This is not to say that multiphase metering is now a mature technology and that there will only be minor improvements. Quite the reverse. I think a useful comparison can be made with the development of the motor car. The modern car is clearly similar to cars of 100 years ago. There were no fundamental breakthroughs in knowledge required to transform the car of then to what we have now, but unquestionably there has been enormous development and improvement.

The pattern recognition approach is the least familiar and most mysterious approach to multiphase metering for most people. Yet the operator who puts his ear to a pipe to listen to the flow, or who feels the temperature of a pipe to judge whether there is a flow inside it is practising a crude form of flow measurement by pattern recognition. It is therefore worthwhile pointing out some of the general features of this approach that distinguish it from the other approaches to multiphase metering. As an example, the pattern recognition meter described in the paper by Toral et al [1] presented at this workshop uses differential pressure, pressure, capacitance and conductance sensors to sense relatively fast (approx. 25 – 500Hz) fluctuations in the multiphase flow. The signals from sensors used in most metering applications are damped to reduce noise and give a good average value of the measured parameter. In the pattern recognition approach the fluctuations are what is important, and the average value may not be used at all. An analysis is carried out of the amplitude and frequency fluctuations of the sensor signals and a large number of "features" are calculated. These characterise various aspects of the signal. Thus each sensor, instead of generating only one parameter, can generate perhaps thirty "features".

In principle we can write an equation for each "feature" in terms of the unknown oil, water and gas flow rates. This means that for the meter referred to above which has five sensors, we can write perhaps 150 independent simultaneous equations in terms of the oil, water and gas flow rates. In an ideal world one could hope to find a feature that responded only to oil, another to water and a third to gas. So far, nature does not appear to be so kind and practical methods have to be used to solve this complicated mathematical problem. In the meter above a feature saliency test is used to find the most significant features and then neural networks are used to calculate the oil, water and gas flowrates. Other mathematical techniques could have been used, however. The essential point is that the fast fluctuations in multiphase flow carry most of the information. By using heavily damped sensors the fine detail is lost with the consequence that multiphase meters using heavily damped sensors are unlikely to achieve high accuracies. Using fast sensors and pattern recognition signal processing, virtually unlimited accuracy should be possible, but one is faced with the difficulty of providing highly accurate calibration data for the meter. I believe that it is practical to achieve relative accuracies per phase of 5% by 2005, and 1 – 2%, near fiscal quality, in certain applications by 2010.

3 THE MULTIPHASE TRIANGLE

The biggest obstacle to the successful implementation of multiphase metering is the general lack of understanding of what it is about. It is difficult to explain simply why multiphase metering is so complex. When discussing multiphase metering with colleagues working on prospect development, the general expectation they seem to have is that there can be a universal multiphase meter that can measure all three phases to high accuracy simultaneously over a wide range of flowrates, different for each phase. They tend to assume that measurements from test or production separators are of relatively high quality, because measurements have been made that way for a long time.

Various ways have been proposed to show how the multiphase flow characteristics of a well or a field change with time, and to show the operating envelopes of multiphase meters. The most useful I have found are the plots of application multiphase flow and meter envelopes on a two phase plot of liquid flowrate against gas flowrate, Fig. 1, and a plot of application watercut against gas volume fraction, Fig. 2 [2,3,4].

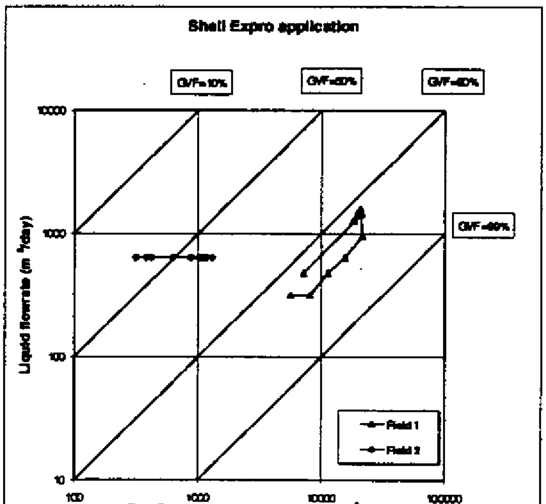

FIG.1 TWO-PHASE FLOW MAP

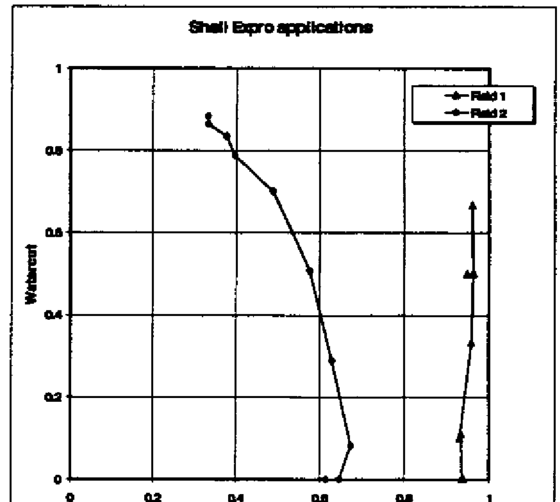

FIG. 2 MULTIPHASE COMPOSITION

Such plots are essential when planning to install a multiphase meter, but they do not give the uninitiated person a grasp of how a specific application fits into the whole multiphase picture.

I have found that in explaining multiphase flow, the "Multiphase Triangle", Fig. 3, is more useful and more readily understood than Fig. 2 above. It is an approach commonly used in other disciplines for displaying properties of three component mixtures.

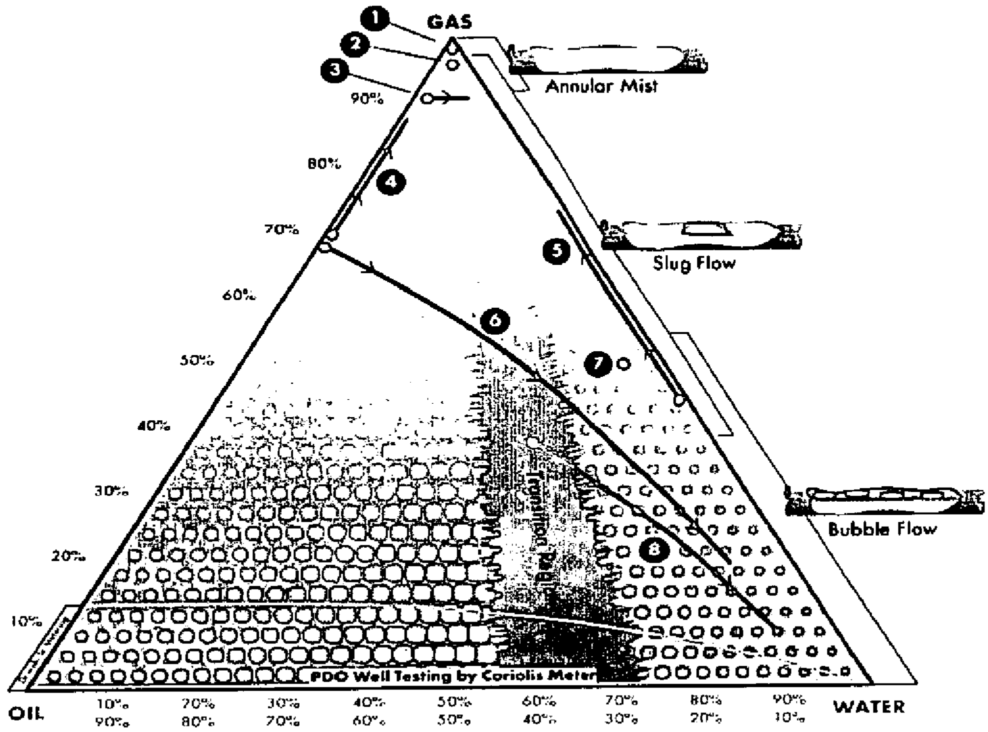

FIG. 3 MULTIPHASE COMPOSITION TRIANGLE

The vertices of the triangle represent single-phase gas, oil and water, while the sides represent two phase mixtures and any point within the triangle represents a unique three-phase mixture. The transition region indicates where the liquid fraction changes from water-in-oil to oil-in-water. The ranges of common multiphase flow regimes, which are affected by temperature, pressure, viscosity and flowline orientation, are indicated at the side of the triangle.

Most of the work over the last two decades has concentrated on developing two-phase meters i.e. oil/gas. New advances in measuring three-phase flow allow us to operate over a larger fraction of the triangle.

A former colleague, Rob Smeenk, proposed this approach in the early 1980's. At that time the triangle was quite bare. We could only measure single-phase flow of oil, water and gas; we could also measure part of the way along the oil-water line. A real indicator of the progress that has been made since then is the detail that has been added to the triangle.

It is easy to use the triangle to show why multiphase metering is complex. If we have difficulty with the single phases, which are so obviously different from each other, we can expect measurement to be at least as difficult for any multiphase composition in the triangle. We have to add to that the complexity from the flow regimes. Flow regime maps have been determined by subjective observation in laboratory testloops, almost always for two-phase mixtures, say oil-gas or water-gas. These maps vary for temperature, pressure, viscosity, pipe orientation. There have been only a few attempts to make three phase flow regime maps, and these are very complex.

This means that it is not practical to predict the performance of multiphase meters from first principles and that detailed empirical testing will be needed. Obviously, the higher the performance demanded from the meter, the better the test facilities need to be. In time, when enough applications have been examined we should be able to see generalities, but for the next few years at least each application will need to be treated on its own merits.

4 APPLICATIONS

I have shown applications that lie in different regions of the triangle. Discussion of these in turn shows how we can build on experience from one application to tackle a more difficult one, and why it is wise not to try to install a multiphase meter in too difficult an application.

Application 1 in Fig. 3 is topsides wet gas metering, using venturi meters, with about 1% by volume of liquid at operating conditions. The corrections to gas flow because of the liquid are derived from a test separator. This is a high quality measurement: the accuracy claimed is about 1.5%.

Application 2 is a gas condensate field with about 2% by volume of liquid, so it is similar to Application 1. To be economically viable, it will probably be developed as a subsea installation. This precludes the use of a test separator. Initially metering is required for well testing for reservoir management, but later in field life may need to be used for third party allocation. Subsea tracer injection to determine the liquid/gas ratio is a possibility, or using the fact that pressure recovery of a venturi meter is related to the liquid/gas ratio. Pattern recognition techniques are also likely to be suitable. In any case, special studies will be required for the initial application, and even more for third party allocation.

Application 3 is another gas condensate field, with about 10% by volume of liquid. Again, to be economically viable, this field will probably have to be developed subsea. It is obviously more difficult to use wet gas metering, but limited studies to date indicate this is probably feasible. Again, the initial application will be reservoir management, but there may be need to meter for third party allocation later in field life.

These three applications illustrate the progression of wet gas metering from dry gas to about 10% liquid, or 90% Gas Volume Fraction (GVF). Compact separators are also practical in high GVF applications, albeit not in Shell Expro's circumstances. Moreover, the phase fraction and velocity measurement approach, which was originally targeted at 50-60% GVF, has been extended to GVFs of over 90% in special circumstances, so that I think it is now best to treat wet gas metering simply as an important subset of multiphase metering.

Application 4 is a very long subsea tieback, with a multiphase meter required for well testing and reservoir management. The well will be natural drive throughout its life, so the reservoir engineers expect hardly any water. This will most likely be Shell Expro's first subsea multiphase meter, and from the multiphase triangle it is easy to see why this is an ideal first application. We only have to measure two phase flow, and have the capability of detecting water breakthrough should it happen. We could do that ten years ago, so from the measurement point of view we can be confident that we can make that measurement subsea. The stiffer challenge is in getting the operational aspects of the installation right to minimise the need for expensive maintenance.

Application 5 is unusual in that it is to measure the water/gas mixture produced in the depressurising of a reservoir. The accuracy required for this two-phase measurement is about 10%, but equipment must be low cost. Again, we know that this measurement can be done by a variety of equipment. As with all multiphase metering, it is not a trivial matter to get it right.

Applications 6 and 8 are subsea tiebacks to a floating production installation where there is a multiphase meter for well testing instead of a test separator. The trajectories followed by these wells across the multiphase triangle show how the small reservoirs being developed in the North Sea today decline rapidly to water.

Application 7 is on an old field, where there is no test separator and well testing had to be done by deferring about £800,000 worth of production each year. If one can reduce this deferment, it is evident that this will help in delaying abandonment. The measurement had to be low cost, and a pattern recognition approach is being evaluated.

I have also included two other fairly general areas of application. In Oman, there are many low-pressure wells with no gas at wellhead conditions, and so are two phase oil-water mixtures. These are tested using Coriolis meters, with the density measurement used to determine the oil and water flowrates.

Well engineers are considering downhole multiphase metering, especially for multilateral wells where there is a need for a meter in each branch of the well. To me, the main advantage in metering downhole is to suppress the gas fraction and reduce the measurement to an oil/water measurement. I would expect the GVF to be low for this area of application, and the meters need to be designed accordingly.

In Shell Expro, apart from the high accuracy wet gas meters, we have found it very difficult to make direct comparisons of the several multiphase meters we have installed with other metering, usually test or production separators. Without exception, however, the multiphase meters have shown up deficiencies in traditional separator measurements. From evaluations carried out in test labs and offshore, I think it is fair to say that several multiphase meters perform as well as traditional test separators.

5 THE MARKET

With this review of multiphase meter applications I think it is clear that there can be no single multiphase meter that can satisfy all requirements. This is good news for multiphase meter manufacturers and developers. Through much of the last two decades, manufacturers and oil companies have chosen a particular approach and have concentrated on that to the exclusion of other approaches, hoping that their approach would be "the winner".

Table 1 WELLS WORLD WIDE (source KOP)

LOCATION	NUMBER	AVERAGE PRODUCTION BBL/DAY
USA	572,000	11
Venezuela	15,000	191
Argentina	13,000	57
Canada	47,000	29
Western Europe	6,420	990
Rest of World	251,000	188

The best way to use multiphase meters is to have one per well. Table 1 shows the number of wells in different regions of the world. There are about one million. Many of these have very low production rates by North Sea standards, but I suggest that a modest target would be for the oil industry to install multiphase meters on 1% of the wells by 2010. That means 10,000 meters, or about 900 a year between now and 2010. I think most of these wells are on land, and that the meters would be used for well testing. Thus with a relatively modest improvement in performance multiphase meters can be deployed widely. At an average cost per meter of £100,000 that is a market of £l Billion. I think there is room for a few winners in that market.

For the North Sea the picture is different. There are about 1000 wells in the North Sea, and I suggest that a reasonable target is about 100 multiphase meters by 2010. Most of these would be subsea for well testing or third party allocation, and will therefore cost more, say an average of £200,000, giving a market of only some £20 Million, less than £2 Million a year between now and 2010.

6 THE FUTURE OF MULTIPHASE METERING

We in the countries around the North Sea like to think we are leading the development of multiphase meters. We have set challenging targets for multiphase meter performance, but it is evident that the North Sea market for multiphase meters is not big enough for manufacturers on their own to develop, say, multiphase meters for third party allocation. For Shell Expro, if the performance of multiphase meters stops at "well testing" standard, we will not require many multiphase meters topsides or subsea, but neither will we get the benefits from using them. Clearly for the North Sea operators there is a major challenge to improve the performance of multiphase meters significantly over, say, a five-year period.

There is little appreciation of the time it takes to develop and test multiphase meters. Last year I made what was intended to be an upbeat presentation to colleagues working on new developments, and told them that we could reasonably expect to develop multiphase meters for third party allocation by 2005. Their response was that they already needed that quality of performance for projects they were working on and that they could not wait for that length of time.

From the testing we have done on multiphase meters offshore, and what I have seen done by other companies, I believe that it is impractical to verify the performance of multiphase meters offshore to high standards except in very exceptional circumstances. Valves on test separators or on production manifolds frequently pass sufficiently to make detailed verifications impossible. It is often difficult to maintain stable operation of separators to allow detailed comparison. To put it simply, if we have the facilities to carry out such verification, we probably don't need to install a multiphase meter.

The consequences of this are that most of the testing to show that a multiphase meter has a high performance will have to be done at special test facilities that can simulate realistic operational conditions. There are one or two facilities that may be suitable, but they are unlikely to be able to cover the likely range of flow conditions. It is unlikely that tests done on current laboratory test loops will be sufficiently convincing.

7 CONCLUSIONS

Multiphase metering is at the stage of development where oil companies can deploy them to bring large benefits:

Multiphase meters are now being applied successfully by a number of companies. Apart from the obvious financial benefits, they allow operators and reservoir engineers to monitor oil and gas production in ways not possible before, thus aiding production optimisation. In the long term, this will probably be the biggest benefit from the use of multiphase metering.

Existing multiphase meters or indeed any multiphase meter likely to be developed can be fitted into one or a combination of the four approaches currently used in multiphase metering. These approaches offer different levels of technical complexity and require different levels of understanding. Operating companies can therefore choose a multiphase metering system suited to their specific needs.

Enough development and testing has now been done to show that high performance multiphase meters for third party allocation and for near fiscal measurement are practical, and that their realisation need not be too far off. In this respect the pattern recognition approach, on its own or in combination with the hardware from the other approaches is most relevant.

The potential market world wide for multiphase metering systems is very large. No single type of meter or metering approach can hope to cover all applications. Although we can expect that some manufacturers will withdraw, others may enter the market. There is clearly room for several suppliers.

However:

Multiphase metering systems are most certainly not "fit and forget" equipment in their present state of development. They should only be deployed where there are clear financial benefits and where there is real commitment to making them work.

Widespread implementation of multiphase metering cannot take place until expertise is spread more widely throughout the oil industry. Most of the expertise in multiphase metering is held by specialists in oil companies, by developers and by manufacturers. Metering consultants and facility design houses are slowly beginning to build their expertise.

Multiphase metering is a complex subject. It is important to develop ways to explain the complexities in a readily understandable way. The Multiphase Triangle approach appears to be a useful tool.

The market situation in the North Sea is different to the rest of the world. The technical requirements for most likely applications are really beyond the capabilities of the products that manufacturers can reasonably supply at present. The North Sea market for multiphase meters on its own is unlikely to bring sufficient return on investment for manufacturers to develop the higher performance meters required in the North Sea.

If North Sea operating companies wish to gain the very large benefits of multiphase metering, they will have to provide the financial backing to support the development of higher performance meters.

8 REFERENCES

[1] H. Toral, S. Cai, E. Akartuna, K. Stothard, A.W. Jamieson, Field Tests of the ESMER Multiphase Flowmeter, 1998, North Sea Flow Measurement Workshop, Gleneagles, Scotland.

[2] C.J.M. Wolff. Required operating envelope of multiphase flow meters for oil well production, 1993, North Sea Flow Measurement Workshop, Bergen, Norway.

[3] Handbook of Multiphase Metering, Norwegian Society of Oil and Gas Measurement

[4] W. Slijkerman, A.W. Jamieson, W.J. Priddy, O. Okland, H. Moestue, Oil companies needs in multiphase flow metering, 1995, North Sea Flow Measurement Workshop, Lillehammer, Norway.