Main Index

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Review of multiphase flowmeter projects

by

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REVIEW OF MULTIPHASE FLOWMETER PROJECTS

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ABSTRACT

Significant progress has been made in the development of multiphase flowmeters over the last 18 months, and a number of manufacturers now have prototypes in the final laboratory and field testing stage.

This paper examines the progress of these leading developments with comment on the available performance data. The flowmeters are grouped under three general descriptions: those using conventional technology such as the Texaco SMS and NEL/SGS meters, those using capacitance, microwave and cross-correlation techniques such as the Fluenta MPFM and the Kongsberg/Shell meter, and those which combine conventional technology with innovative techniques, such as the flowmeter manufactured by Framo.

From the review it is concluded that no particular flowmeter is capable of providing an accurate measurement of multiphase flows across the entire flow composition and flow velocity ranges. With this in mind the most suitable area of application for each approach is noted.

1 INTRODUCTION

The demand for multiphase metering technology is now well established and has been commented on in many articles and conferences over the last decade. However, to the authors' knowledge no multiphase flowmeters have been installed for operational purposes, either topside or subsea. A lot of experimental development and testing, both in the laboratory and in the field has been taking place, and a number of metering systems are now being promoted as direct replacements for test separators and for subsea reservoir management and control.

While much has been said in the past about the numerous independent multiphase flowmeter developments, it has unfortunately resulted in a rather incoherent strategy for the development of this technology. NEL has recently launched an industry funded Multiphase Flow Club with the specific aims (amongst others) of re-focusing that strategy and developing user-friendly standards relating to multiphase metering.

The purpose of this paper is to give an up-to-date appraisal of the technologies used for multiphase metering, which will aid in the re-focusing process. A full review of all the meters in a single paper is not possible, so the approach has been to select multiphase flowmeters from each of three "technology" categories and to comment on their respective strengths and weaknesses. It should be stressed that this is done from an independent stand point.

The advantages and limitations of the techniques used to derive multiphase measurements are discussed and their potential for further development is assessed. Comments are also made on the validity of the common approach taken by all the projects, wherein the phase flowrates are derived from several inter-dependent measurements. This latter point leads on to discussion of the expectations of potential users of multiphase flowmeters, and these expectations are contrasted with the performance of current and foreseeable developments.

2 GENERIC MULTIPHASE FLOWMETER DESCRIPTIONS

There are three basic types of multiphase flowmeter systems that can be considered as generic types:

a A system of three sensors, one sensor to measure each of the individual phase flowrates (oil, water and gas). The measurements from each sensor are unaffected by the presence of the other two phases;

b A system that measures the cross sectional area of the pipe occupied by each phase, and measures the average velocity of the individual phases so that flowrates can be computed;

c A system that mixes the flow to provide a uniform flow velocity (no slip), and provides techniques for deriving the phase fractions.

The ultimate goal is to achieve a system such as that described in (a), but this is highly unlikely within the next 10-15 years. Present developments centre mainly around the generic system (c) and as such this puts current technology into perspective. There is considerable scope for future development.

3 DESCRIPTIONS OF THE REVIEWED FLOWMETERS

Within the generic range (c) referred to in Section 2, present multiphase flowmeters can be conveniently categorised in terms of their operating principles:

Type 1 Metering systems which comprise instruments which have a proven track record in single-phase flow, or oil/water flows;

Type 2 Instruments using fluid property characteristics - capacitance, inductance, microwave absorption - in combination with cross correlation flow metering. These instruments are much smaller than Type 1 multiphase meters;

Type 3 Instruments which utilise some of the features of Type 1 and some of the features of Type 2, and are often termed 'hybrid' multiphase flowmeters.

Type 1 multiphase flowmeters include those developed by Texaco and NEL/SGS. The Texaco SMS shown in Fig 1 is designed to operate in a subsea environment. The device consists of a subsea gravity separator, a vortex shedding meter on the gas outlet to provide the gas flow rates and a differential pressure flowmeter to measure the total liquid flowrate. The water content is determined from a StarCut microwave water monitor sited in a sampling loop which abstracts liquid from the separator. By combining these various readings with those of temperature and pressure, a measure of the oil, water and gas flowrates is achieved.

The NEL/SGS multiphase flowmeter, shown in Fig 2, utilised an upstream static mixer and venturimeter for total flowrate measurement. The mixture density was measured at the venturi throat using a gamma densitometer. To measure the water cut in the liquid a small sample of the oil/water/gas flow was extracted from the main flow and passed into a compact gas/liquid separator. The separated liquid phase returned to the main flow through an in-line density transducer, thereby allowing the water cut to be derived.

Type 2 meters include those developed by Fluenta and Kongsberg in conjunction with Shell. The Fluenta MPFM 1900 has been developed from an earlier multiphase fraction meter, the MPFM 900. In its present form the water content is derived from non-intrusive capacitance/inductive sensors, and the mixture density from a gamma densitometer. The phase fractions are calculated from these measurements. The phase flowrates are derived from velocity measurements based on cross-correlation between the signals from two axially spaced capacitance sensors. The velocities of large gas voids and small bubbles are measured independently and simultaneously, and it is assumed that the liquid velocity is equal to the small bubble velocity.

The Kongsberg multiphase flowmeter also uses capacitance sensors and is effectively a very sophisticated level measurement system. Two thin parallel plates are mounted in a vertical sense within the flow passage. An array of capacitance sensors is mounted on the surface of each plate. The measured capacitance allows the location of the gas/liquid interface, and therefore gas fraction, to be determined. The average water cut of the liquid is derived from the capacitance measurements from the sensor pairs which are immersed in liquid. The meter makes use of the slug flow pattern to cross-correlate between sensor signals to give the slug velocity. A slip correlation is then used to estimate the bulk gas and liquid velocities, with subsequent calculation of the volume flow rates.

An example of the Type 3 hybrid multiphase flowmeters is the meter developed by Framo. This uses a mixer which provides temporal mixing as well as spatial mixing to produce an approximately homogeneous flow with near-equal gas and liquid velocities. The mixture then passes through a venturimeter which measures the total flowrate. The gas fraction and water content are derived from a dual energy gamma densitometer system which is mounted across the throat of the venturimeter. The phase fractions and total flowrate are combined to give the phase volume flowrates.

4 PROGRESS OF PROJECTS

Extensive testing of the Texaco SMS has been conducted in both the laboratory and in field trials by Dowty et al[1]. The initial laboratory results were promising and the optimum configuration for the meter was finalised, but foaming problems were experienced at the meter inlet during the field trials in the North Sea. The foaming reduced the effectiveness of the gas/liquid separation, and the poor quality of separation caused problems in the single-phase metering runs on the separator outlets, resulting in a reduced performance when compared to the laboratory conditions. The SMS has since been modified to counter the foaming problems and is presently under further trials at Texaco's onshore facility at Humble near Houston. Recent results are favourable according to Texaco.

The NEL/SGS multiphase flowmeter underwent extensive laboratory trials over the full range of gas and water fractions. The final prototype measured the total volume flowrates to within 15 per cent of the reference flowrates at the majority of flow conditions, Fig 3. The individual phase flowrates were measured less accurately, with uncertainties of around 25 per cent at most test conditions. Higher uncertainties were found at low phase fractions. The reasons for this are discussed in more detail in Millington[2], but in short are due to the diminished presence of that particular phase. This is a mathematical reality common to all multiphase flowmeters which use multiple inter-related measurements to derive the phase flowrates.

The NEL/SGS development project was concluded - perhaps prematurely - after emulsions in the separator were found to reduce the effectiveness of gas/liquid separation, which caused incorrect water cut measurements. The problems experienced using a compact gravity separator were felt likely to be exacerbated under field conditions.

The Fluenta MPFM 1900 is presently being evaluated at NEL for Amerada Hess prior to field trials in the North Sea. Conoco (US) and Statoil are also evaluating the meter, the former in condensate/gas flows and the latter at Gulfaks B. Published results are presently unavailable from these commercial evaluations, but early trials by Dykesteen and Midttveit[3] at CMR showed that the total volume flowrate can be measured to within 10 per cent, Fig 4. However, the measurement of the individual phase flow rates was less accurate for the reasons referred to above.

The Kongsberg MCF has been tested under laboratory conditions in oil/water/gas flows by Brown et al[4]. The meter was shown to perform well in slug flow under oil continuous flow conditions. (A further development programme is underway to extend the range of the meter to water external emulsions). The laboratory trials indicated that the flowrates can be predicted to within 10 per cent in slug flow and with a repeatability of approximately 5 per cent, Fig 5. Outside of the slug flow regime the results, as expected, were less accurate since the prime objective of this instrument is for application in slugging flows.

Torkildsen and Olsen[5] have evaluated the Framo multiphase flow meter under laboratory conditions over the full range of gas and water fractions expected under normal operation. The total mass flowrate was measured to within 10 per cent at the majority of the test conditions, but the meter was less accurate when predicting the individual phase flowrates, and gave uncertainties of typically 25 per cent. The phase flowrate uncertainties varied according to the phase fraction as described above. The laboratory trials were judged to have been sufficiently successful for the Framo meter to go for field trials in the North Sea during 1993. Results are awaited.

5 STATE-OF-THE-ART IN MULTIPHASE METERING

Multiphase flow measurement poses many challenging problems and it can be seen from the progress of some of the leading projects referred to in Section 4, that no complete solution has yet been found. All the projects referred to have contributed to the knowledge of the problems involved with multiphase flow metering and each has made some progress towards solving these problems.

Work using Type 1 multiphase flowmeters has demonstrated the limitations of established technology when confronted with non-standard fluid mixtures. Major difficulties exist in obtaining homogeneous mixtures, both spatially and in particular temporally. There is considerable doubt about the effectiveness of mixers, and in relation to the potential blockage effects that they may cause, it is difficult to argue a case for their general inclusion in all meters. Indeed some of the meters (eg Fluenta) rely on not mixing the flow for the cross correlation systems to be most effective.

The limitations of scaled down separation technology were clearly identified in the NEL/SGS project. This continuous method of sampling, separation and return to the main flow has been avoided in the meter recently developed by Paul Monroe. The batching system used in this meter may prove advantageous, although there are considerations of batch interval which need to be addressed.

The Type 2 multiphase flowmeters, which employ capacitance, inductance and microwave technology have found limitations imposed by the state of the oil emulsion, and by the flow regime. When certain required features within the flow are not present then accuracy suffers, often dramatically and the challenge here is to know when the readings are in error because of the flow conditions and not because of instrument malfunction; not an easy task if the meter is subsea. However, experience in the laboratory environment has shown the Type 2 multiphase flowmeters to generally be as accurate, if not more accurate, than the proven technology instruments.

In terms of commonality of approach, nearly all multiphase flowmeters use nucleonic techniques for either determining the gas fraction, or determining gas fraction and water content in the liquid. Considering the relatively modest performance of such instrumentation it is perhaps surprising that alternative gas measurement systems have not been proposed. It is certainly one area of the technology were improvements in performance could be achieved. In dual energy systems, which offer gas and water fraction measurement non-invasively over the full composition range, particular care must be exercised as there are several fundamental problems. Firstly, the highest attenuator is the pipe wall, particularly at low photon energies, which results in large sources being required. Secondly, mass absorption coefficients may prove difficult to establish in practice and this can have serious consequences in terms of uncertainty. Dual energy techniques rely on the difference in mass absorption coefficient of water and oil to infer water cut, but this difference is only a few per cent at photon energy levels down to approximately 60 keV, therefore any uncertainty in the mass absorption coefficient, or for that matter measured count rates, can have serious effects on water content measurement.

In summary, all the techniques so far used for multiphase metering have their own advantages and disadvantages, but from available evidence the present state-of-the-art is measurement of phase flowrates to approximately 10 per cent over reasonably wide operating envelopes. This level of performance will not be achieved over the entire flow composition range until direct, and independent, measurements of phase flow rates can be made.

6 USER EXPECTATIONS AND THE FUTURE

Expectations of the performance of multiphase flowmeters vary considerably. Those perhaps less familiar with the subject often believe uncertainties normally associated with single-phase flowmeters can be achieved, while those with considerably more experience in this technology usually take a more pragmatic view and aim for uncertainties similar to those achieved using test separators. The latter view is perhaps the most sensible approach to adopt at present because it avoids stating hard percentage figures which at best are often mis-understood, and at worst totally mis-leading.

Irrespective of the technology used to determine the phase flowrates, the uncertainties are always a function of the phase fraction. Low phase fractions have a higher uncertainty, and vice-versa Simply stating an objective of say 5 per cent uncertainty is not good enough, the figure must be related to a phase fraction value, or envelope, over which it applies.

This leads on to the next difficulty in terms of user requirements, that is the operating range, or in single-phase metering terms, the turndown ratio. With a turbine meter for example, the user might expect a turndown of 10:1 on flowrate, but many potential users of multiphase flowmeters are expecting a system capable of metering flows with 0-100 per cent gas, 0-100 per cent oil and 0-100 per cent water as well as a total flowrate turndown of 10:1, or better. The perception of the capabilities of multiphase meters often does not match reality.

It is the flow composition measurements that are most crucial, Millington[2], and in view of the comments made above there is now a gradual change in attitude within the industry to the performance of multiphase flowmeters. It has been realised that the future will probably see a range of flowmeters which cover specific application areas, eg wells with high water will have different flowmeters from gas lifted wells. The belief that one manufacturer could dominate the market in the same way as Microsoft have done in the computer operating system market, has diminished over the last couple of years.

In response to this realisation, and because potential users will want to know which one of the current multiphase flowmeters best suits their requirements, NEL have launched a JIP called Multiflow to evaluate all the leading meters over a wide range of operating conditions. Using the same test facility throughout, this work will be the first definitive intercomparison of multiphase flowmeters from which firm conclusions can be drawn. All previous test work has been performed on different facilities, and with different oils and water. Effective comparison of the results is impossible.

Beyond this project, it appears unlikely that significant improvements in metering uncertainty can be made within the (b) and (c) generic classes of multiphase flowmeters, see Section 2. It is the authors' view that in the medium term the use of tomographic techniques to quantify flow composition, the development of an alternative to gamma densitometry for gas fraction measurement, and the application of neural networks, will bring about the most significant advances. Beyond the medium term the goal must be to develop sensors capable of directly metering the individual phases. The future is challenging, but holds considerable promise.

ACKNOWLEDGEMENTS

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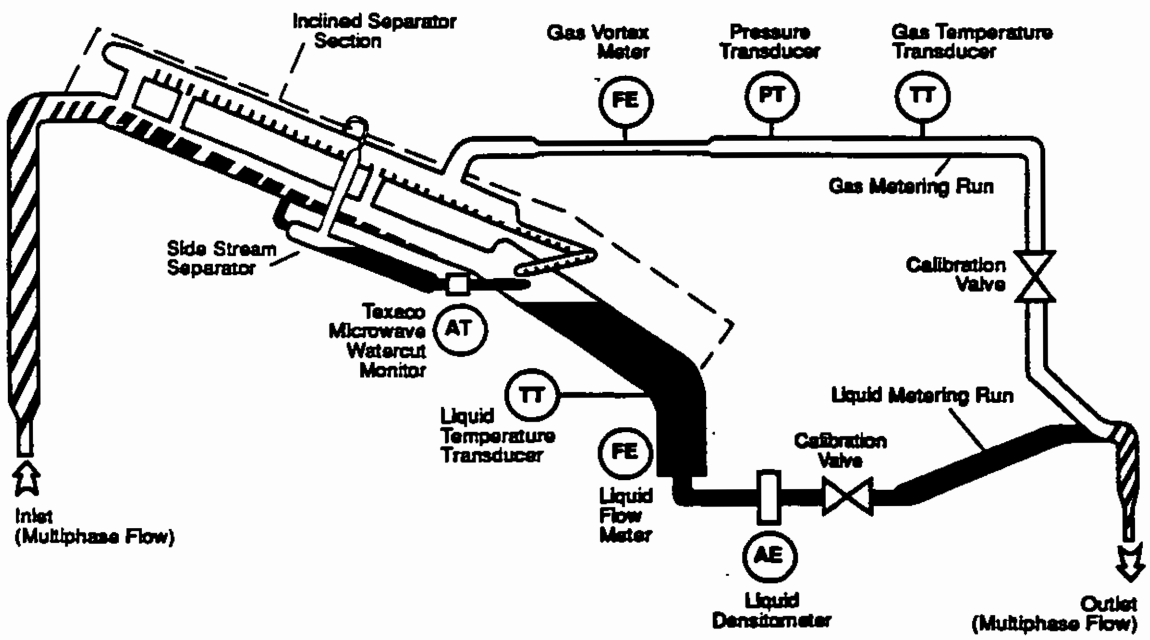

Fig 1 The Texaco SMS multiphase metering system

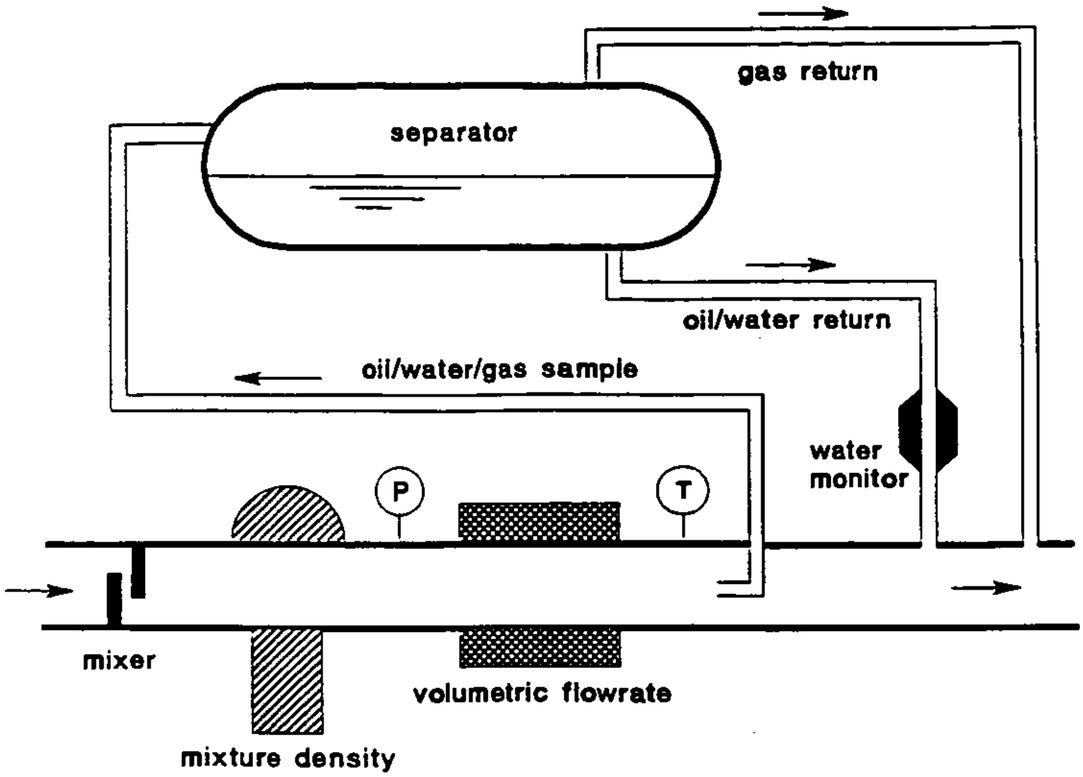

Fig 2 The NEL/SGS multiphase flowmeter

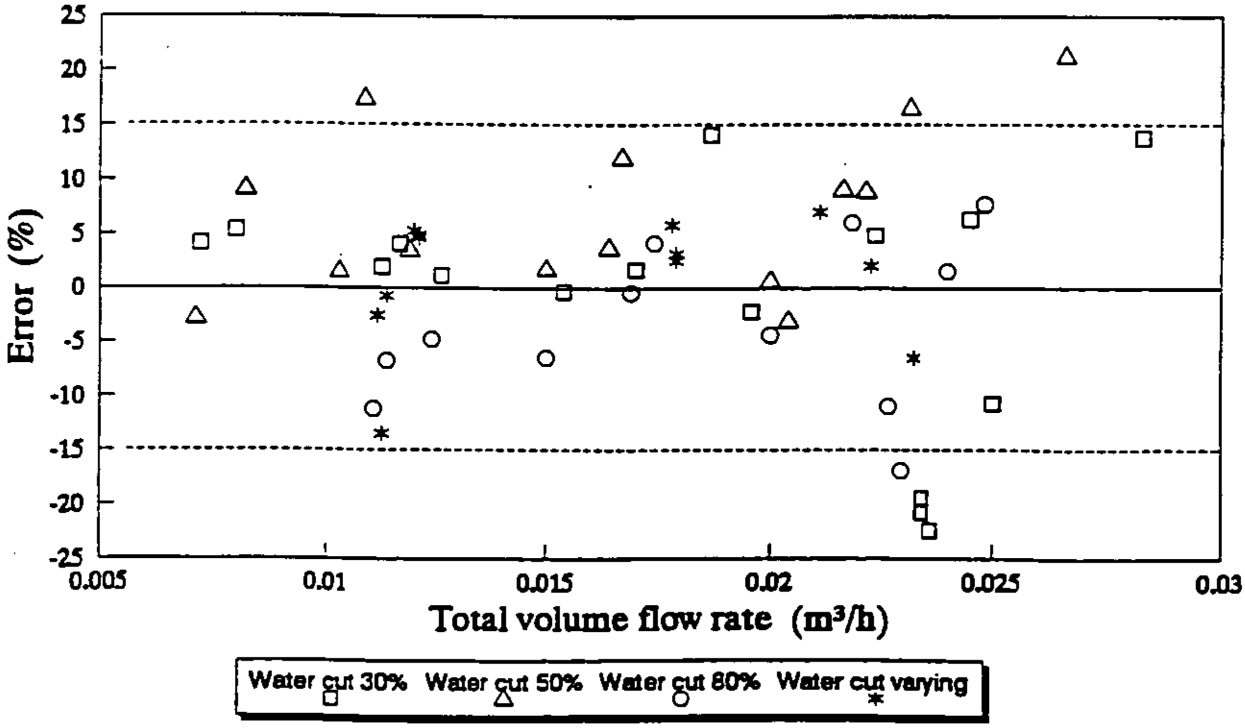

Fig 3 The performance of the NEL/SGS multiphase flowmeter

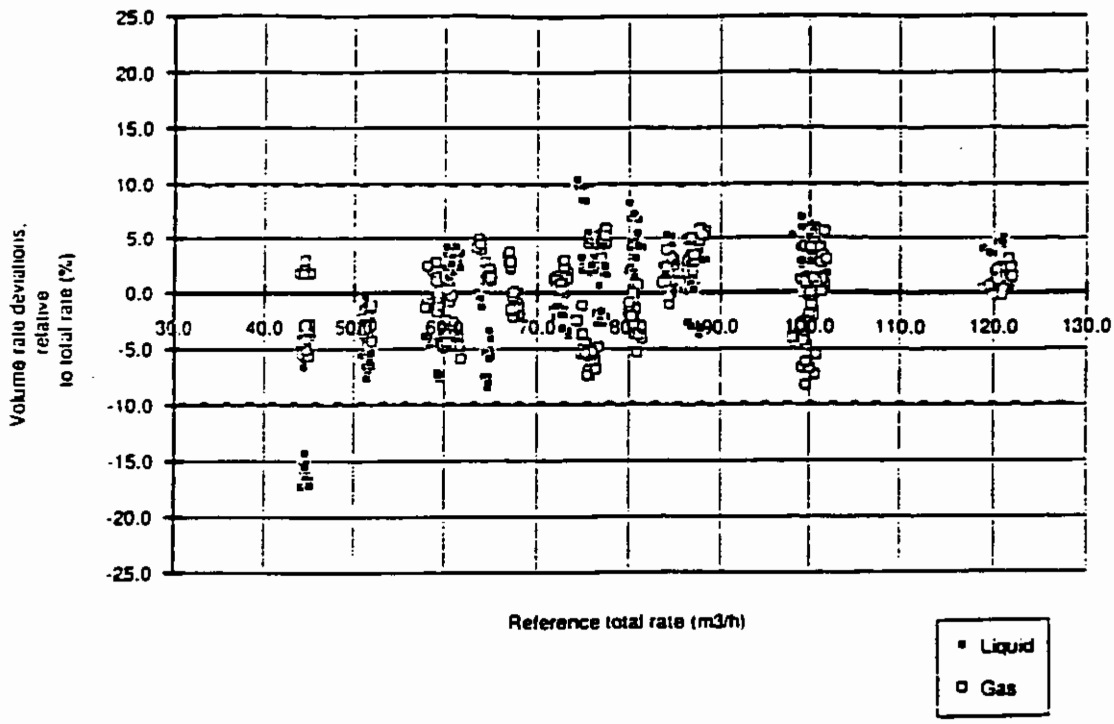

Fig 4 The performance of the Fluenta MPFM 1900 multiphase flowmeter (ref 3)

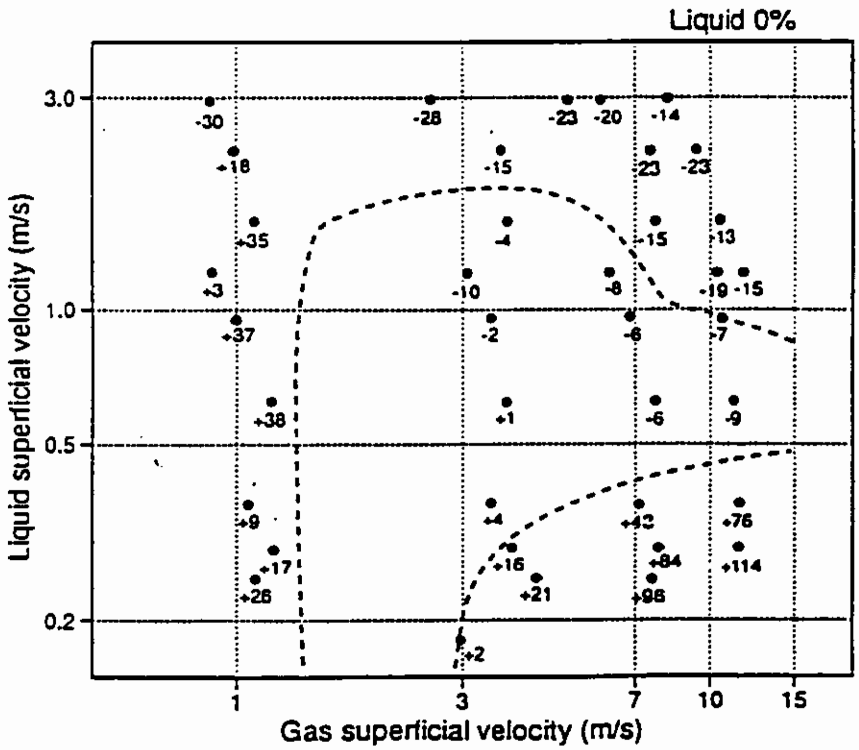

Fig 5 The performance of a 75mm diameter Kongsberg MCF (ref 4)