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FLUENTA MULTIPHASE FLOW METER, TESTED AND MARINISED

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FLUENTA MULTIPHASE FLOW METER, TESTED AND MARINISED

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SUMMARY

This paper describes the technology and principle of operation of Fluenta's multiphase flow meters, for both topside and subsea applications. It also deals with the basis of the design of the subsea multiphase flow meter, and Fluenta's collaboration with Amerada Hess and Kværner FSSL (KFL). The paper further describes the qualification programme and test results obtained at the National Engineering Laboratory (NEL) for this world first installation of a subsea multiphase flow meter, the SMFM 1000, and the benefits and savings this meter will provide to the South Scott field where it was installed in May this year.

1. INTRODUCTION

The ultimate goal for multiphase flow metering has always been to use the technology in a subsea environment. The technology do represents substantial operational and cost savings for topside applications, but being able to implement this technology for subsea applications, means that a higher proportion of proven hydrocarbon reserves found in economically marginal fields can be developed and turned into profitable developments. This is due to the huge savings obtained by eliminating test flow lines and test separators.
In the next couple of years the oil companies have planned to develop a substantial part of their new fields using this technology.

1.1 The background for Amerada Hess Ltd's involvement

Amerada Hess Limited (AHL) is committed to the development of new technology to support and enhance its business activities of finding, developing and producing offshore hydrocarbons. To this end AHL launched a Business Driven New Technology Initiative. This seeks to identify key technology requirements, to initiate R&D projects to fulfil them, and to ensure that the results are commercially exploited.

Amongst the selected areas are health & safety, the environment, drilling costs, mini-field developments, reservoir characterisation/performance and geological basin modelling.

One of the main requirements in the mini-fields area is the development of technology to enable longer and more cost effective satellite tie-backs for small accumulations. This primarily focuses on subsea technology, including separation, and multiphase transportation of produced fluids.

Within this technology thrust, the possibly most significant gap in the armoury of available technology is a reliable non-intrusive subsea multiphase flowmeter.

The applications are endless for a device shown to work satisfactorily in a subsea environment. No more test separators, no more test flow lines. A subsea manifold could contain all the valving required along with a multiphase flow meter, to remotely test each well in turn and still produce via a single flow line back to a remote platform. The ultimate solution would be a gathering platform with subsea satellites scattered over a large area collecting from small fields and providing central processing.

There is no doubt that when the technology is proven the whole face of subsea oil production from marginal fields will change.

1.2 A three stage development project

In a unique joint venture Amerada Hess Limited and Amerada Hess Norge joined forces (Norway supplying the funds and U.K. supplying project co-ordination and monitoring) in backing one of the three phase race contenders.

The project was carried out in three stages.

Stage 1 was completed in 1992. This involved the purchase and testing of the basic fraction meter version of the device. The meter was installed and tested in the new multiphase laboratory at the National Engineering Laboratory in East Kilbride, near Glasgow.

The aims of Stage 1 were to prove that the technology works and determine by experimentation the limitations of use of the instrument. This was successfully done.

In Stage 2 of the project Amerada Hess purchased the three phase flowmeter meter version of the Fluenta device - the MPFM 1900.

The MPFM 1900 was extensively tested at N.E.L. and has now been installed on the AH001 Floating Production Facility. The MPFM 1900 is installed upstream of the test separator between two chokes which will allow direct comparison between the 2 technologies. The signals were integrated into the AH001 Metering Database system, a Eurotherm Maxi-Vis system which provides comparison with the conventional metering system currently installed on the test separator.

The Maxi-Vis Metering Database on the AH001 was reprogrammed to provide the data reporting required to prove the device under real conditions rather than the controlled conditions at N.E.L. This reporting includes duplicated well test reports, one report based on the original test separator metering and a second report using the three phase meter data.

By installing the meter between the two chokes on the inlet pipework to the test separator we were able to simulate either test separator conditions at the three phase meter or increase the pressure closer to subsea pressures.

The AH001 Floating Production Facility (FPF) produces oil and gas from three subsea fields; Ivanhoe, Robroy and Hamish. The well flowrates, GORs, GLRs and oil viscosities are extremely variable and the results so far have reflected this! The meter has been installed to provide long-term evaluation.

The final stage of the project is completed. This was split into two parts. The first was a study of the requirements for a subsea meter. Do we want a meter that can be fitted by divers or ROV? Do we want a complete skid designed including self-calibration checking facilities?. Do we want a single meter on a subsea manifold or one meter per well? What will it cost? After a great deal of thought a report was produced that provided the final specifications for a subsea version of the Fluenta meter, which included for water-continuous measurement up to 100% water in oil.

Part 2 of the project was to build a meter for installation and testing on the South Scott Project.

KFL was selected to work with us on this phase of the project, and they also helped with the funding. The Fluenta electronics were integrated with KFL's fourth generation subsea electronics .

2.0 FLUENTA'S MULTIPHASE FLOW METERS (MPFM)

2.1 Description of the MPFM 1900VI/900VI

Both the MPFM 1900VI and MPFM 900VI are flow meters designed for accurate flow rate metering of the oil, gas and water phases of a multiphase flow, without separation of the well stream. The non-intrusive, real-time instruments require no by-pass line and no mixing device. Both instruments divide the measurements into two; measurements of fractions, and measurements of flow rates.

The fraction part is determined in the same way for both meters: three independent equations are needed and these are obtained by measuring the dielectric constant (permittivity) of the mixture (oil/gas/water) with the capacitance sensor, measuring the same mixture in a gamma radiation path, in which the measured absorption of gamma particles is a function of the density of the mixture measured by the gamma densitometer, and using the third and last equation that the sum of the three fractions will always be equal one.

For water-continuous mixtures an inductive sensor is used instead of the capacitance sensor. The principle is basically the same, except that now conductivity rather than permittivity is measured. Two toroids induce a constant current through the multiphase mixture while the differential voltage is measured across two electrode plates placed between the toroids. As the current is constant, the voltage drop is a measure of the electrical conductivity of the mixture, which in turn is affected by the composition of the mixture (oil/gas/water). The conductivity measured by the inductive sensor is thus a measure of the mixture (oil/gas/water) similar to the permittivity measured by the capacitance sensor used in oil-continuous mixtures (oil/gas/water). The expression of this module is the capital letter "I".
An illustration of the measurement principle is shown below in figure 1.

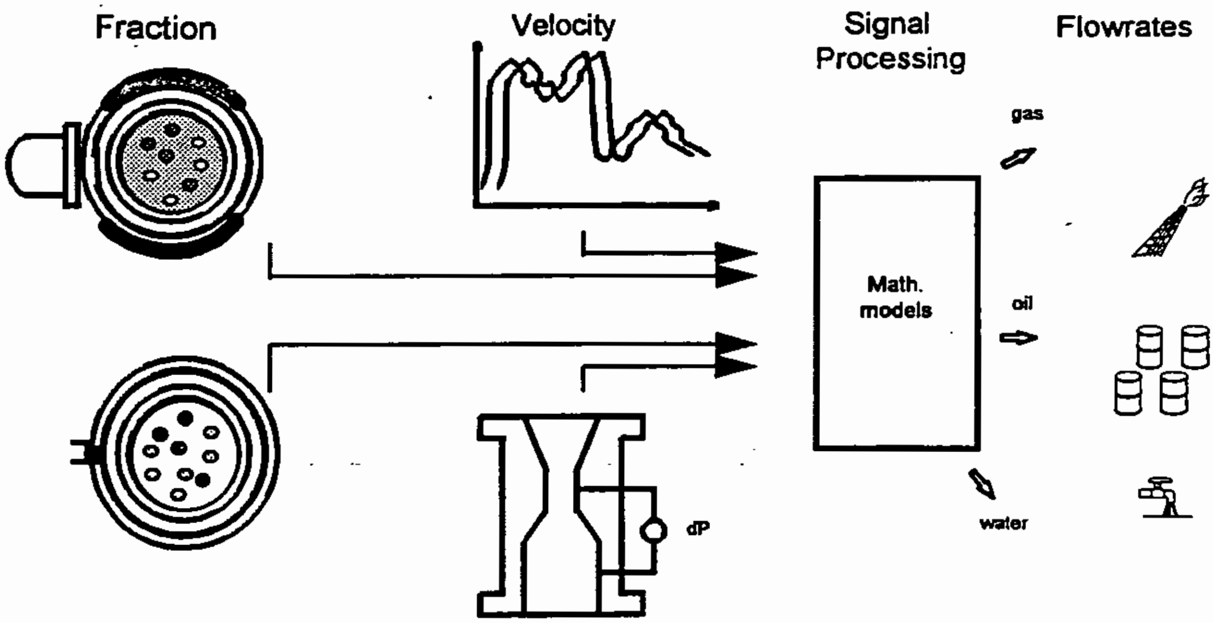


Figure 1 Measurement principle

2.1.1 MPFM 900 series

Flowrates in this meter are measured by a venturimeter "V", and measurements are combined with the fractions. For oil-continuous mixtures (oil/gas/water). The meter is named MPFM 900V. If the meter is to be used for applications in which water-continuous mixtures are expected, it will be delivered with the inductive unit as well, then named the MPFM 900VI.

2.1.2 MPFM 1900 series

This meter uses cross-correlation techniques to determine the velocity of large and small gas bubbles. Simplified, the two velocities indicate the gas and liquid velocity. The sensor contains a number of electrodes with different sizes and patterns, and the two velocities are determined by cross-correlating signals obtained from pairs of electrodes.

The flow velocity can also be determined by the venturimeter. This gives redundancy in the multiphase flow meter. The meter is named MPFM 1900V. If, as for the MPFM 900 series the meter is to be used in water-continuous mixtures the inductive module will be included, and the meter is designated the MPFM 1900VI.

A more detailed description of the operating principles can be found in reference /1/ and /2/. The Fluenta MPFM 1900VI is illustrated in the figure below.

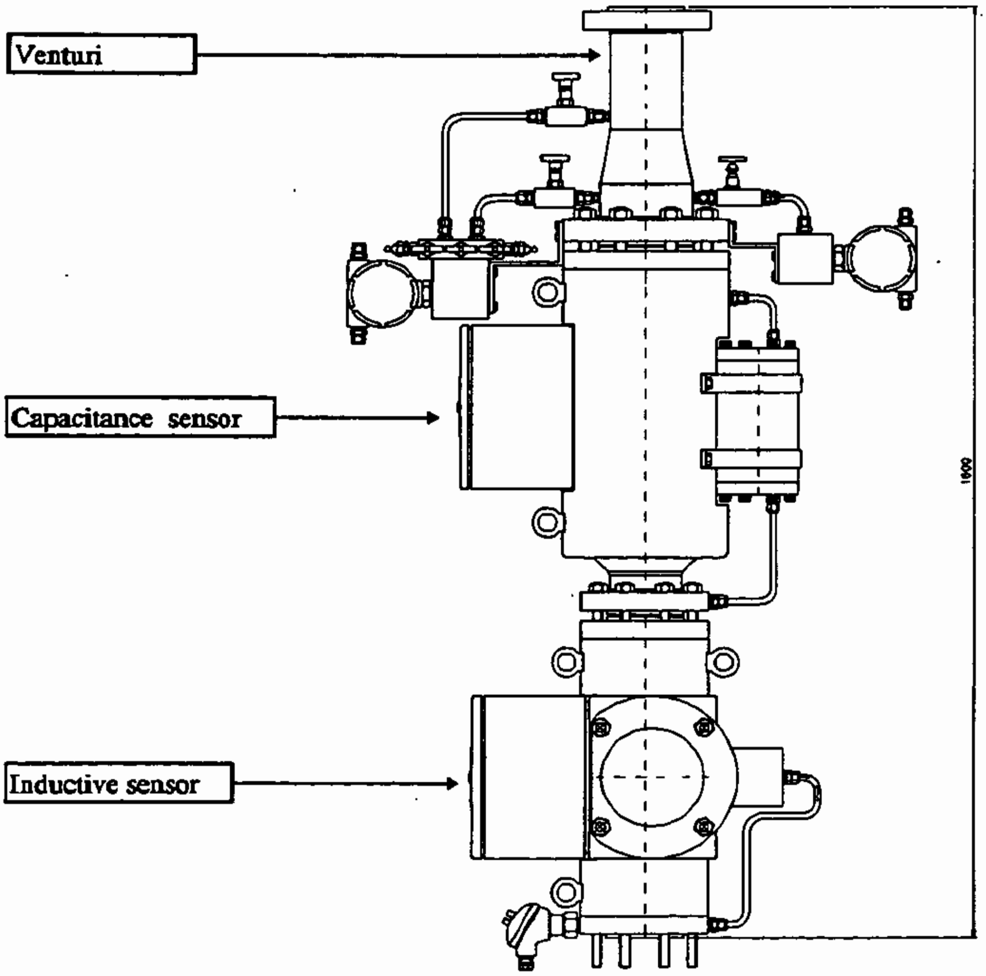


Figure 2 Fluenta MPFM 1900VI

Fluenta has designed a range of meters, underlining our ability to supply our clients with the right meter for specific applications, with respect to price, accuracy, operating range and reliability. Different line sizes are available as well as high-pressure units (15,000 psi). The instruments are designed for use in remote areas where solar panels and batteries may be the only power source.

2.2 Testing and qualification

As the nature of multiphase flow is so complex, it is impossible to generate fully representative laboratory conditions for testing of multiphase meters. For this reason it is essential to develop meters on the basis of experience of a wide range of test conditions and field trials.

This has been the philosophy behind Fluenta's development and so far we have made 15 field installations at many locations in Norway, France, Egypt, UK, and USA. We feel that multiphase meters still have great potential for achieving better accuracy and reliability. Thus we are constantly working on improvements together with companies such as Amerada Hess/Conoco/Saga Petroleum and KFL.

Below we have listed some of the most important tests/qualifications carried out.

Year	Type of test	Instrument	Site - Company
1990	Field test	MPFM 900	Wytch Farm (BP)
1992	Lab test	MPFM 900	NEL Glasgow (Amerada Hess)
1992	Field test	MPFM 1900	Gullfaks B (Statoil/Saga)
1993	Field test	MPFM 900VI	Lafayette (Conoco)
1993	Field test	MPFM 1900VI	Lafayette (Conoco)
1993	Field test	MPFM 1900	Pecorade (Elf)
1993	Lab test	MPFM 1900	NEL Glasgow (Amerada Hess)
1994	Field test	MPFM 900VI	Humble (Texaco)
1995	Lab test	MPFM 1900VI	Hydro Porsgrunn (Statoil/Saga/Hydro)

2.3 Measurement envelope

Very early in the development phase of the MPFM 1900 system, it was found extremely difficult, not to say impossible, to use a mixer to generate a homogeneous mixture over more than a very narrow band of flow conditions. The idea of including some kind of flow conditioner as part of the multiphase meter was dropped, and it was decided to develop a meter capable of a very wide range of operating conditions, requiring no flow conditioning.

In order to limit the range of different flow regimes through the meter, the installation of the meter has been restricted to be vertical with upwards flow, at a distance of 5 - 20 diameters downstream of a blinded T. This installation is shown in Figure 3.

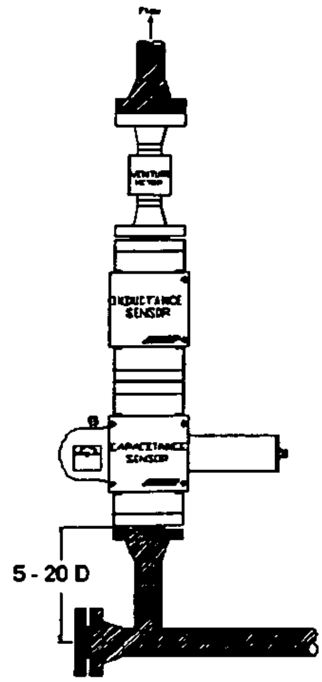


Figure 3 Recommended installation of Fluenta multiphase meters

It is advantageous for a multiphase meter to be able to cover as wide an operating range as possible, for several reasons:

- At the project stage when the design of a multiphase meter must be fixed, there is normally some uncertainty in the process data, and the flow conditions cannot always be confirmed.

- Estimates of flow regimes are very uncertain, particularly for a location where fully developed regimes are not likely to occur.

- The meter may have to operate on a number of wells with very different flow conditions.

- As large a turndown ratio as possible is preferred.

The flow regimes which can occur in vertical upwards flow are illustrated in Figure 4. The meter is capable of operation in all the flow conditions; single phase, bubbly flow, churn flow, slug flow and annular flow. The multiphase meter is relatively unaffected by slug flow, in comparison with process equipment like test separators. Due to the extream high time response of the meter (less than one second) long slugs will not create a problem, since these will be treated as rapid and steady changes in the composition of the flow.

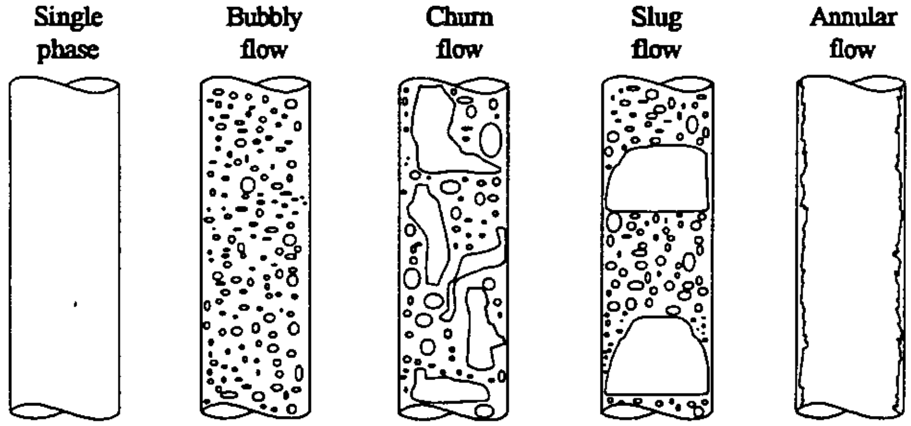


Figure 4 Flow regimes in vertical upward flow

The MPFM 1900 VI has a measurement range of 0 - 100% watercut and 0 - 100% gas fractions.

The multiphase meter has a turndown ratio of at least 1 to 10. For low gas fractions, the minimum multiphase velocity is 1.5 m/sec. For high gas fractions the minimum velocity is 2.5 m/sec. Upper velocity is less critical. For design purposes 1.5 m/sec and. 2.5 m/sec should be used, depending on gas content. As upper limit is less critical, velocities above 15 m/sec through the meter are acceptable. The velocity range is indicated in Figure 5.

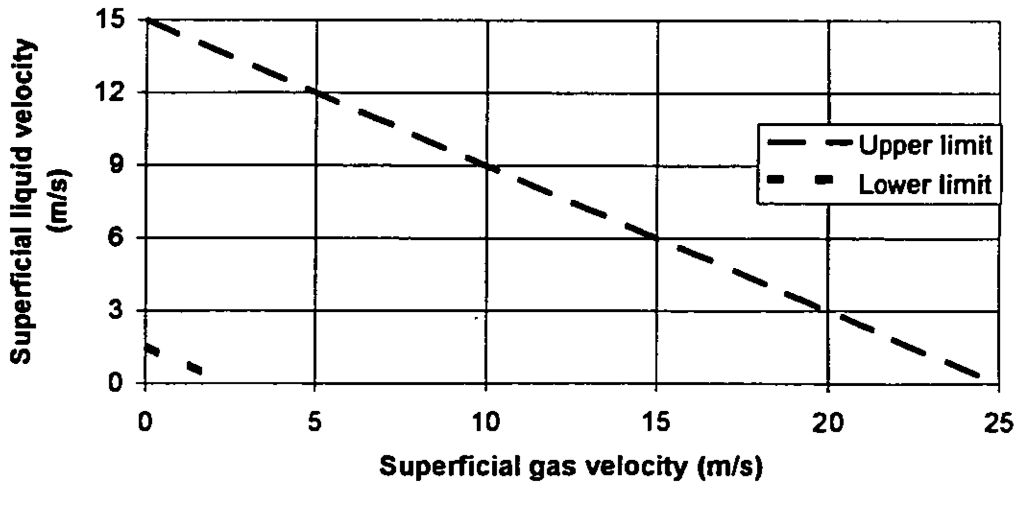


Figure 5 Velocity range of the MPFM 1900VI

2.4 Measurement uncertainties of the MPFM 1900VI

Different flow regimes and changes in the composition of oil, water and gas make it impossible to give one fixed value for the measurement uncertainty. For this reason we have given realistic values of the performance for different ranges of gas fractions. Values are given for liquid flow rate, gas flow rate, watercut and gas fraction. At the outer limits of the operating range, uncertainties might be slightly greater.

On the basis of the results of ongoing qualification tests, new performance specifications for the meter have been defined. Due to requests from potential users the flow rate uncertainties are specified as values relative to actual volumetric flow rates. Uncertainties in fractions are expressed as absolute deviations.

Uncertainties in volumetric flow rates are given as relative uncertainty to actual volumetric flow rates. (not to *total* flow rate)

Fraction measurements are given as absolute deviations from actual measurements.

Total flow rate: ± 5 %

Gas fractions:	0 - 30 %	30 - 60 %	60 - 80 %	80 - 90%	90 - 96%	96- 100%
Liquid flow rate	± 5 %	± 7 %	±10 %	±15 %	±20 %	-
Gas flow rate	-	± 10 %	± 15 %	± 10 %	± 10 %	± 10 %
Water cut (Oil cont. liquid)	± 2 %	± 3 %	± 5 %	± 7 %	± 12 %	-
Watercut (Water cont. liq)	± 5 %	± 7 %	± 10 %	± 15 %	-	-
Gas/liquid fraction	± 2 %	± 2%	± 2%	± 2%	± 2%	± 2%

3.0 SUBSEA MULTIPHASE FLOW METER

3.1 Subsea design by KFL/Fluenta

The project to develop a subsea multiphase flowmeter, SMFM 1000 started in 1994 as a cooperative project between Fluenta and KFL, with Amerada Hess and KFL funding the project. Ref /3/.

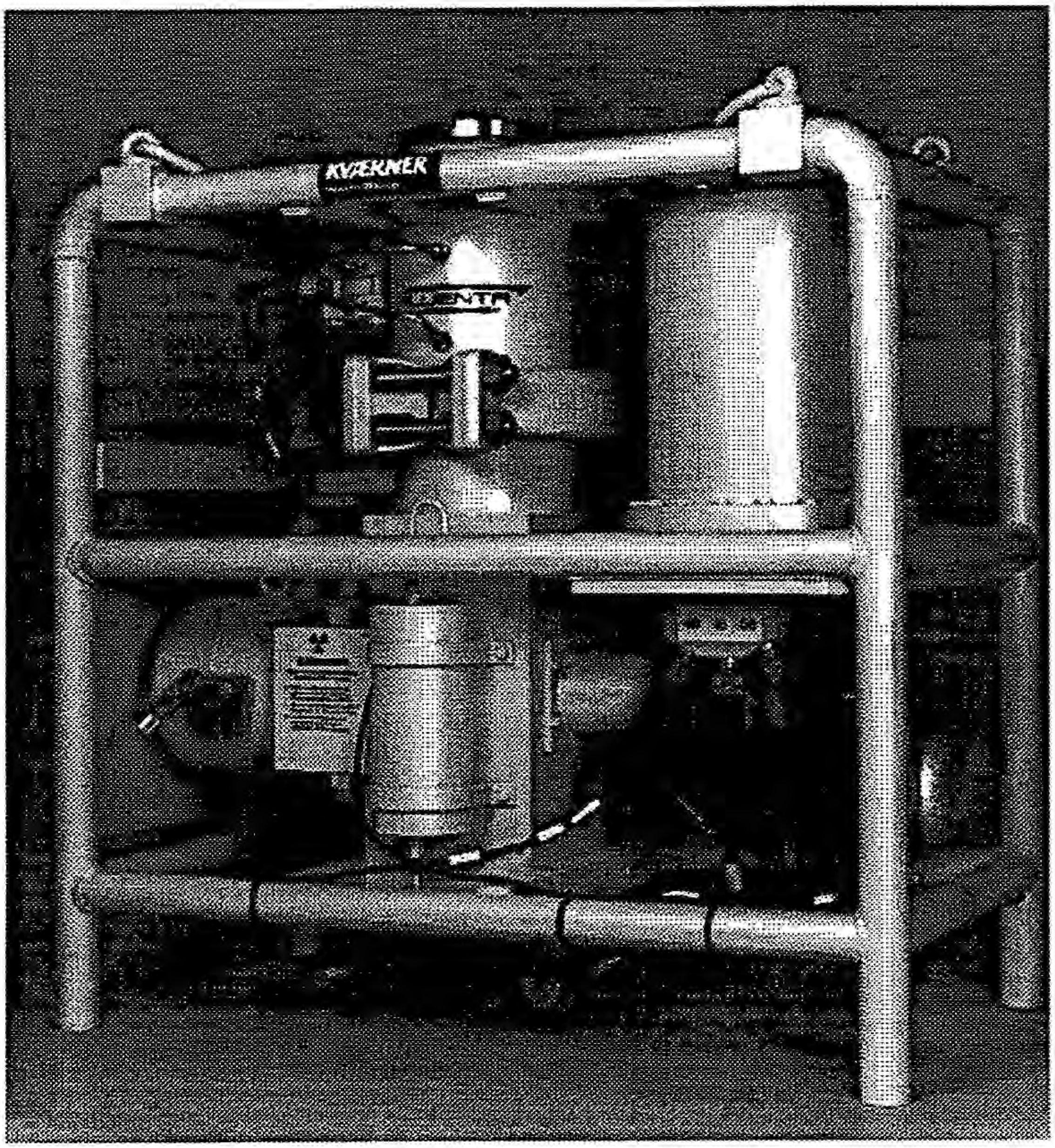


Figure 6 Fluenta SMFM 1000 delivered for South Scott

3.1.1 Design criteria

The design of the SMFM 1000 has been based as far as possible on the existing MPFM 1900VI and integrating it with the Kværner FSSL ASE 4000 subsea control system, see figure 7.

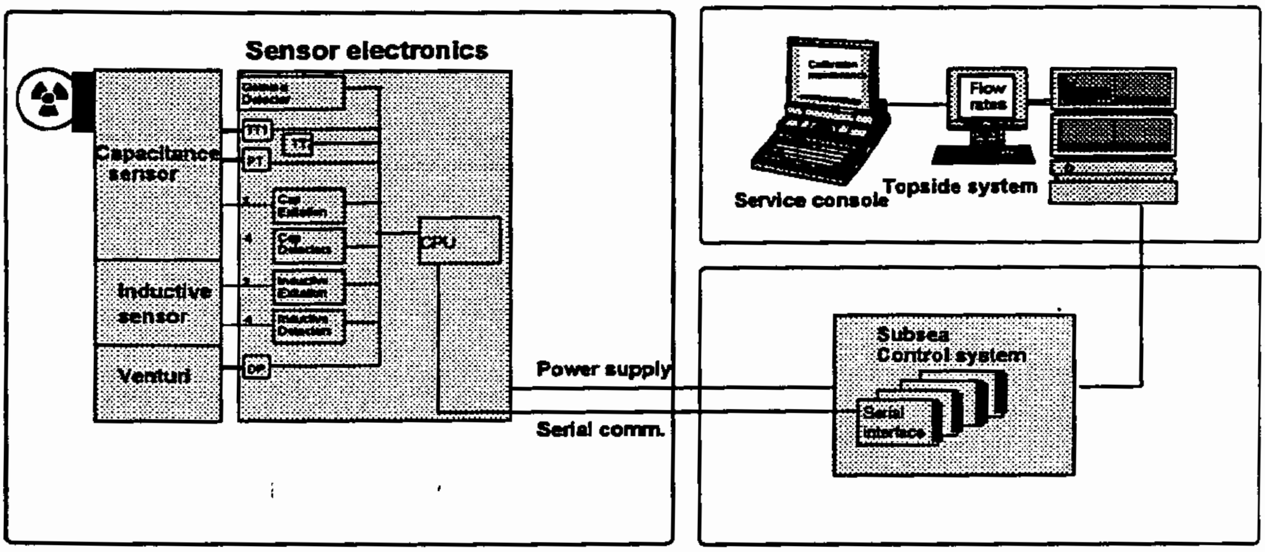


Figure 7 Schematic block diagram of the SMFM 1000

The meter system has been designed in accordance with the following specifications:

Pressure	Up to 6000 psi shut-in well pressure
Temperature	Up to 150°C fluid temperature
Oil Fraction	0 to 100%
Gas Fraction	0 to 100%
Water Fraction	0 to 100%
Sour service	Suitable for fluids with H_2S content up to 600ppm
Carbon dioxide	Suitable for fluids with CO_2 content up to 12 mole%
Min. flow velocity:	1.5 m/sec.
Design life:	25 years in subsea environment

<u>Environmental</u>

Water Depth	670 metres maximum seawater. (All components are easily upgradeable for 2000 m water depth)
Ambient Temp.	-5 to +30°C

<u>MTBF</u>

The system has been designed to have an overall MTBF as high as practically possible, with a design aim of 15 years.

Installation/Replacement

The standard version requires diver-intervention. Alternative designs for ROV maintenance and retrieval of electronics unit or guidewire line installation and retrieval of the complete assembly are available

Materials

Process fluid-wetted parts are made of super duplex stainless steel. Seawater-wetted parts are made of AISI 316 stainless steel, or carbon steel, protected by a paint system designed for long-term subsea use.

Serial Link

Communications between the Subsea Production Control System and the meter take place via a serial link through a cable that also supplies the power. The communication protocol between the meter and the Subsea Production Control System is Modbus.

Power Supply

The multiphase meter's power requirements are 24 V DC, 1.0 A.

3.1.2 Subsea Production Control system

The meter is integrated with KFL's Subsea Production Control System (KFL ASE 4000) which also controls the local manifold, and valves, and acquires data from other sensors. Data from the SMFM 1000 are integrated with the Subsea Production Control System and are available from the platform Data Control System.

The meter could easily be interfaced with similar control systems.

3.2 Qualification of the SMFM 1000 at the National Engineering Laboratory (NEL)

3.2.1 Description of NEL test facility

The Multiphase National Standard Facility at NEL is based on a three-phase separator. This vessel contains the working inventory of oil and water in separate compartments. Each liquid phase is drawn from its separator compartment by a variable speed pump and passed, via the primary reference flowmeter skids, to the mixing section. The gas phase is passed from the supply to the mixing section via a reference meter skid. At the mixing section the water and oil are commingled and the gas phase is injected a short distance downstream. The multiphase mixture then enters the test section, which can be up to 60m in horizontal length or 10m in height. A diagram of the facility is shown in Figure 8. For this evaluation the SMFM 1000 was connected to the facility test section 50m downstream of the mixing section. After the test section the mixture is returned to the separator, where the gas phase is exhausted to the atmosphere and the water and oil are separated by gravity.

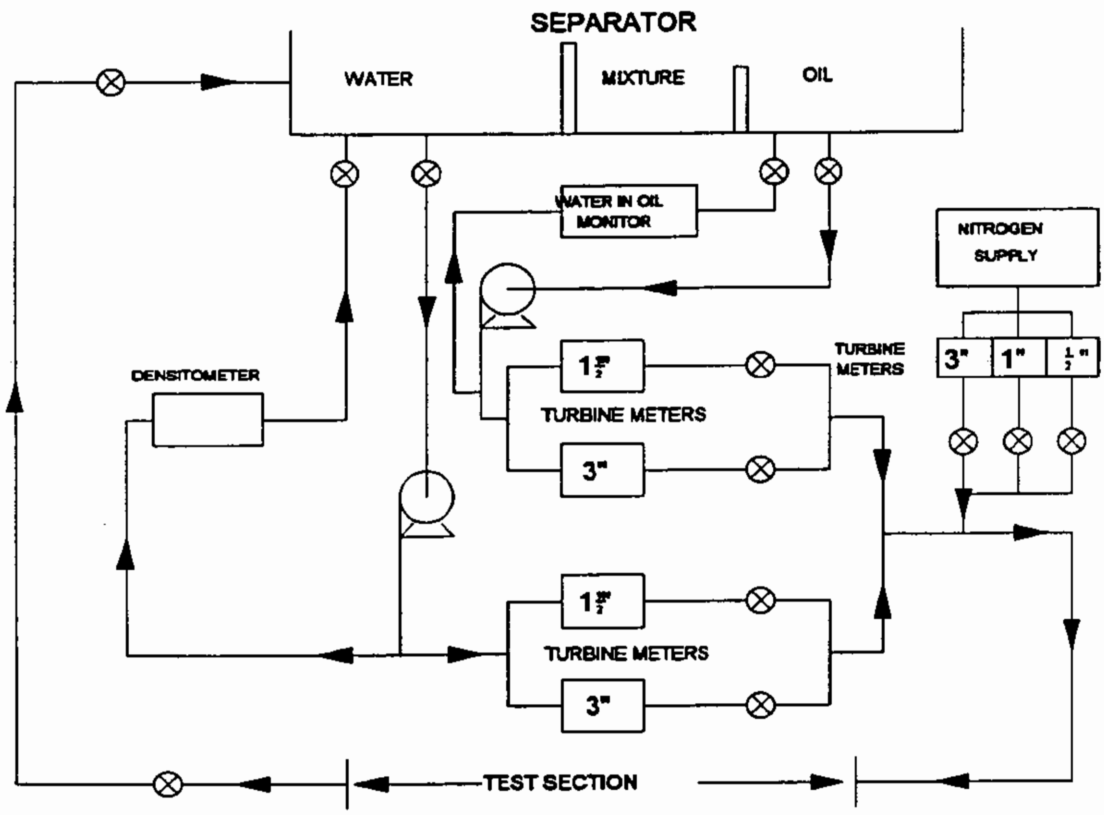


Figure 8 Diagram of NEL Multiphase National Standard Facility

Some carry-over from the separator is inevitable, and both the oil and water feeds from the separator were fast-loop sampled to measure the composition of each process stream. Conditioning circuits allow operation of the facility at temperatures between 10°C and 50°C, to within 1°C, and the operating pressure may be up to 10 bar gauge. Temperature and pressure were also measured at several points in the test section, at the oil/water monitors and at the reference meters and mixing sections.

A programmable logic controller (PLC) controls operation and data acquisition from all the field instruments. During the evaluation all relevant data were written to a test log file which was time- and date- stamped for cross-reference to the SMFM 1000 log file. All measurements are automatically corrected for temperature and pressure, the reference flow rates are also compensated for the carry-over in the process streams. All the instruments are regularly calibrated to local secondary standards, and density curves for the liquid phases are measured before each evaluation commences.

The oil used during this evaluation was a mixture of stabilised Forties crude (flashpoint 60°C) and Exxsol D80 in a 70/30 ratio. The viscosity of the oil was 12.6 cSt at 18°C, and its density was 860.7 kg/m^3 at 20°C. Brine was simulated by the additional of magnesium sulphate ($MgSO_4$) salt to de-ionised water at concentrations of 25g/l and 50g/l. The conductivities of these solutions at 25°C were 0.64 S/m and 1.05 S/m respectively, while the densities at 20°C was 1010.45 and 1018.4 kg/m^3 respectively. The gas phase was nitrogen.

3.2.2 Test matrix and procedure

The basic test matrix is shown in Table 1 and was run for water cuts of 10, 30 and 70%.

Table 1: Evaluation matrix

Qliq (l/s)	GVF 0%	20%	50%	80%
11.1	x	x	x	x
16.67	x	x	x	x
25	x	x	x	
34.72	x	x	x	

For each evaluation the initial condition was set for approximately 20 min in order to enable the SMFM 1000 to achieve thermal equilibrium with the test fluids. After this period the test conditions were set for five minutes to allow the conditions to stabilise, before data recording started. The reference flow rate measurements were recorded at five-second intervals for one minute, and the SMFM 1000 readings were continuously averaged and written to file every minute. The PC system clocks were synchronised prior to each evaluation in order to permit cross-reference and comparison of the readings.

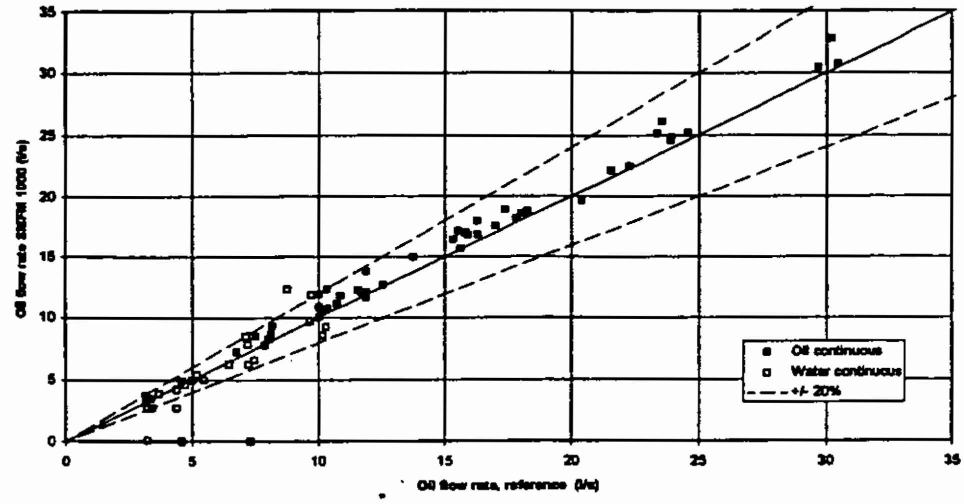
An additional repeatability test was performed continuously over an eight-hour period. The condition was set to 16 l/s and 50% Gas Void Fraction (GVF) and the water cut was cycled at 30 minute intervals between 30 and 70%. The SMFM 1000 data were recorded continuously during the test, the reference data were stored at one-minute intervals over a twenty-minute period at each stabilised condition.

3.2.3 Test results

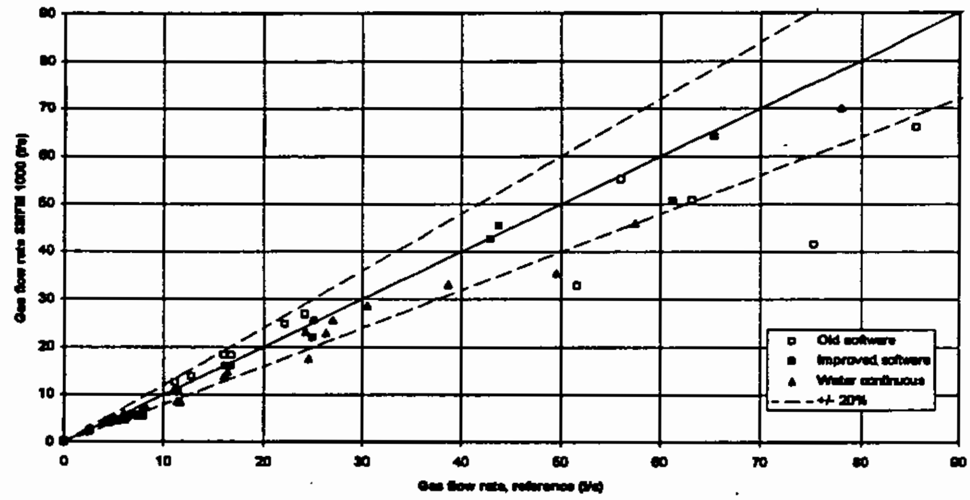
The SMFM 1000 tested at NEL measured the individual flow rates by means of a multi-velocity system based on cross-correlation of capacitance signals, with a venturi meter providing additional velocity measurements. Fractions of oil, gas and water were determined by combining capacitance and gamma densitometer signals in the oil-continuous phase, and by combining inductance and gamma densitometer signals in the water-continuous phase. This eliminates the need for any mixing device, since the meter is capable of measuring both gas and liquid velocities (slip conditions).

Figure 9, shows separate graphs for oil flowrates, gas flowrates and water flowrates for all test points run during the extensive test series. Oil- and water-continuous test points have been plotted together, but with different legends. During the test, new improved software was installed. Test points from these tests have been given their own legend.
All test points have been plotted against the reference values from the test-rig. A deviation band of ± 20% has been dotted into all graphs.

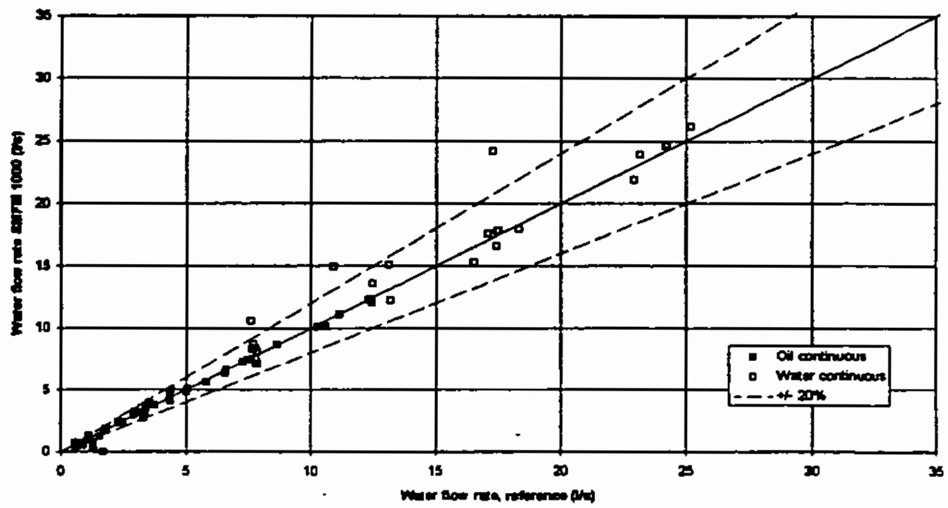
In figure 10, the test results have been plotted against the claimed specifications given by Fluenta for oil- and water-continuous flow. In the watercut versus gas fraction graph, both claimed specifications for oil- and water-continuous flow have been plotted, since these are not the same. The dotted lines represent specifications for water continuous flow, while the continuous lines represent oil-continuous flow. Virtually all test points were inside the limits specified, although the gas flowrate was generally underestimated. Most of these underestimated test points occurred when the GVF was lower then 20% (then only the venturi was used for velocity measurements), when flowrates were low and at the lower limits of the dP transmitter's operating range in the venturi.
At high GVF there was a great improvement with the new software. These test points have been given their own legend.



Oil flow rates

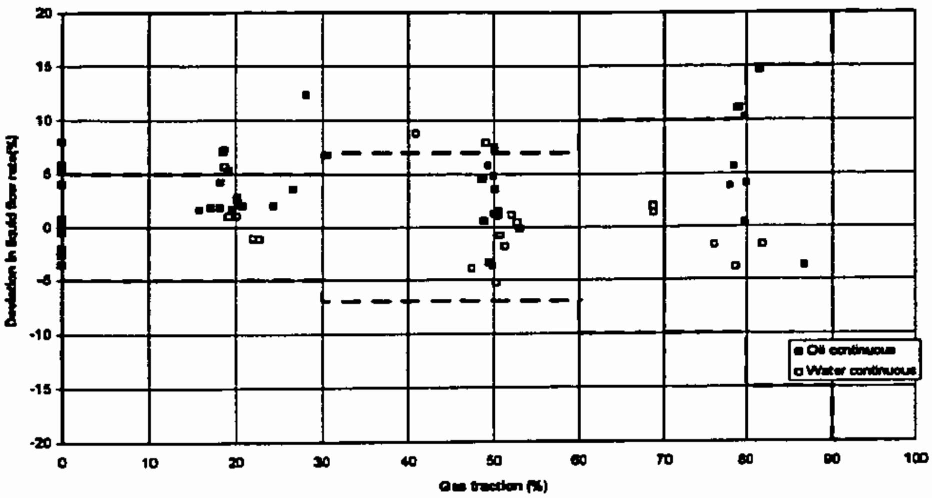


Gas flow rates

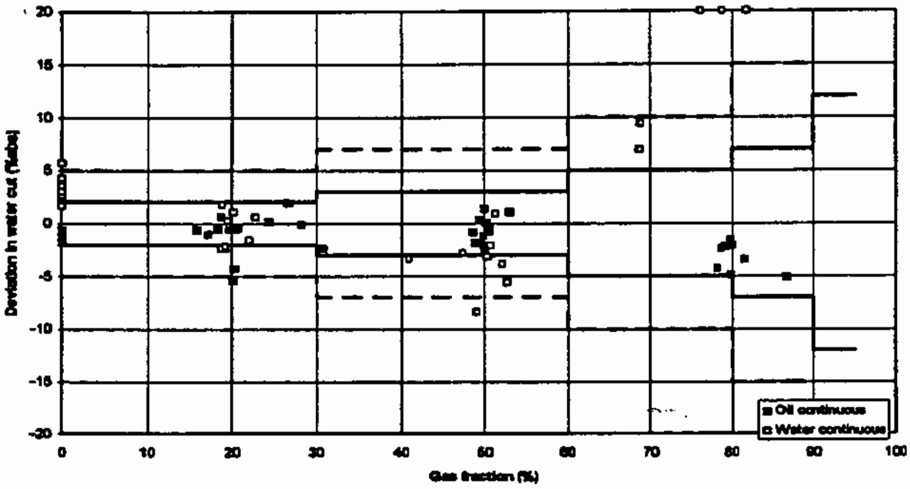


Water flow rates

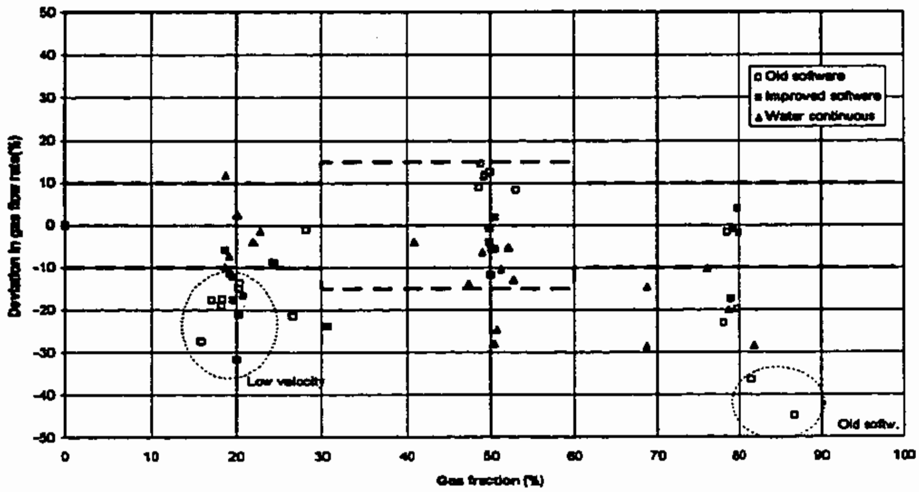
Figure 9



Liquid flow rates vs. gas fraction



Watercut vs. gas fraction



Gas flow rate vs. gas fraction

Figure 10

3.2.4 Conclusions

The meter performed reliably during the evaluation once it had been set up. No intervention was required. The measurements of phase flow rates reflected the changes made to the reference flow rapidly and followed the trends closely. Operation was not affected by whether the liquid mixture was oil- or water-continuous. In general the meter performed optimally in making velocity measurement using the venturi meter, or the venturi combined with the cross-correlation meter.

The gas flowrate was consistently under-estimated across the range of GVF tested, and the magnitude of the error increased with GVF. During the limited range of tests in which the new software was used, gas flowrate measurements were much improved, particularly at high GVF.
This trial demonstrated that there may be scope for improvement in the software model; this could have a beneficial impact on the meter's performance, particularly at high GVF.
The repeatability of all measurements was seen to be very good when cycling from oil- to water-continuous regimes.

On the basis of these excellent results, Amerada Hess found the meter acceptable for installation subsea at the South Scott field.

3.3 Fluenta SMFM 1000 installed in the South Scott template

South Scott is an extension of the main Scott reservoir and contains recoverable oil reserves of approximately 60 million barrels. The South Scott manifold is located 5 km south of the Scott platform. The field has been developed with a manifold for four wells and a production line tied into the Scott platform. No test line has been installed. Savings obtained by Amerada Hess in using this SMFM 1000 instead of a traditional test line solution are expected to be around GBP 8 -9 million. Ref. /4/.

The SMFM 1000 has now been installed on the seabed as part of the South Scott manifold and after recent successful commissioning and checks of communication and static readings we are currently waiting for "first oil" which is due before the end of September.

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